
High-risk intersections guide





NZ Transport Agency (NZTA)
High-risk intersection guide
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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 46% of deaths and serious injuries happened at intersections. On rural roads, with speed limits of 80km/h or above, 17% of deaths and serious injuries were at intersections.

The people, community and broader economic costs of crashes at intersections are high. The government's road safety strategy Safer Journeys 2020 signals that more must be done to improve safety on our high-risk intersections. The vision of Safer Journeys 2020 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 under the strategy as requiring early action.

The second Safer Journeys action plan sets out to: 'use the *High-risk intersections guide* to identify and target the 100 highest-risk intersections to address by 2020. A programme will be developed to improve at least 20 intersections in the course of this plan'.

Safer Journeys 2020 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 NZ Transport Agency launched in September 2011. Both guides are a flagship Safer Journeys 2020 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* 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. Applying Safe System concepts to intersections has been challenging. A number of the concepts in it are new.

This guide has been prepared by the NZ Transport Agency assisted by safety engineers and others from a number of Road Controlling Authorities. I would like to thank all who have contributed.

If you are involved in managing a road network, I encourage you to think about how applying the *High Risk Intersections Guide* can change for the better what you do. Because we are only beginning our journey to understand what Safe Systems means mean for design and management of our intersections, we will need to update the guidance regularly. Your experiences and suggestions will be most welcome.



Geoff Dangerfield
Chief Executive
NZ Transport Agency



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Glossary of terms

3 E's	Engineering, education and enforcement
AA	Automobile Association
AADT	Annual average daily travel
ATP markings	Audio tactile profiled markings
Collective risk	Collective risk is a measure of the risk of deaths and serious injuries within 50 metres of an intersection in a crash period.
Estimated risk	An estimate of the risk of deaths and serious injuries calculated from the reported history of all injury crashes and the severity index. (See below). Usually expressed as DSI equivalents.)
EWS	Electronic warning sign(s)
DSIs	Number of deaths and serious casualties. May be reported, estimated or predicted. To avoid confusion if describing estimated or predicted risk, it is described as DSI equivalents.
F&S	Worst injury in crash was fatal or serious
HRIG	High-risk intersection guide
HRRRG	High-risk rural roads guide
Intersection	For the purposes and clarity for using the guide an intersection is: <ul style="list-style-type: none"> • 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. (Note: it is easy to overlook these when searching in CAS.)
KiwiRAP	The NZ Joint Agency Road Risk Assessment Programme
LoSS	Level of safety service
MoT	Ministry of Transport
NZTA	NZ Transport Agency
OECD	Organisation for Economic Cooperation and Development
Personal risk	This is measure of the risk of death or serious injury per 100 million vehicle kms travelled within 50 metres of an intersection.
Predicted risk	This is determined by prediction models based on traffic and road characteristics which have been developed in NZTA research projects, some of which have been included in the NZTA's <i>Economic evaluation manual</i> (EEM), and newer simplified models in the appendices to this guide.
RCA	Road controlling authority
Reported risk	A measure of risk using the number of fatal and serious crashes reported in CAS at a site.
RISA	Road Infrastructure Safety Assessment
RoNS	Roads of national significance
Severity index I	Severity Index is the expected ratio of DSI casualties to all injury crashes. Tables of severity indices for each crash movement type, intersection type and speed limit are in Appendix 3. They are applied to each injury crash when deriving estimated DSI equivalents and an average value for all movement types is used to convert predicted injury crashes to predicted DSI equivalents.
TCD	Traffic control devices

1 Introduction

1.1 Purpose

The New Zealand Ministry of Transport's (MoT) New Zealand's road safety strategy 2010–2020 (Safer Journeys 2020) focused efforts to improve the safety of roads and roadsides on high-risk rural roads and high risk urban intersections, because these are where most deaths and serious injuries can be prevented. The *High-risk intersections guide* (HRIG) has been prepared by the NZ Transport Agency (NZTA) to provide guidance on high-risk urban and rural intersections together because the significant number of rural intersection crashes and higher crash severity at them, and their common issues and solutions means that it is sensible to address all intersections, in one guide.

Road safety action plans have been developed by the National Road Safety Committee to give effect to Safer Journeys 2020. The first of these set actions starting in 2011–2012 and included developing the HRIG. The second action plan covering 2013–15 targets improvements to high-risk intersections based on the HRIG – quoted in the box below.

The objective of the HRIG is to provide practitioners with best practice guidance to identify, target and address key road

Improve high-risk intersections

We will use the *High-risk intersection guide* to identify and target the 100 highest-risk intersections to address by 2020. A programme will be developed to improve at least 20 intersections in the course of this plan. Improving urban intersections will benefit pedestrians and cyclists. Planning will also commence for accelerated improvements during the 2015–18 National Land Transport Programme, using the Safe System interventions from the guide.

safety issues at high-risk intersections. It is designed to accompany the *High-risk rural roads guide* (September 2011), and *Safer journeys for motorcycling on New Zealand roads*. It 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 a 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 recommended way for road controlling authorities (RCAs) to manage the safety of intersections within their road networks, and to identify and prioritise these along with their own issues in an integrated way.

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 2010–20 (March 2010)
- the National Road Safety Committees Safer Journeys Action Plan 2013–15
- 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 and guidelines
- published standards of various organisations and authorities.

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 authority transport networks. The HRIG is intended to provide guidance to a range of technical practitioners, including:

- those from RCAs
- state highway and territorial authority 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 deaths and serious injuries at 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. Feedback from stakeholders 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/NZS ISO31000: 2009 *Risk management: principles and guidelines* and chapters 3 and 9 of SAA/SNZ HB 436: 2004 *Risk management guidelines*, and NZTA safety management systems guidelines.

1.5 Definitions

- For the purpose of this guide only, an intersection is:
 - where two or more streets or roads join or cross, or
 - where a major public driveway¹ joins a street or road and is constructed as an intersection

¹ Such intersections may include entrances and exits to and from large retail developments, large public parking areas, airports and hospitals. For the legal definition of an intersection see the Land Transport Rule: Traffic Control Devices Rule 2004. .

- 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 either the collective risk or the personal risk is classified as high or medium–high compared with other intersections, using the measures defined in section 4.2.

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 2020 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.
Section 7	Implementation, monitoring and evaluation	Describes the processes involved with prioritising programme works identified by the processes in this guide. Provides advice on how best to monitor and evaluate completed countermeasures at high-risk intersections.

2 Strategic context

2.1 Safer Journeys: New Zealand's road safety strategy 2010–2020

The New Zealand government released Safer Journeys: New Zealand's Road Safety Strategy 2010–2020 in March 2010 [29]. Safer Journeys is a national strategy to guide improvements in road safety over the period 2010 to 2020. Safer Journeys 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.
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.

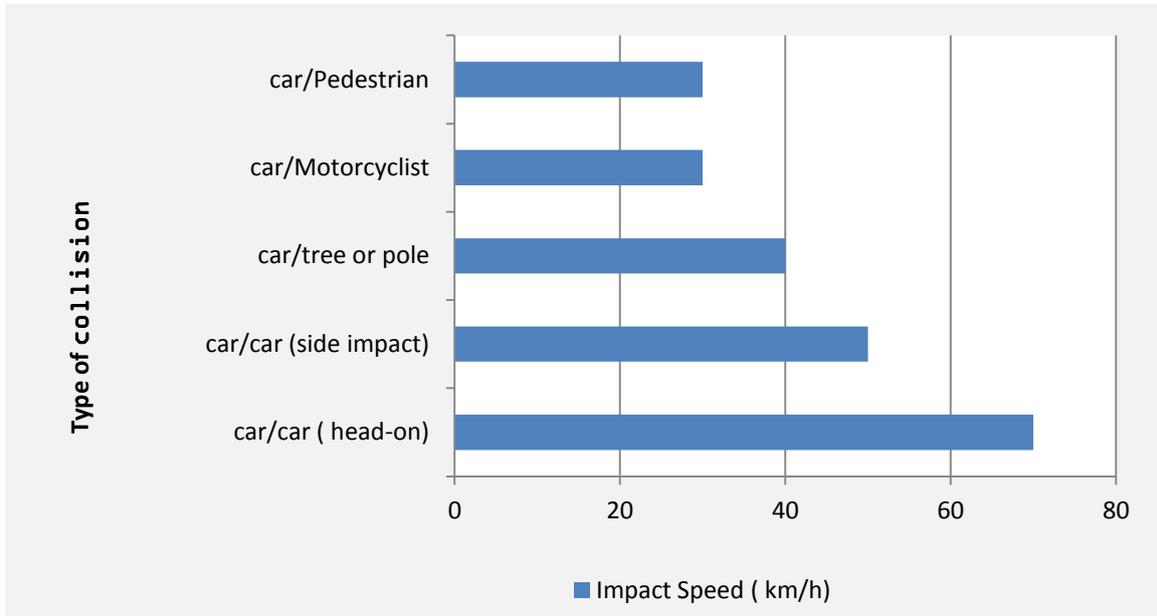
Scandinavian research [2] indicates that even if all road users complied with all road rules, fatalities would only fall by around 50% and serious crashes by 30%. Putting this in a New Zealand context, if everybody obeyed all the road rules, there would still be around 200 road deaths each year (based on fatalities in recent years).

The traditional 3 E's approach to road safety – engineering, education and enforcement – has proved useful in achieving current levels of road safety and these elements remain important funding and delivery mechanisms. However, the 3 E's 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, are governed by the inescapable laws of physics which determine how much force the human body experiences when each of these four elements interact in the event of a crash. The OECD [30] states that 'the human body's tolerance to physical force is at the centre of the Safe System approach'. figure 2-1 and shows impact speeds that are considered to be survivable for a number of crash scenarios,

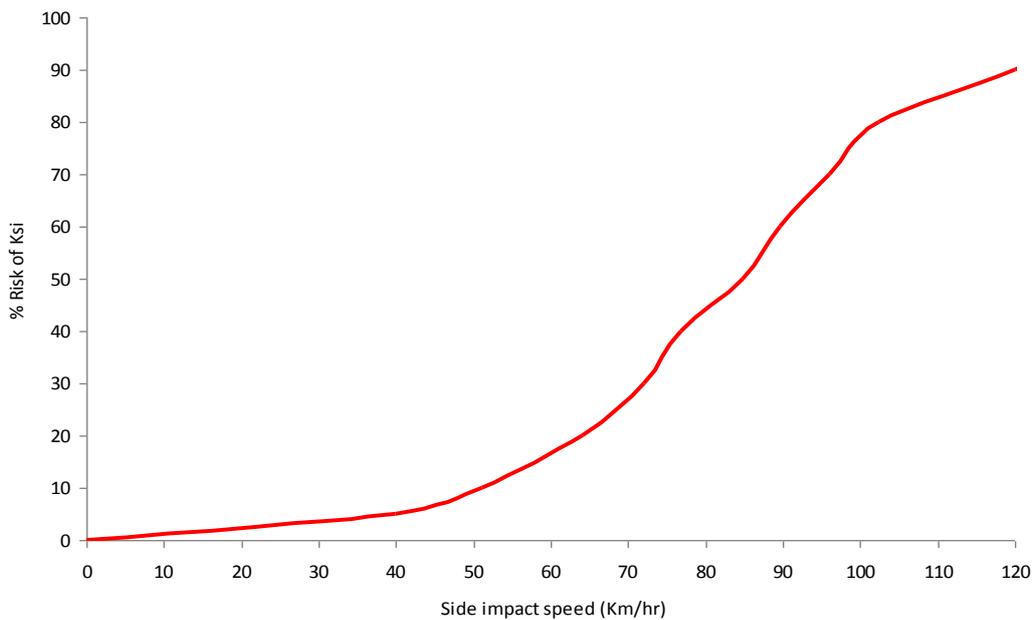
Figure 2-1: Survivable speeds for different scenarios



Source: Australian National Road Safety Strategy (2011-2020)

Figure 2-2: shows that the risk of a reported injury side impact collision resulting in death or serious injury 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: Risk of death or serious injury vs car side impact speeds



Source: adapted from TRL 2009, Richards, D. and Cuerden R.[31]

It should be noted that figure 2-2 is based on in depth study data of police reported injury crashes where vehicles were struck on the same side as the injured occupant who was wearing a safety belt. The original source used the instantaneous change in speed of the struck vehicle. (It is this sudden change in speed that does the damage.) This has been converted to equivalent impact speed by doubling the value (assumes both vehicles involved have similar mass).

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 would ensure impacts speeds do not exceed 30–40km/h. Intersections with possible side-on impacts between vehicles would have speeds through them that result in impacts 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

2.2.3 Effect of travel speed

The laws of physics interact with driver characteristics to govern the effect of vehicle speeds on the risk of death and serious injury at intersections. Modest reduction in travel speed approaching intersections can produce quite large reductions in risk of deaths and serious injuries, due to a number of reinforcing factors.

Drivers are poor at estimating the speed of approaching vehicles, and consistently underestimate the speed of faster vehicles. On rural roads especially, misjudgement is more likely among inexperienced and elderly drivers. When traffic travels at slower and more uniform speeds, it is less likely that traffic required to give way will misjudge the speed of through vehicles.

When a conflict happens at slower speeds, a driver travels a shorter distance in the time required to react, increasing the opportunity to avoid a collision. Once the brakes are applied the stopping distance increases with the square of the initial speed. All this means that a modest reduction in approach speed makes a much larger change in impact speed.

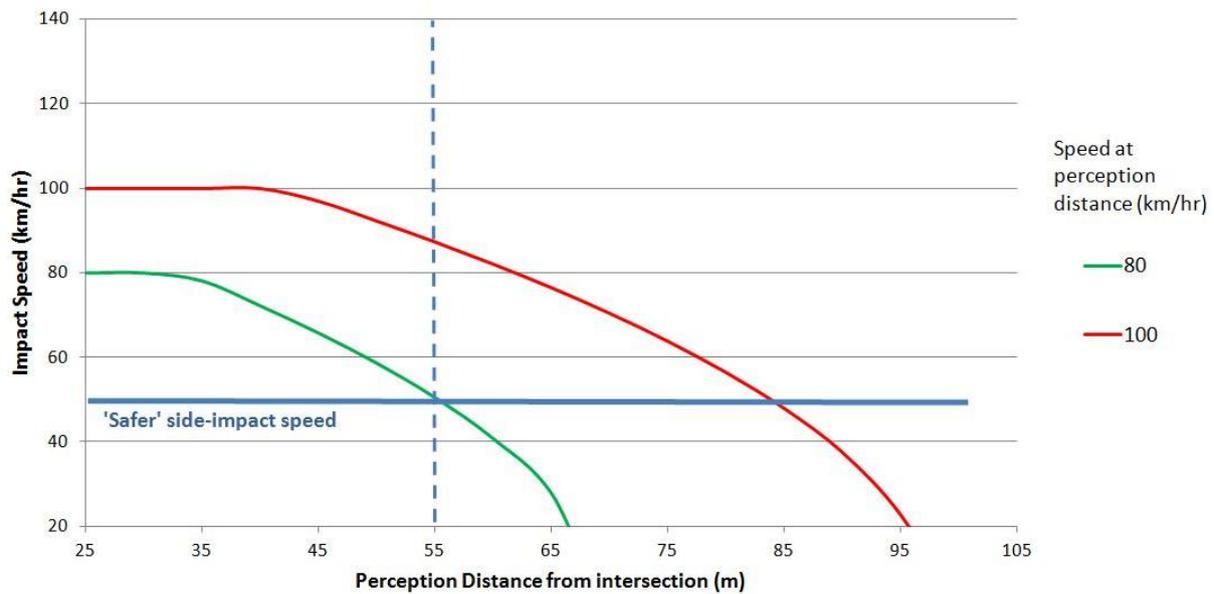
This is illustrated in figure 2-3 which shows what happens when if a driver 55 metres from an intersection observes a vehicle emerging from a side road and jumps on the brakes. If travelling at an initial speed of 100km/h, the vehicle travels 42 metres in the 1.5 seconds before an alert driver typically hits the brakes. This leaves only 13 metres left to panic brake until the impact at about 88 km/h. However if the approach speed is 80km/h, the vehicle travels 33 metres before braking leaving 22 metres for braking and an impact speed of 50km/h. So in this case slowing by 20km/h on the approach reduces impact speed by 38km/h.

Finally the energy of the moving vehicle to be dissipated by the forces in a crash varies with square of the vehicle impact speeds.

Where Safe System treatments such as rural roundabouts are not practical speed reducing measures 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 2-2: Relationship between intersection approach speed, perception distance and impact speed



Note: A reaction time of 1.5 seconds and deceleration of 0.7g have been used for this example. Source: adapted from figure 12 [32]

2.2.4 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 2-3 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 2-3: 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.
- consistency is provided between intersections and approaches.

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.
- Manage intersection approach speeds so that they reflect a Safe System.

Road safety action plans have been developed by the National Road Safety Committee to give effect to Safer Journeys. The first of these set actions starting in 2011–2012 and included developing the HRIG. The second action plan covering 2013–15 targets improvements to high risk intersections based on the HRIG– quoted in the box below.

Improve high-risk intersections

We will use the *High-risk intersection guide* to identify and target the 100 highest-risk intersections to address by 2020. A programme will be developed to improve at least 20 intersections in the course of this plan. Improving urban intersections will benefit pedestrians and cyclists. Planning will also commence for accelerated improvements during the 2015–18 National Land Transport Programme, using the Safe System interventions from the guide.

Another Safer Journeys action that is expected to have a positive influence on safety at intersections is the change to the give way rule at intersections, which came into effect on 25 March 2012. This change to the give way rules has simplified the complex demands placed on road users at intersections and is estimated to reduce the number of give way related crashes at intersections by around 7%.

2.4 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 now focuses on reducing deaths and serious injuries and adopts a Safe System approach in line with Safer Journeys. The high strategic fit assessment of the IRS currently includes the 'potential to significantly reduce the number of crashes involving death and serious injuries in line with Safer Journeysat a high-risk intersection'. Projects designed to improve high-risk intersections identified according to the procedures in this document, meet the criteria for high strategic fit provided the proposed works significantly reduce the risk of deaths and serious injuries. For more details on applying this criteria when developing programmes, refer to the NZTA's Planning and investment knowledge base www.nzta.govt.nz/resources/planning-and-investment-knowledge-base/.

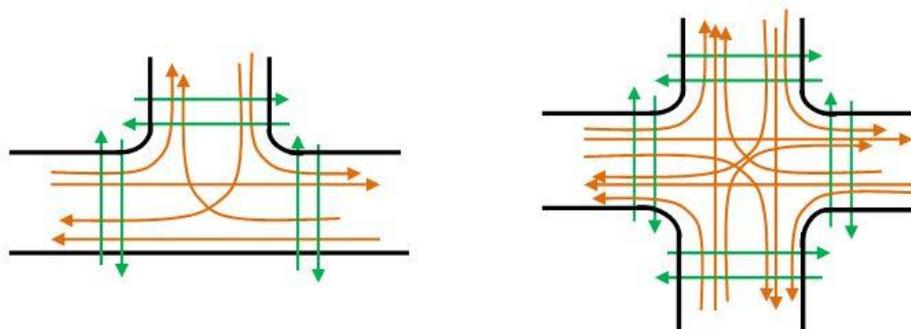
This investment focus combined with this HRIG is aimed at strongly encouraging RCAs to focus their efforts on the Safer Journeys priorities and actions.

3 Crash priorities

Intersections are places on the road network where road users' 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 increases as the number of arms on the intersection increases (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. At urban intersections, busy environments can place significant demands on road users and pedestrians and cyclists are at particular risk of higher severity crashes.

Photo 3–1: A typical priority controlled rural intersection



Photo 3–2: A typical stop controlled urban intersection



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

During 2008–2012, 30% of all deaths and serious injuries on NZ roads were at intersections. 17% of all deaths and serious injuries on rural roads were at intersections and 46% of all urban deaths and serious injuries were at intersections.

Despite 82% of intersection injury crashes, happening at urban intersections, more people (170) died at rural, compared to 158 at urban intersections. The rural crashes are much more severe due to the higher impact speeds that frequently exceed Safe System thresholds. The significant influence speed limit has on crash severity is shown in figure 3-2.

Figure 3-2: Severity of injury crashes at intersections in New Zealand by speed limit

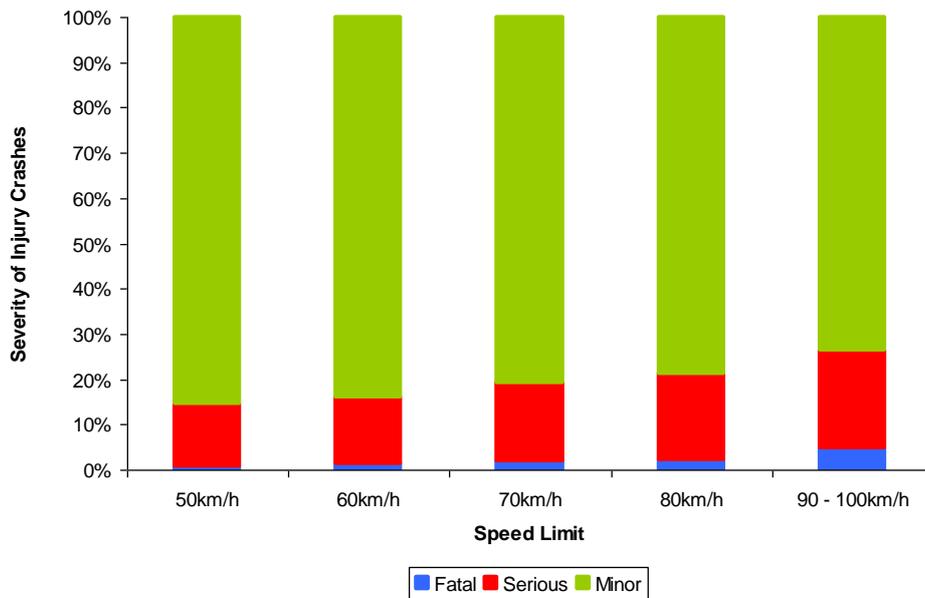


Figure 3-2 shows that the risk of a crash at an intersection involving fatal or serious injuries increases as the speed limit increases. The proportion of injury crashes by severity occurring at intersections in urban and rural environments is shown in figure 3-3.

Figure 3-3: Intersection crashes by severity and speed environment

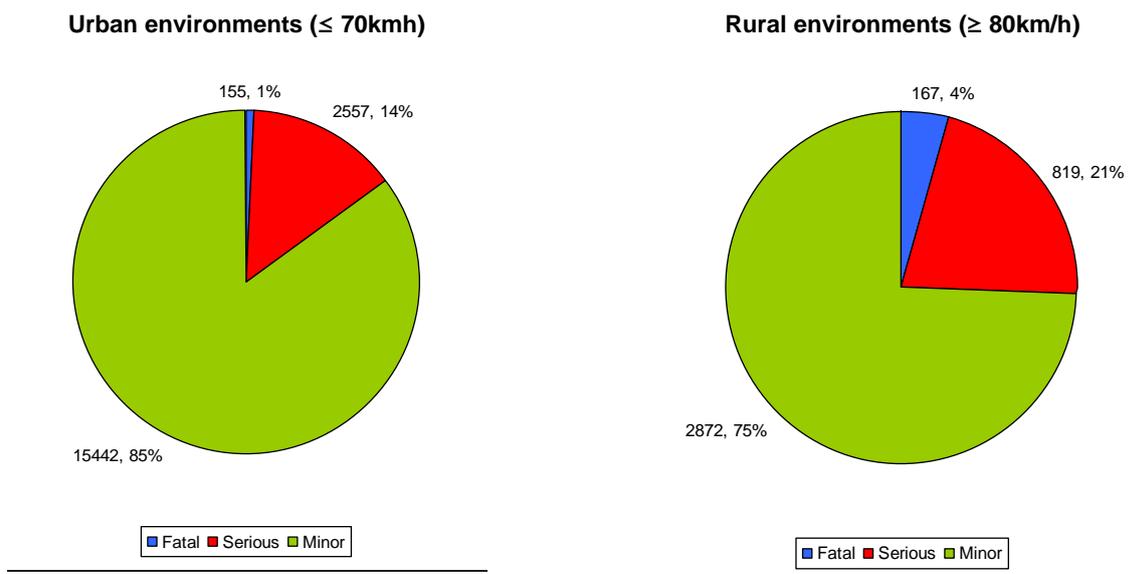
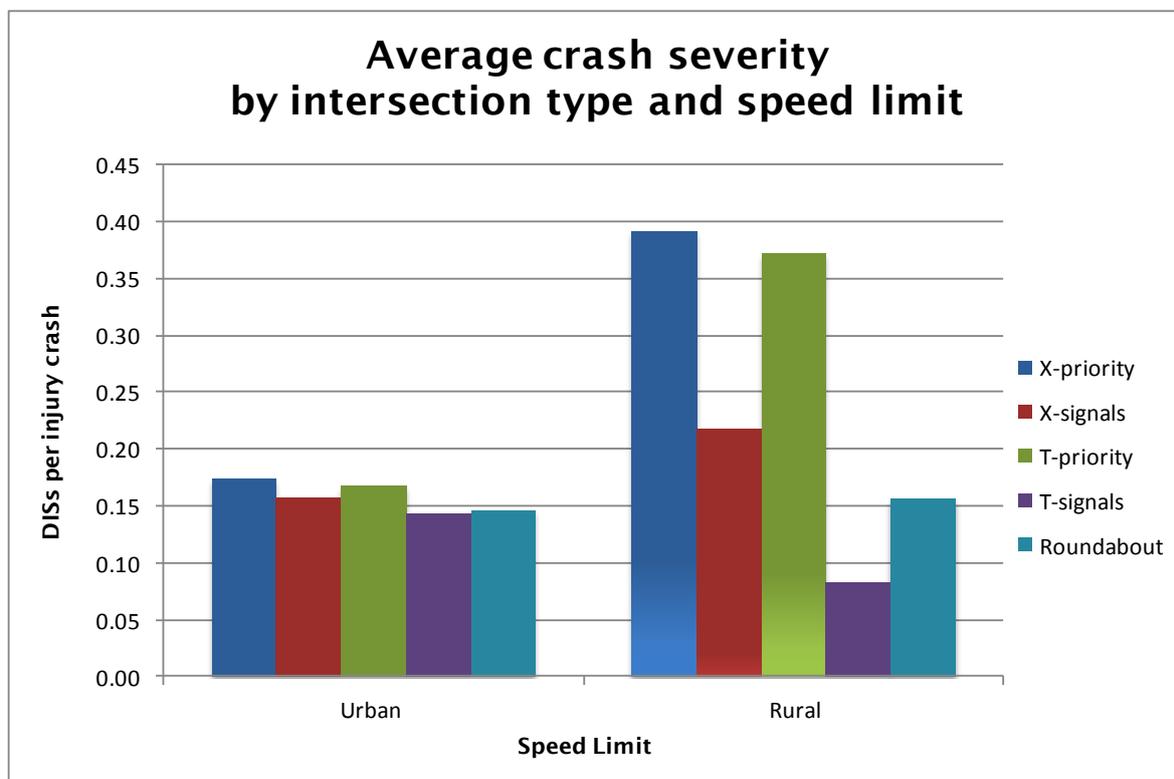


Figure 3-3 shows that the proportion of fatal and serious (F&S) crashes increases with the speed limit. In urban environments the proportion of F&S crashes of all injury crashes is 15% compared with 25% in rural environments. Overall, the majority of F&S crashes occur in the urban environment due to the higher traffic volumes and number of crashes.

Figure 3–4 shows that the number of deaths or seriously injured people (DSI) in an average injury crash is typically 0.15 at all intersections in an urban speed environment. However they are typically more than twice severe at priority intersections in a rural speed environment. There are however well performing exceptions, with the few rural signalised T-junctions in New Zealand having surprisingly low severity – even better than in urban areas, however because it is based on modest sample size it would be unwise to presume this would always be the case. More details can be found in the crash severity index tables in Appendix 3. To properly compare safety performance with respect to DSIs, the frequency of injury crashes also has to be considered. A full comparison is provided in figures 6-1 to 6-4 in section 6.2.2.

Figure 3-4: DSI casualty ratios at intersections



3.2 Key F&S crash movement types by environment

This analysis is across all intersections of all types and concentrates on the key crash movement types for reported F&S crashes and deaths and serious Injuries (DSIs). The DSI analysis is used as it 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, and 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 3-5 and figure 3-6 and Appendix 2. The full list of NZTA Crash Analysis System (CAS) crash movement codes is provided in Appendix 1.

Table 3-1 and table 3-2 show the main crash movement codes at intersections in urban and rural environments. They also show which crash movement types have historically resulted in more than one death or serious injury in a crash.

Figure 3-5: F&S urban ($\leq 70\text{km/h}$) intersection crashes and casualties by crash movement type (2006–2010)

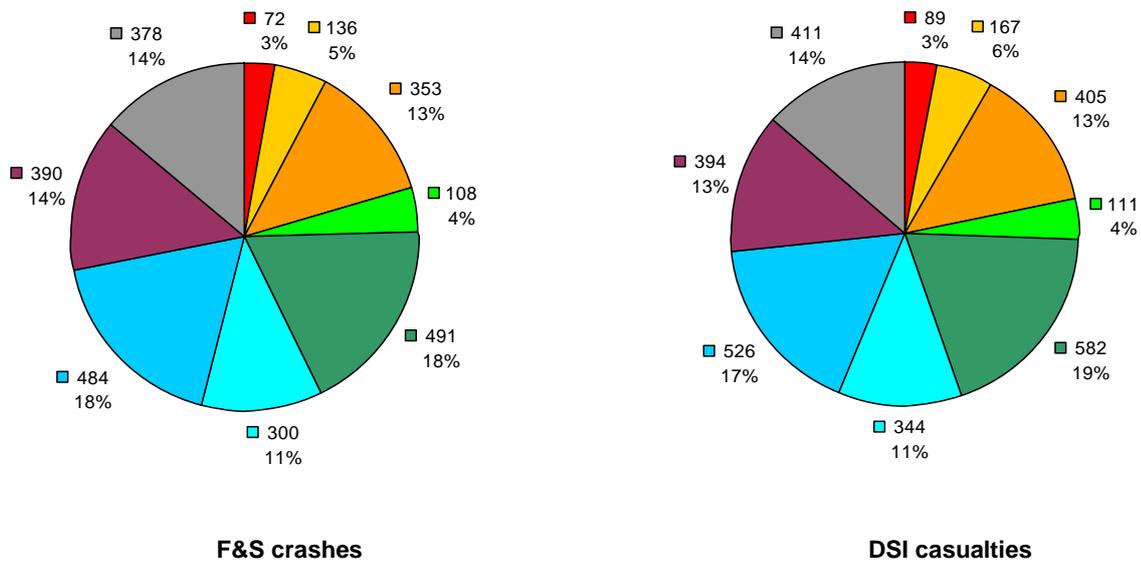
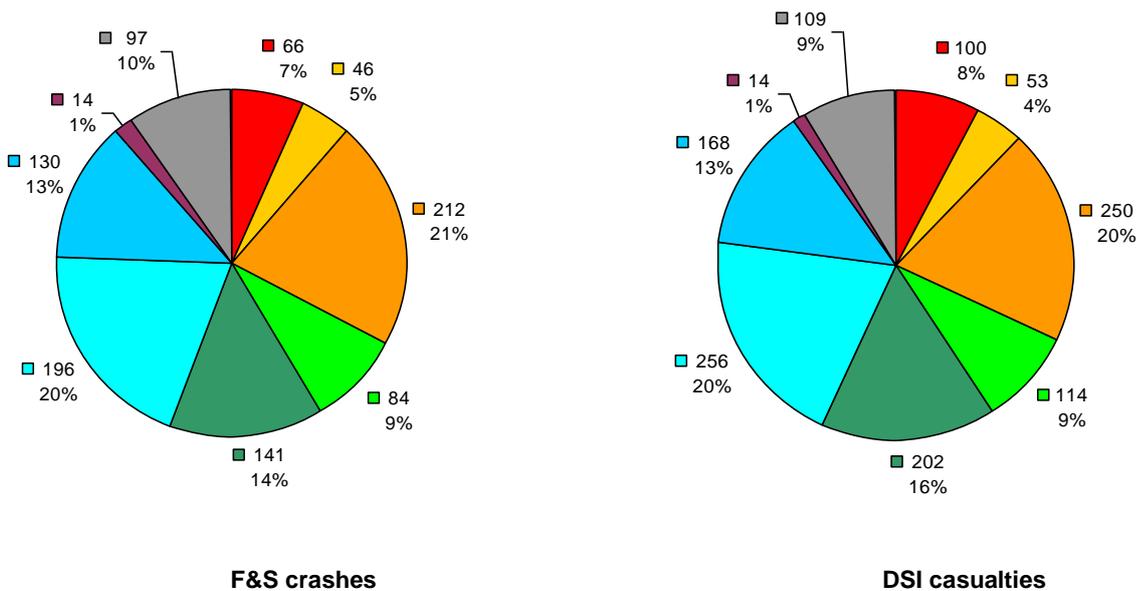


Figure 3-6: F&S rural ($\geq 80\text{km/h}$) intersection crashes and casualties by crash movement type (2006-2010)



Key for both figure 3-5 and figure 3-6

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

3.2.1 Urban intersections

The movement types that are most likely to lead to fatal and serious crashes in urban intersections are shown in table 3-1. Crashes involving each of these movements make up at least 10% of fatal and serious crashes, or 10% of deaths and serious casualties, at urban intersections.

Table 3-1 Main movement types for F&S crashes in urban intersections

Type H ■ crossing (no turning)							
Type L ■ right turn against							
Type N ■ pedestrian crossing road							
Type D ■ cornering							
Type J ■ crossing (turning)		OBSOLETE					

Using the reported crashes from CAS, the overall 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 (head-on), Type C (off road on straight) 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 confirms that the key crash movement types that should be focused on at urban intersections are those shown in table 3-1.

3.2.2 Rural intersections

The movement types that are most likely to lead to fatal and serious crashes in rural intersections are shown in Table 3-2.

Table 3-2: Main movement type for F&S crashes at rural intersections

Type D ■ cornering			
Type J ■ crossing (turning)		OBSOLETE	
Type H ■ crossing (no turning)			
Type L ■ right turn against			

Using CAS, the ratio of DSI casualties to F&S crashes is 1.28 at rural 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 (head-on) and Type H crashes were most likely to result in there being multiple DSI casualties.

This analysis confirms that the key crash movement types that should be focussed on at rural intersections are those shown in Table 3-2.

3.3 Main DSI crash movement types by intersection form

The composition of the key crash movement types 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. A summary of the results of this analysis are shown in table 3–1 for urban environments and table 3–4 for rural environments. A more detailed analysis is provided in Appendix 2.

Table 3–3 shows that there is one crash movement that stands out as the major contributor of DSI casualties at each urban intersection form, with the exception of uncontrolled intersections (low volume T-junctions). Specifically, right turn against (Type L) movements at signalised intersections, crossing–turning (Type H,J,L) movements at roundabouts and priority crossroads and crossing–turning type (Type J) movements at priority T and Y intersections. There are a number of other crash movement types that are still significant and should not be overlooked from analysis.

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

	TYPE								
	Head On	Off road straight	Off Road bend	Rear end turning	Crossing, no turns	Crossing turning	Right turn against	Pedestrian crossing	Other
Traffic signals	Green	Yellow	Yellow	Green	Orange	Green	Red	Orange	Yellow
Roundabout	Green	Yellow	Orange	Green	Red	Yellow	Yellow	Yellow	Orange
Priority crossroads	Green	Green	Yellow	Green	Black	Yellow	Yellow	Yellow	Yellow
Priority T&Y intersections	Green	Yellow	Orange	Yellow	Green	Red	Orange	Yellow	Yellow
Uncontrolled	Green	Yellow	Orange	Yellow	Green	Green	Orange	Orange	Orange

Key ■ Less than 5% ■ 5 to 14% ■ 15 to 24% ■ 25 to 34% ■ 35% or more

Table 3–4 shows that there is one crash movement type that stands out as the major contributor of DSI casualties at each rural intersection form, with the exception of signalised intersections. Specifically, cornering (Type D) at roundabouts and uncontrolled intersections, crossing/turning (Type H) movements at priority crossroads, and crossing–turning (Type J) at priority T and Y intersections. The proportion of DSI casualties caused by the dominant crash movement type is more marked at rural intersections than urban intersections.

Table 3–4: Composition of key crash movement types by intersection form in rural speed environments

	TYPE								
	Head On	Off road straight	Off Road bend	Rear end turning	Crossing, no turns	Crossing turning	Right turn against	Pedestrian crossing	Other
Traffic signals	Green	Orange	Yellow	Green	Green	Yellow	Yellow	Yellow	Orange
Roundabout	Green	Orange	Black	Green	Yellow	Yellow	Yellow	Green	Yellow
Priority crossroads	Green	Green	Green	Yellow	Black	Yellow	Yellow	Green	Yellow
Priority T&Y intersections	Yellow	Green	Orange	Yellow	Green	Black	Orange	Green	Yellow
Uncontrolled	Orange	Yellow	Black	Yellow	Green	Green	Yellow	Green	Yellow

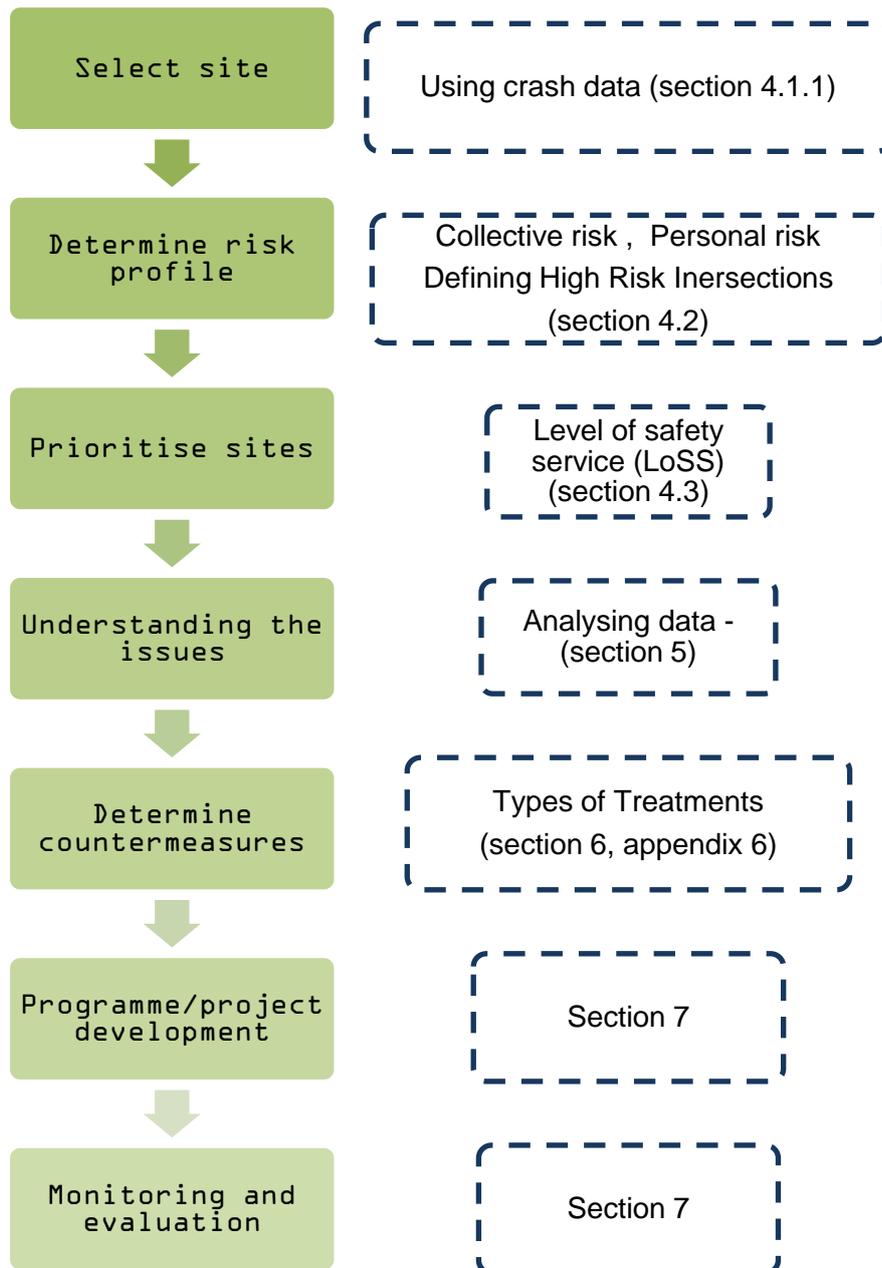
Key ■ Less than 5% ■ 5 to 14% ■ 15 to 24% ■ 25 to 34% ■ 35% or more

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 identifying 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. A summary of the process is provided in figure 4-1.

Figure 4-1: General summary of process to determine, manage, implement and monitor high-risk intersection sites



4.1 Assessing risk of death and serious injury

High-risk intersections are intersections with a higher than normal risk that people will die or be seriously injured in the future. This section describes the measures used to assess risk so that a risk profile can be developed and those intersections with a higher than normal risk can be identified.

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, fulfilling the long-term vision of Safer Journeys. It is also beneficial to consider the surrounding area in identifying issues and developing countermeasures. Further information is provided in section 6.3.

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

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.

The HRIG does not use the reported deaths and serious casualties (DSIs) directly to identify high risk intersections. This is because of the random nature of multiple casualties at individual intersections. For instance one of the worst intersections based on reported DSIs alone was a site that only had only one F&S crash that involved many seriously injured occupants of one van. The number of DSIs in intersection crashes is on average only 10–15% more than the number of F&S crashes. However, rural priority intersections and rural signalised crossroads are much more severe. So the approach taken for this guide is to work initially with F&S crashes directly or to estimate DSI equivalent metrics from injury crash data by using the typical ratio of DSIs to injury crashes for each intersection type. Tables of severity ratios appear in Appendix 3.

Risk can be assessed using three main methods:

- The risk can be estimated directly using the recent history of Fatal and Serious crashes. This is called reported risk.
- The risk can be estimated based on the reported injury crashes adjusted for the typical proportion of DSIs in each injury crash of each type, This is called estimated risk in this guide and the results described as DSI equivalents.
- The risk can be predicted using the physical and operational characteristics of an intersection that are known to affect the risk. This is called predicted crash risk in NZTA investment criteria.

4.1.1 Using crash history

In the past, 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 that may not be indicative of a high probability of future fatal and serious crashes.

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

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 reported risk and the unit is F&S crashes.

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 RCAs addressing randomly occurring crashes within the network. For this reason, intersection should have at least 3 fatal and serious crashes before being considered to have high collective risk. However, only about 80 intersections in New Zealand have three or more fatal and serious crashes in a five-year period, and these tend to differ greatly from one five year period to another. .

This small numbers problem also results in another distortion in the estimation of crash risk. Sites selected on the basis of recorded F&S crashes typically overestimate the crash risk by a factor of about 2. Because of this it is not appropriate to adjust the numbers of F&S crashes at intersections up to an equivalent number of DSIs. Rather the estimated number of DSI equivalents derived from injury crashes is on average approximately half the number of recorded F&S crashes.

To improve the statistical significance of estimates based on crash history, we can increase the number of years of crash data used to smooth out the influence of random processes on crash distribution. However, this approach is only valid if the crash risk has not significantly changed, which it often will have due to changing traffic volumes, intersection improvements and vehicle or driver characteristics. Caution is advised at sites where the crash problem is mostly more than five years ago.

(b) Using DSI equivalents estimated from 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. This extra data can be used to estimate the risk of DSIs, called DSI equivalents. We do so by applying our knowledge of the usual severity of each crash type.

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. In contrast, rear-end collisions rarely result in death or serious injury. Different intersection forms and controls also have different average severities – roundabouts in particular are designed to reduce crash severity, and 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.

The severity ratio is the probability that any crash of that type will result in fatal or serious injuries. Severity ratios have been developed using recent five years of crash data from all intersections in New Zealand. Appendix 3 contains tables giving separate severity ratios for each:

- crash movement type
- intersection form and control
- speed limit.

The process of estimating DSI equivalents involves the multiplication of each injury crash at an intersection by the average number of deaths and Serious Injuries per injury crash for that crash type. This is called the DSI casualty severity index. To estimate DSI equivalents at a particular intersection based on all injury crashes, use the rightmost column of the severity index tables provided in Appendix 3 – labelled 'Adjusted DSI casualties/all injury crashes'.

This method has been shown to be better at estimating the likelihood of future DSIs than the actual F&S crash history alone.

Appendix 3 includes a simple example of this method, and the case studies in section 4.6 give more examples.

(c) Using CAS to identify intersections within a network for further investigation

When first determining whether or not you have high-risk sites within a network some basic analysis can be undertaken using CAS. This process involves selecting intersection within your networks, grouping the crashes and removing smaller sites. Once this data is obtained, risk metrics can be calculated that permit the risk profile of the sites to be classified. (section 4.2).

Instructions for using CAS to select and group intersection crashes are in Appendix 2b.

Crashes used in the assessment of risk metrics are confined to those crashes occurring within 50m of an intersection (refer to section 1.5 for definition). However, if it can be demonstrated that a 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 crash may be included in the risk assessment. Note that the default radius for grouping crashes in CAS is 30m. Whilst this would generally ensure that only crashes relating to the intersection would be included, it is recommended that a 50m radius is used and further analysis on the crash history is undertaken to ensure all crashes in the vicinity are checked to determine whether or not they are related to the intersection.

4.1.2 Using crash risk prediction models

Crash risk can also be assessed by using crash risk prediction models. Models have been developed in NZTA research projects, some of which have been included in the NZTA's *Economic evaluation manual* (EEM) [1]. A wide variety of models exist, ranging from simple approach flow only models through to conflicting flow models for different road user types. The conflicting flow models take the characteristics of a site into account to predict the typical crash rate for the intersection.

While the more complex models should provide better crash prediction estimates, there is only a small dataset of intersections with sufficiently detailed information to use them. Therefore, it is not currently possible to use this method to identify likely high-risk intersection sites on a nationwide basis. However, for the simpler models that only require flow data, traffic volume data is consistently available nationally. In the preparation of this guide, flow data was collected using GIS tools for a large number of urban and rural intersections. This means that the expected range of injury crashes in relation to traffic volume is now available and much more reliable especially for rural intersections, where previously there was a very small sample. The charts appear in Appendix 5. The values in the appendix should be used in preference to the EEM simple flow only crash prediction models.

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.

Crash prediction models are usually used where it is not appropriate to use reported crash data such as to estimate the expected crash performance of a new intersection form or control. They are also useful for prioritising sites for attention, where crash numbers are insufficient, such as when setting up a programme of improvements on a network of rural crossroads.

4.2 High-risk intersection metrics

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

- **Collective risk** is measured as the total number of fatal and serious crashes or deaths and serious injury equivalents per intersection in a crash period.
- **Personal risk** is the risk of death or serious injuries to each vehicle entering the intersection.

The personal risk is calculated from the collective risk divided by a measure of traffic volume.

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 using crash data to define collective risk at intersections. The collective risk is the highest of the methods.

(a) *Reported F&S crashes*

The criteria for reported crash is 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 has high collective risk, there needs to be:

- three or more fatal and/or serious reported crashes in five years; or
- five or more fatal and/or serious reported crashes in 10 years.

(b) *Estimated DSI equivalents*

Estimated DSI equivalents are categorised by checking against the thresholds in table 4-1. These thresholds have been determined by analysing a large number of existing intersections, and set so that medium-high and high-collective risk intersections together make up approximately 5% of all intersections. An initial assessment of 2008–2012 CAS data shows there are approximately 250 intersections that are high collective risk and approximately 350 intersections that are medium high collective risk under this criteria.

Table 4-1: Criteria for identifying intersection collective risk

Collective risk level	Estimated DSI equivalents (5 years)
High	≥ 1.6
Medium-high	$1.1 - <1.6$
Medium	$0.6 - <1.1$
Low medium	$0.3 - <0.6$
Low	< 0.3

4.2.2 Personal risk

Personal risk measures the risk to each person using the intersection. In practice only the number of motor vehicles is routinely available, so the personal risk is calculated from the collective risk divided by a measure of traffic volume exposure.

At low traffic volumes, crash numbers are also typically very low so the personal risk is highly sensitive to a small change in crash numbers. So it is sensible to treat personal risk values at low traffic flows with caution. To have an estimate of personal risk that is sufficiently reliable for deciding that a site is really a high or medium high personal risk, it should have four or more recorded injury crashes in the past five years. So where an intersection has three or fewer injury crashes, an indicative personal risk may be calculated for describing the risk profile, but this should not be used to qualify the site as a high-risk intersection.

In order to develop the measure of traffic volume, the annual average daily traffic (AADT) volume data is required for each leg of an intersection. 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 flows in CAS. AADTs are often extrapolated from single or weekly counts, but this accuracy is usually sufficient for personal risk estimation. In all situations the accuracy of the data must be considered before using it.

The simplest measure of traffic exposure is the total number of vehicles entering the intersection. However, the measure of traffic volume or personal exposure used for personal risk calculations at intersections is based on the product of the conflicting flows entering from each approach. This measure is used instead of the simpler approach of summing the flows entering from each leg, because it relates directly to the number of potential conflicts between vehicles. This method is much better at accounting for intersections between major roads and side roads with low traffic volumes. In theory, the crash risk would follow a relationship that is the square root of the conflicting flows (mathematically raising the product to the power of 0.5), but in practice, raising the flows to a power of 0.4 provides a better straight line fit to the crash data, and better compensates for the reduced risk that is observed at higher traffic flows.

The traditional traffic exposure measure that has been used in road safety analysis is crashes per 100 million vehicle kms. So the personal risk metric for this guide is adjusted to be equivalent to DSIs per 100 million vehicle kms.

The daily product of flow formula (PoF) is:

$$PoF = \left(average(Q_{major_1}, Q_{major_2}) \cdot average(Q_{minor_1}, Q_{minor_2}) \right)^{0.4}$$

- Q_{major_1} and Q_{major_2} = the two-way link volume (AADT) on each leg of the major road. The formula presumes that the entering traffic is half the two-way total.
- Q_{minor_1} and Q_{minor_2} = the two-way link volume (AADT) on each leg of the minor road.
At a T intersection the same equation is applied, but with Q_{minor_1} set as the side road AADT, and Q_{minor_2} defined to be zero.

The product of flow formula also applies to roundabouts.

This daily PoF has to be adjusted to the same time period as the crash history, by multiplying by the number of years and the number of days in a year.

The personal risk calculation uses the same metric calculated for the collective risk. The full personal risk calculation formula is:

$$Personal\ risk = \frac{\max(\text{reported F\&S crashes} \cdot 0.5, \text{estimated DSI equivalents}) \cdot 10^8}{\left(\text{average}(Q_{major_1}, Q_{major_2}) \cdot \text{average}(Q_{minor_1}, Q_{minor_2}) \right)^{0.4} \cdot 5\ \text{years} \cdot 365\ \text{days} \cdot 1.7}$$

Where the reported F&S crashes or estimated DSIs are per five years, and 1,7 is a conversion factor to make the exposure equivalent to vehicle kms travelled through the intersection. This conversion factor takes account of the distance travelled by each vehicle using the junction of 100 metres, and an approximate correction for the PoF exponent of 0.4 departing from the theoretical exponent of 0.5. Note also in this case the number of F&S crashes are halved as discussed above.

The personal risk value can then be given a personal risk level as shown in table 4-2.

Table 4-2: Personal risk levels and risk metric values

Personal risk level	Estimated DSIs per 100 million vehicle kms
High	> 32
Medium-high	16 – <32
Medium	10 – <16
Low medium	6 - <10
Low	< 6

The criteria in table 4–2 has been developed by examining the personal risk measures calculated from intersections located in large RCAs that have been entered in a GIS data base. This sample covers a majority of intersections. The results indicate that the above thresholds result in about the same number of intersections as for collective risk, or about 5% classified as high or medium high personal risk. Some of these also have high or medium high collective risk. Those with high or medium high personal risk only, but lower collective risk, are most likely to be urban intersections with a potential for significant risk reduction with modest investment.

Proactive risk assessment

The above two definitions are reactive being based on crashes in the past. There is a desire to move towards a more proactive risk assessment based approach to road safety.

For rural roads the KiwiRAP star rating system for state highways, and RISA (Road Infrastructure Safety Assessment) 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. Unfortunately there is not currently a full database of intersection features to enable this. 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 and prioritise remedial works.

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. There is a need for guidance on the data needs so a proactive list of potentially at risk intersections can be developed.

4.2.3 Defining high-risk intersections

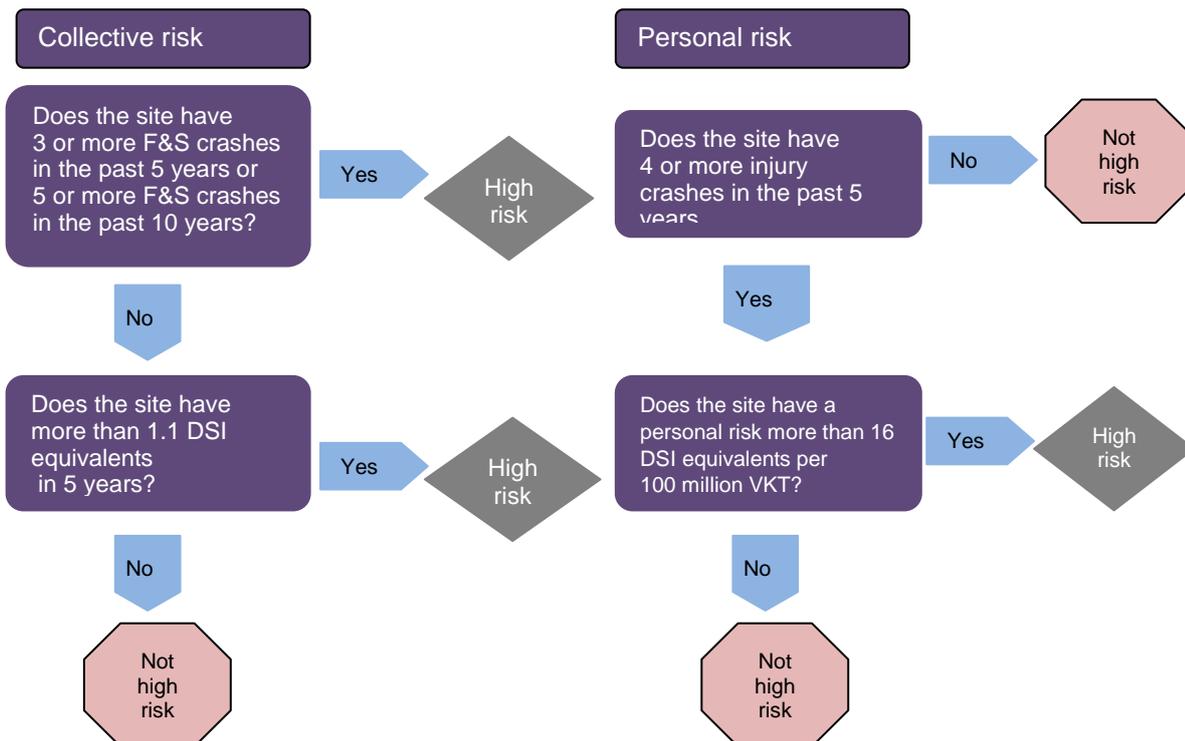
Once the collective and personal risks have been estimated and classified, these measures are used to identify those intersections that have a higher than normal risk of deaths and serious injuries. A high-risk intersection is one with:

- high or medium high collective risk, or
- high or medium high personal risk.

Note for this purpose the personal risk calculation must be based on 4 or more injury crashes.

The process is outlined in the flowchart in figure 4-2.

Figure 4-2: Process for identifying high-risk intersections



Note: For personal risk, if the site does not have four or more injury crashes but has three or more injury crashes and two of those are fatal and serious then it should be included in the above process.

4.3 Prioritising high-risk intersections for investigation

4.3.1 Purpose

The collective and personal risk indicators are a good way of identifying high-risk intersections. However, in order to target those high-risk intersections with the highest likely value for money of improvements, it is necessary to apply a prioritisation process. This method identifies 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 of intersections with the same control and similar flows. Those that have a worse than expected crash history are likely to have unsafe features, such as a poor layout, poor visibility or inappropriate signal phasing, and are most likely to have effective countermeasures that can be applied without changing the intersection type. In contrast, intersections that perform better than similar intersections – but are still high risk – are likely to require more expensive countermeasures or total transformation.

The purpose of this section is to provide RCAs with methods for prioritising these intersections for investigation within a limited funding base. The method acknowledges that some RCAs will not have sufficient funding to investigate all high-risk intersections and introduce many transformational 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 substantial benefits without expensive transformation 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

Level of safety service is a measure of the historic intersection safety performance relative to that expected based on a statistical analysis of New Zealand intersections. It identifies intersections that perform poorly relative to similar intersections of the same configuration, taking into account the speed environment, intersection form and amount of traffic travelling through the intersection. LoSS calculations do not require any additional information beyond that used to calculate personal risk levels.

The injury crash performance of an intersection has been separated into five LoSS bands to help prioritise intersections for treatment that have the same collective and/or personal risk levels. The LoSS bands are shown in table 4-3.

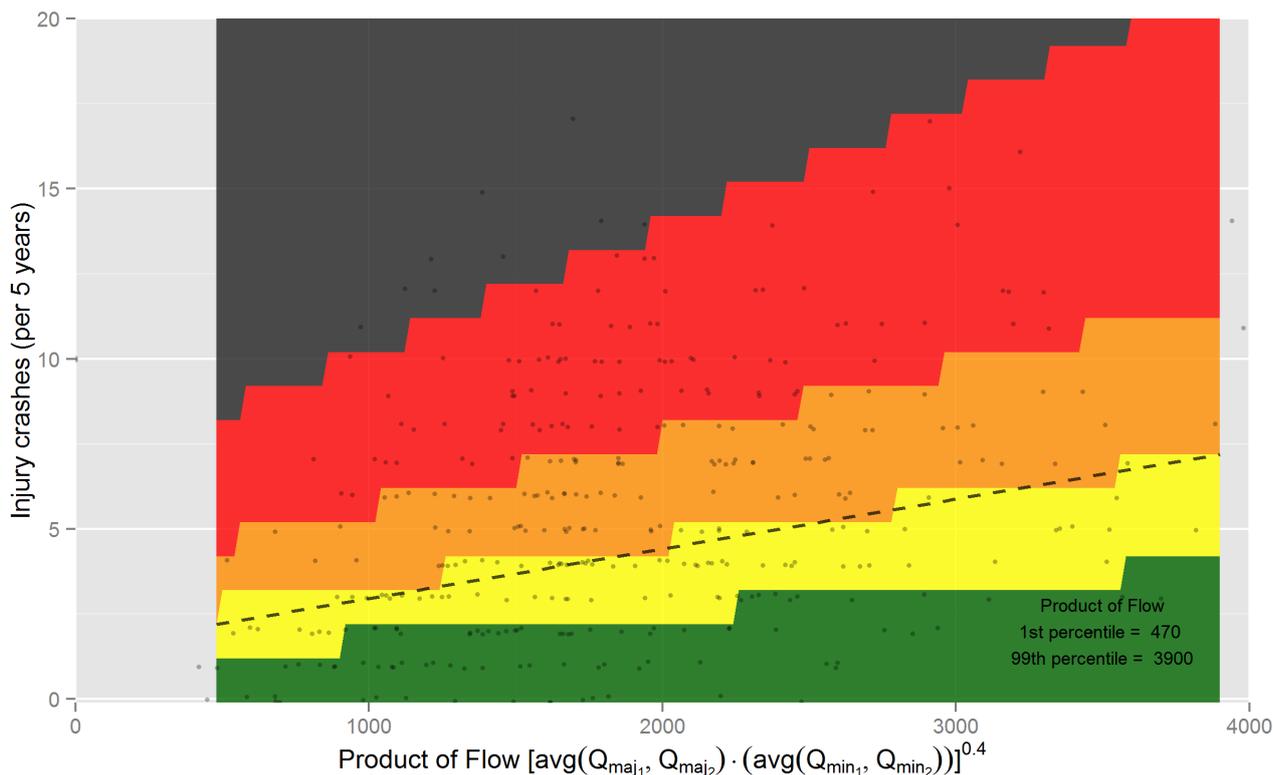
Table 4-3: Level of safety service bands

Level of safety service	Safety performance	Definition
LoSS V	90–100 th percentile	The observed injury crash rate is in the worst 10% band – higher (worse) than that expected of 90% of similar intersections.
LoSS IV	70–90 th percentile	The observed injury crash rate is in the worst 30%, lower (better) than that expected of 90% of similar intersections, and higher (worse) than that of 70%.
LoSS III	50–70 th percentile	The observed injury crash rate is lower (better) than that expected of 70% of similar intersections, and higher (worse) than that of 50%.
LoSS II	30–50 th percentile	The observed injury crash rate is lower (better) than that expected of 50% of similar intersections, and higher than that of 30%
LoSS I	0–30 th percentile	The observed injury crash rate is lower (better) than that expected of 30% of similar intersections.

Intersections classified as 'LoSS I' have a safety performance that is in the best category, when compared to the safety expected of 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 being in the worst ten percent group when compared to the performance expected from similar intersections. Each chart has a dashed line which is the 50thile. Half the intersections perform worse and half better than this line. It represents the expected performance of a typical intersection.

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 these types of charts is shown in figure 4-3.

Figure 4-3: Example of LoSS chart for urban signalised crossroads intersection



4.3.3 Transformation reduction potential

It is important to note that the LoSS is a prioritisation technique that compares an intersection only against other intersections of the same form. Transformation to a different intersection control should also be considered, especially if LoSS performance is good but the intersection still has high collective and/or personal risk. For instance a priority rural crossroad with a medium LoSS could still have a high collective risk and conversion to a roundabout is likely to be much more effective than improvements under the same control type.

The relative safety performance of different intersection controls with varying traffic volumes are shown in figures 6-2 to 6-5. The graphs display the range of collective risk expected for priority control, traffic signals and roundabouts. There are separate graphs for urban and rural T intersections and crossroads. They permit an estimate of the typical reductions in DSIs that could be expected from a transformation to a different control. They also provide the expected risk that would result from a transformed intersection. This can be compared with the existing DSI risk to estimate the potential to reduction in DSIs that might be achieved by a successful transformation. There are more details in section 6.6.2.

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, and transformation potential together.

The manner in which intersections with different risk rating combinations are most appropriately treated is described in section 4.5.

4.3.4 Metric for prioritising works:

Once the options for improvement have been identified and rough costs estimated, the safety works programme should be prioritised to maximise the return in terms of DSIs saved for the available budget. There is quick and simple method to use as an initial guide for each project.

Each DSI saved is worth approximately \$1million (rural is slightly more, urban slightly less) . The annual savings may be roughly converted to the present value of the whole of life of a project with long term benefits by multiplying by 16.

This can be used to estimate the DSIs saved per \$100 million spent.

If the number is over 100 then the project benefits due to DSI savings alone are likely to exceed the costs. This value is consistent with the estimation of other benefits from minor crashes, travel time savings etc that would be used in a full economic analysis, to arrive at a comprehensive benefit/cost ratio. Typically the addition of minor crashes is likely to

double the benefits achieved from DSI savings alone, but this depends on the nature of the remedy. Depending on the treatment and site details, the other benefits such as travel time savings may be positive or negative.

The project with the highest DSIs saved per \$100 million spent would be the best purely from a Safe System perspective, and should have the highest priority for safety investment.

4.4 Identifying high-risk intersections in a road network

4.4.1 Crash risk maps

Crash risk maps are very useful for visualising the risks on a network. They may show the historic safety performance of intersections in terms of collective risk, personal risk and LoSS.

Crash risk maps can be a particularly useful tool to identify routes or clusters of intersections that have a high 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 of information on traffic flows, speed limits and the form of intersection control (if crashes have occurred there). 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 ten years).

This process requires 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, but one useful technique is to use ten years data, but double the weight for the most recent five years. This technique uses a greater number of crashes for analysis while recognising that recent changes may have occurred.

To assist local authorities, the NZ Transport Agency intends to publish a national list of high risk intersections based on collective risk. 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 most instances will be held locally.

On rural state highways the KiwiRAP star rating system takes into account the risk presented by intersections, using a rudimentary risk assessment, based on what can be observed intersection features. The star ratings are not based on crash history, but are based on the known relationships between injury crash rates and the physical and operational features of the roads and roadsides.

There is currently no adequate system for star rating the risk of the majority of intersections. This may be an area for future development. RCAs may wish to start collating information on their intersections that will allow star ratings to be developed in the future.

(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 4.3.2, each intersection in a network can be classed as performing much better than comparable intersections through to much worse than comparable intersections (LoSS I to LoSS V). Using colour coding and a GIS system, it is possible to show those intersections that perform well and poorly across a network based on the intersection form, speed environment and number of vehicles travelling through the intersection.

An example of a LoSS map in an urban area is shown in figure 4-4: Example of a LoSS map for an urban area.

Figure 4–4: 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, determine the level of risk for each intersection. Using the calculated collective and personal risk levels, use the 'treatment philosophy strategy' (Figure 4-5) for guidance on the appropriate treatment type for each intersection.

Figure 4-5: Intersection treatment: Safety improvement strategy

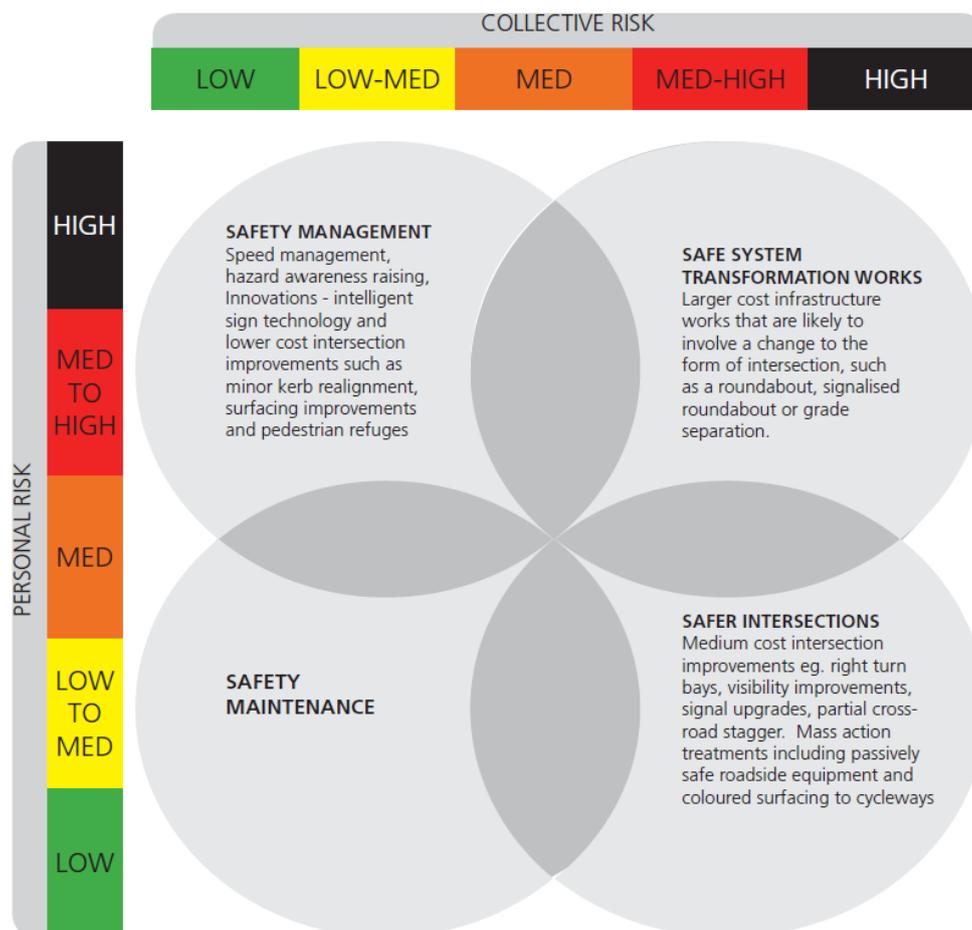


Figure 4-5 provides a schematic of the general treatment philosophy strategy that has been developed to guide the selection and implementation of various improvement measures based on the main metrics that define the risk of a particular intersection under consideration. These are:

- collective risk, shown on the horizontal x-axis, and
- personal risk, shown on the vertical y-axis.

In the upper right corner are those intersections with both high collective and personal risk. Intersections in this quadrant have considerable scope to reduce personal risk and have sufficient DSI 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, worthwhile 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 effective speed management measures to reduce collision forces and mass action treatments. As these intersections have a lower personal risk there are unlikely to be sufficient crash benefits to justify a complete transformation of the intersection, unless supported by travel time savings. 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 lower product of flow calculation. At these intersections, the potential crash reduction benefits in terms of absolute DSI savings are limited, but low-cost safer intersection improvements are likely to be effective at reducing the potential for future DSIs. Therefore strategies focused around minor improvements to address deficiencies at the intersection, such as visibility, signage, markings, shoulder sealing 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.

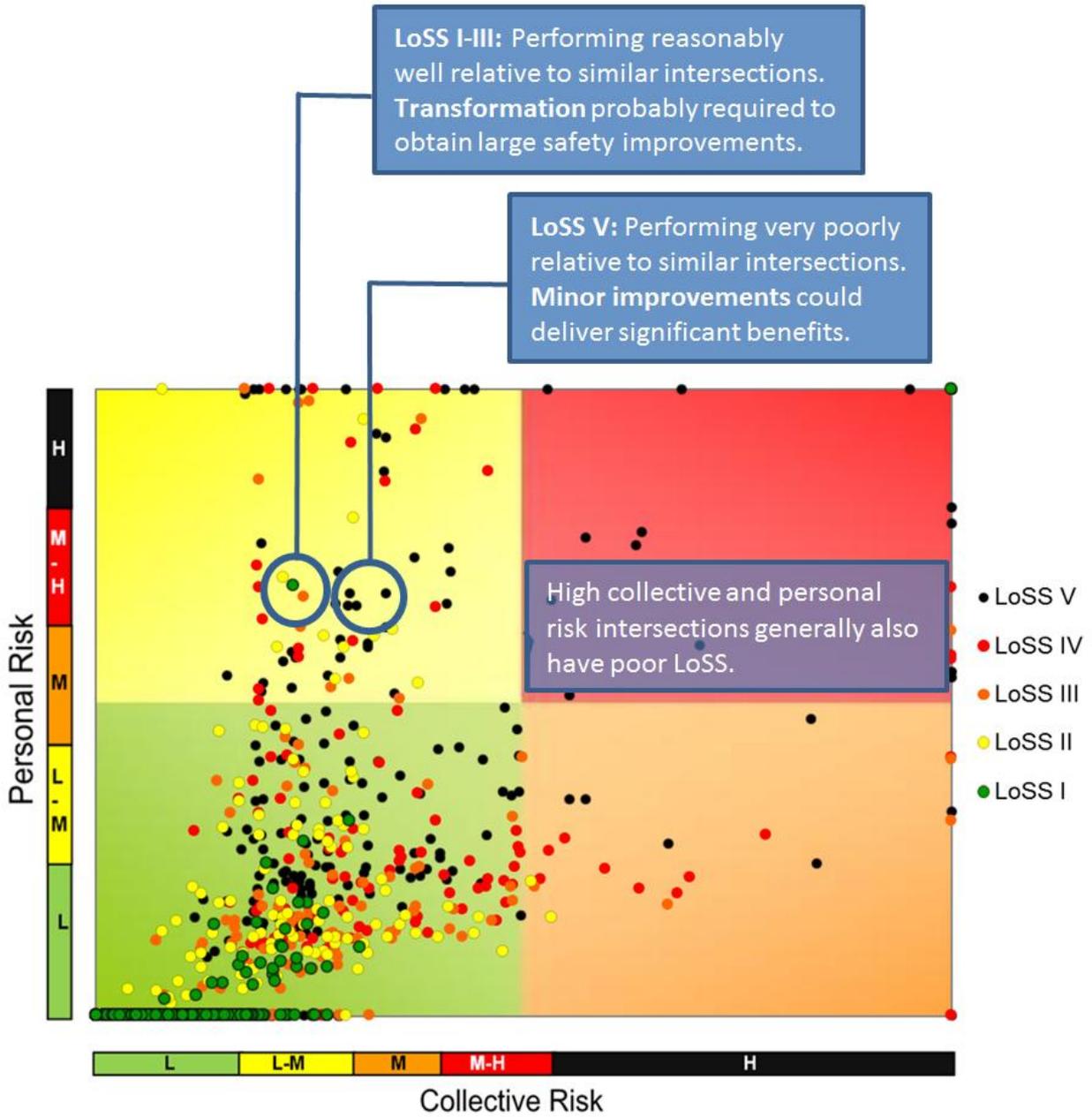
It should be noted that those sites which fall outside of transformational works, whether they are high personal or collective risk, may benefit from a combination of safer intersections or safety management.

In most jurisdictions a combination of transformational improvement at the high personal and collective risk sites, lower-cost improvements to sites with high collective risk but lower personal risk, safety management treatments at sites that are only high personal risk and mass-action application of new safety measures at sites with known risky features. A balanced strategy should seek to maximise the safety return in each RCA in terms of the number of DSIs saved in ten years per \$100m invested. The calculation of DSIs saved per \$100m dollars invested is described in section 4.3.4. It is expected that most RCAS will have some projects in each of these categories.

Figure 4-6 shows a sample group of intersections plotted in terms of their collective and personal risk, colour-coded according to their LoSS ratings. Intersections that are high-risk in terms of both collective and personal risk have the greatest need for safety improvements. These intersections generally have poor LoSS showing that they perform worse than comparable intersections, so can be cost-effectively targeted. Intersections that are high risk for either collective or personal risk have potential for improvements, but the cost-effectiveness of these varies.

For intersections with similar risk profiles, those with poorer LoSS are likely to be more cost-effective to treat. Intersections that perform poorly compared to other similar intersections will often have inherent flaws that can be readily mitigated for relatively low cost, without the need for transformation. Those that perform as expected are likely to require more extensive transformation at higher cost to deliver safety improvements. However for rural sites with priority controls, the benefits of transformation are so high that a transformation solution should always be considered.

Figure 4-6: Intersection data points plotted in terms of collective (total) risk and personal (per user) risk, with chart enhanced by colour-coding points according to LoSS rating



(a) *What type of safety problem do we have?*

While figure 4-5 provides guidance on the 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*.

(b) *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 Examples of risk profile assessment and treatment strategy

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 Rural T intersection

(a) Description

This intersection of two main state highways is located in the Central Waikato. It is situated in a rolling 100km/h rural environment and is commonly used by tourists. The 'through' route negotiates a tight bend and is the main north/south route for the north island. The other highway joins the through route at approximately the apex of the bend, as shown in Photo 4-1.

Photo 4-1: State highway – major T intersection



Aerial view of intersection; north toward top.



Looking southeast towards the intersection on through route



Looking north towards the intersection on the through route



Looking northwest towards the head of the intersection on minor road

(b) High-risk metrics assessment

To determine the risk profile, a number of steps need to be undertaken. To determine collective risk, crash data is analysed; to determine personal risk, the collective risk is divided by the traffic exposure measure; and to determine the level of safety service (LoSS), actual injury crashes are compared to typical crash rates for specific intersection types. Finally the potential benefit of transformation is considered in the analysis below.

Reported collective risk
(5 years – 50m radius)

7 injury crashes, 3 F&S crashes in 5 years.

However see below that previous safety management works 4 years ago, have affected the crash rate. 2 injury crashes in 2008 had crash causes that have been effectively remedied. So corrected crash rate is 5 injury crashes including 2 F&S crashes in 5 years.

This is insufficient on its own to be certain that the intersection still presents a high collective risk.

<p>Estimated collective risk</p> <p>DSI equivalents</p>	<p>Calculating the estimated risk from the crash data and the severity index in Appendix 3 table A3-11.</p> <p>There are 5 injury crashes, all with J type movement – severity index is 0.37 DSIs per injury crash.</p> <p>Collective risk = $5 \times 0.37 = 1.85$ DSI equivalents per 5 years.</p> <p>Comparing to table 4-1,</p> <p>Collective risk is high</p>
<p>Personal risk</p>	<p>Product of flow measure</p> <p>Using traffic volumes ($Q_{major1} = 11332$ vpd, $Q_{major2} = 7932$ vpd, $Q_{minor1} = 3461$ vpd, $Q_{minor2} = 0$) to calculate product of flow:</p> <p>$= (\text{average}(11332, 7932) \times \text{average}(3461, 0))^{0.4} = 774$</p> <p>Personal risk = $1.85 \times 100,000,000 / (774 \times 5 \times 365 \times 1.7) = 77$ DSI equivalents per 100M VKT</p> <p>Comparing to table 4-2, Personal risk = high</p>
<p>LoSS</p>	<p>We can determine LoSS using the rural priority-control T-intersections LoSS figure, Appendix 5 figure A5-11 and looking up the x axis PoF value of 774 and y axis 5-year injury crash rate of 5.</p> <p>LoSS = IV</p> <p>LoSS IV is poor performing – this intersection has a crash rate worse than expected of 70% of all rural priority T intersections. (as defined in table 4-3). Using the crash prediction equation in Appendix 5 for a rural T-junction, the typical injury crash rate would be 2.3</p>
<p>Transformation potential</p>	<p>We can estimate the likely benefits from changing the form or control of the intersection by comparing the expected DSIs for each control type at the traffic flows by using the figures in section 6.6.2.</p> <p>Using the PoF value of 774 using the 50%ile prediction equations in appendix 5, to get the expected DSIs for a rural T-intersection, and the corresponding figure for a roundabout, (illustrated in figure 6-4)</p> <p>For the existing control this gives a typical (50%ile) value of 0.86 DSIs in 5 years.</p> <p>A roundabout at a T-junction would be expected to have fewer than 0.1 DSIs in 5 years.</p> <p>At this traffic volume transformation from a typical priority T to a roundabout would be expected to save 86% of the DSIs. Given that the existing intersection with an estimated 1.85 DSI equivalents in 5 years, is worse than a typical priority T-intersection the potential reduction may be as high as 1.75 DSIs in five years. In economic terms this DSIs reduction alone is worth about 5.6 million dollars in the long term, so a significant investment would appear to be warranted.</p>

(c) *Previous improvements*

Some safety improvements to this intersection were made in 2009:

- ‘Stop ahead high crash rate’ signs installed.
- Vehicle activated ‘Stop ahead’ flashing warning sign installed on the right-hand side of the minor leg 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 minor leg approach to reduce visibility to the south.

There is evidence that the above measures have been effective in reducing the incidence of crashes where vehicles failed to stop at the stop sign. But taking this into account, the intersection still has a high collective risk. There is still an unacceptable crash risk for drivers that stopped but then proceeded to turn out in front of a through vehicle from the right. So with the collective and personal risks are still quite high, further remedial measures are required.

(d) *Treatment approach*

The poor LoSS value shows us that the intersection is performing poorly relative to comparable intersections. This suggests that there should be more potential to improve the safety performance without changing the control method. However the geometry of this intersection is not typical, being more complex than most rural priority T-intersections, with the priority route turning a corner, left turn slip lanes both onto and off the side road, which involves extensive channelisation. Two of the five crashes also involved foreign tourists that looked the wrong way, which suggests that something about the layout is confusing drivers used to driving on the other side of the road.

Alongside the above considerations, the high-risk metrics assessment shows that the intersection is high-risk in terms of both collective and personal risk, and warrants investigation of a transformational approach such as conversion to a roundabout, or grade-separation. The potential reduction in DSIs alone over 40 years would be worth about \$5.5 million towards the benefits justifying a transformation.

4.6.2 Rural crossroads: 10-year analysis

(a) Description

This crossroads intersection is situated in a saddle of a rolling 100km/h rural environment. The through route (two-way AADT on north side: 4500 vpd; on south side: 3600 vpd) slopes gently to the south (photo 4-2). The minor roads (two-way AADT on west: 700 vpd; on east: 2400 vpd) have steep up-hill grades towards a crest at the intersection on both approaches.



Photo 4-2: Example of rural intersection.
Source: Google Maps 2011

(b) High-risk metric assessment

To determine the risk profile, we wish to calculate the collective risk, personal risk, LoSS and transformation potential. These are shown in the example below. Ten years data is used as the site has remained substantially unchanged.

(c) Previous improvements

From CAS records it is apparent that traffic islands with duplicated central stop signs have been present for at least the whole 10-year period. The intersection has also been widened at some stage to provide for shoulders/auxiliary left turn lanes. So the usual low cost treatments have already been applied for some time.

Further treatments are currently being planned with a proposed speed limit reduction from 100km/h to 80km/h through the route.

(d) Treatment approach

The high-risk metrics assessment shows that the intersection is still estimated to be high-risk in terms of both Collective Risk and Personal Risk, and the poor LoSS suggest there is substantial room for improvement with the existing control. This suggests that initially, a safer intersection approach should be investigated. However, the risk profile also suggests a transformation to a roundabout should also be considered, with the potential to save 1.9 DSIs in 5 years alone worth about \$6.3million in benefits. A roundabout may also have operational benefits given the approach flows on three legs are reasonably balanced. However, the uphill approaches from the side roads presents a challenge to achieving an economical roundabout design.

Given the recent recommendation to use a safety management approach to lower the speed limit, it would be prudent to do this, but the expected effectiveness of such measure would be modest, so this should not prevent the investigation of other options.

<p>Reported collective risk</p> <p>F&S crashes (10 years – 50m radius)</p>	<p>11 injury crashes.</p> <p>1 F&S crash.</p> <p>As the intersection does not have five or more F&S crashes in the past 10 years that means it is not a high-risk intersection in terms of fatal and serious crashes alone.</p>																																
<p>Estimated collective risk</p> <p>DSI equivalents (10 years – 50m radius)</p>	<p>We now determine the estimated collective risk using SI table A3-8 (for rural priority controlled crossroads) to determine estimated collective risk.</p> <table border="1" data-bbox="360 488 1294 808"> <thead> <tr> <th>Movement type</th> <th>No. of injury crashes</th> <th>Adjusted SI (DSIs / injury crashes) - table a3-8</th> <th>Estimated no. of DSI equivalents</th> </tr> </thead> <tbody> <tr> <td>H</td> <td>6</td> <td>0.50</td> <td>3.0</td> </tr> <tr> <td>F</td> <td>1</td> <td>0.10</td> <td>0.10</td> </tr> <tr> <td>D</td> <td>1</td> <td>0.30</td> <td>0.30</td> </tr> <tr> <td>L</td> <td>1</td> <td>0.35</td> <td>0.35</td> </tr> <tr> <td>J</td> <td>1</td> <td>0.36</td> <td>0.36</td> </tr> <tr> <td>G</td> <td>1</td> <td>0.25</td> <td>0.25</td> </tr> <tr> <td>Total</td> <td>11</td> <td></td> <td>4.36</td> </tr> </tbody> </table> <p>Using the estimated number of DSI equivalents in 10 years of 4.36/2 = 2.18 DSIs in 5 years.</p> <p>Referencing table 4-1 indicates that there is a high collective risk. This shows that the low number of F&S crashes is most likely due to chance, and is likely to be higher in the next five years.</p> <p>Collective risk is high</p>	Movement type	No. of injury crashes	Adjusted SI (DSIs / injury crashes) - table a3-8	Estimated no. of DSI equivalents	H	6	0.50	3.0	F	1	0.10	0.10	D	1	0.30	0.30	L	1	0.35	0.35	J	1	0.36	0.36	G	1	0.25	0.25	Total	11		4.36
Movement type	No. of injury crashes	Adjusted SI (DSIs / injury crashes) - table a3-8	Estimated no. of DSI equivalents																														
H	6	0.50	3.0																														
F	1	0.10	0.10																														
D	1	0.30	0.30																														
L	1	0.35	0.35																														
J	1	0.36	0.36																														
G	1	0.25	0.25																														
Total	11		4.36																														
<p>Estimated personal risk</p>	<p>Using the through route flows of 4500 and 3600 vpd, and sideroads, 700 and 2400</p> $\text{PoF} = ((4500 + 3600) \times 0.5 \times (700 + 2400) \times 0.5)^{0.4} = 524$ $\text{Personal risk (section 4.2.2)} = \frac{2.18 \text{ DSIs} \times 10^8}{524 \times 5 \text{ years} \times 365 \text{ days} \times 1.7}$ <p>Personal risk = 134</p> <p>As the personal risk value metric is greater than 32</p> <p>Comparing with table 4-2.</p> <p>Personal risk is high</p>																																
<p>LoSS</p>	<p>To determine LoSS, use Appendix 5 figure A5-10 for rural priority controlled crossroad intersections which compare actual injury data against typical crash rates for specific intersection types. The product of flow was calculated above as 524 and the number of reported injury crashes in ten years is 11 so rate per 5 years is 5.5.</p> <p>Using table 4-3</p> <p>LoSS = IV.</p> <p>The observed injury crash rate is in the worst 30%, performing worse than expected of 70 percent of similar intersections. The 50%ile rate would be approximately 1.8 injury crashes in 5 years</p>																																
<p>Transformation potential</p>	<p>We can estimate the likely benefits from changing the form or control of the intersection by comparing the expected DSIs for each control type at the traffic flows by using the figures in section 6.6.2.</p> <p>Using the PoF value of 524 use the prediction tables in appendix 5 to get the expected DSIs for a rural cross-junction under priority and roundabout control (illustrated in figure 6-3).</p> <p>For the existing priority control this gives a 50%ile value of 0.7 DSIs in 5 years.</p> <p>A roundabout would be expected to have fewer than 0.28 DSIs in five years.</p> <p>At this traffic volume transformation from a typical priority X to a roundabout would be expected to save 60% of the DSIs. However given that with 2.18 DSI equivalents the existing intersection is worse than a typical priority X junction the potential reduction may be as high as 1.9 DSIs in 5 years. In economic terms this DSIs reduction alone is worth about 6 million dollars in the long term, so a significant investment would appear to be warranted.</p>																																

4.6.3 Urban signalised crossroads

(a) *Description*

This intersection is an urban signalised crossroads located in a busy CBD with a 50km/h speed limit. One of the roads is one-way northbound

(b) *High-risk metric assessment*

The table below shows the calculation of all the metrics required to assess the risk profile of the intersection.



Photo 4–3: Example: Urban signalised intersection. Source: Google maps (2011)

Reported collective risk F&S crashes (5 years – 50m radius)	<p>5 injury crashes. 2 F&S crashes.</p> <p>As the intersection does not have three or more F&S crashes in the past five years (2007–2011) that means it does not achieve high collective risk in terms of reported F&S crashes alone.</p>																
Estimated collective risk DSI equivalents	<p>There were four pedestrian injury crashes and one crossing crash in five years.</p> <p>Using severity index from table A3-2;</p> <table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr style="background-color: #D3D3D3;"> <th>Movement type</th> <th>No. of injury crashes</th> <th>Adjusted SI (DSIs / injury crashes) – table a3-</th> <th>Estimated no. of DSI equivalents</th> </tr> </thead> <tbody> <tr> <td>H</td> <td>1</td> <td>0.19</td> <td>0.19</td> </tr> <tr> <td>N</td> <td>4</td> <td>0.23</td> <td>0.92</td> </tr> <tr> <td>Total</td> <td>5</td> <td></td> <td>1.11</td> </tr> </tbody> </table> <p>1.11 estimated DSI equivalents in 5 years.</p> <p>Collective risk is medium high</p>	Movement type	No. of injury crashes	Adjusted SI (DSIs / injury crashes) – table a3-	Estimated no. of DSI equivalents	H	1	0.19	0.19	N	4	0.23	0.92	Total	5		1.11
Movement type	No. of injury crashes	Adjusted SI (DSIs / injury crashes) – table a3-	Estimated no. of DSI equivalents														
H	1	0.19	0.19														
N	4	0.23	0.92														
Total	5		1.11														
Personal risk	<p>7,200 vehicles enter the intersection northbound on the one-way street.</p> <p>On the eastern leg, the two flow is 1497 vehicles per day and the western leg has 2321.</p> <p>So the daily PoF exposure function is: $(7200 \times ((1497+2321)/2))^{0.4} = 717$.</p> <p>Personal risk uses the higher of 2 F&S / 2 =1 and the estimated DSIs of 1.11.</p> <p>Personal risk (5 years) (section 4.2.2) = $\frac{1.11 \text{ DSIs} \times 10^8}{717 \times 5 \times 365 \times 1.7}$</p> <p style="text-align: center;">= 50</p> <p>Using Table 4-2 the intersection is classified as:</p> <p>Personal risk is high.</p> <p>This is partly due to the type of crashes being more severe than typical.</p>																

LoSS	<p>Using figure A5-1 for urban signalised controlled crossroad intersections, the product of flow is 717 and there were 5 injury crashes.</p> <p>LoSS = III.</p> <p>Using table 4-3 describes what this means i.e. the observed injury crash rate is a little worse than expected of 50% of similar intersections where 2.8 injury crashes would be expected. This typical injury values is also high due to the typically poor performance of traffic signals at lower volume cross roads.</p> <p>However as this intersection is on a one-way route, the comparison with all crossroads controlled by signals may not be entirely valid. We would expect an intersection on one way route to perform more safely than if all approaches were two-way.</p>
Transformation potential	It is not feasible to transform to a roundabout due to the one-way road, and the lack of space.

(c) *Previous improvements*

In November 2005 this intersection was upgraded from a priority control to signals including parallel pedestrian phases operating as filtered turns. Following this transformation, there were 4 pedestrians injured over 4 years, including 2 of them seriously. This period was the initial analysis period performed in 2011.

It appears that after 2008, the intersection phasing has been altered during off peak times to remove co-ordination and make the signals more responsive to side road and pedestrian demands.

(d) *Treatment approach*

The high-risk metrics assessment shows that the intersection is medium – high for collective risk and high for personal risk and the LoSS metric shows there is likely to be only limited opportunity to improve the crash rate with the existing controls, though this may be an underestimate.

There have been no crashes in the three and a half years since mid 2009, so it may be that the more recent improvements have helped.

It seems appropriate to monitor the intersection each year to confirm that the problem is not re-emerging.

4.6.4 Urban single lane roundabout

(a) *Description*

This single lane roundabout intersection photo 4–4 is situated in urban 50km/h speed environment.

(b) *High-risk metric assessment*

The table below shows the calculation of all the metrics required to assess the risk profile of the intersection.



Photo 4–4: Example: Single lane urban roundabout. Source: Google Maps (2011)

Reported collective risk	6 injury crashes. 3 F&S crashes in 5 years.																												
Actual crash data (5 years – 50m radius)	As the intersection had three or more F&S crashes in the past five years that means it has high collective risk in terms of recorded F&S crashes. However going back 10 years the intersection has been unchanged. There were 10 injury crashes of which 4 were F&S, so a rate of 2 F&S in 5 years is likely to be more accurate.																												
Collective risk: estimated DSIs	<p>As there have been no changes to the site and the 10-year crash profile is similar to the most recent 5 years, the 10-year pattern is likely to provide a more reliable measure. We now determine the estimated collective risk using SI table A3-6 (for urban roundabouts) to determine estimated collective risk</p> <table border="1" style="width: 100%; border-collapse: collapse; text-align: center;"> <thead> <tr style="background-color: #d9d9d9;"> <th>Movement type</th> <th>No. of injury crashes</th> <th>Adjusted SI (DSIs / injury crashes) – table a3-</th> <th>Estimated no. of DSIs</th> </tr> </thead> <tbody> <tr> <td>H</td> <td>1</td> <td>0.15</td> <td>0.15</td> </tr> <tr> <td>K</td> <td>1</td> <td>0.10</td> <td>0.10</td> </tr> <tr> <td>D</td> <td>2</td> <td>0.20</td> <td>0.40</td> </tr> <tr> <td>Cyc</td> <td>5</td> <td>0.21</td> <td>1.05</td> </tr> <tr> <td>M/C</td> <td>1</td> <td>0.30</td> <td>0.30</td> </tr> <tr style="border-top: 1px solid black;"> <td></td> <td>10</td> <td></td> <td>2</td> </tr> </tbody> </table> <p>Estimated risk is 2 DSI equivalents in 10years or 1 in 5 years.</p> <p>Comparing to table 4-1, estimated collective risk is medium.</p>	Movement type	No. of injury crashes	Adjusted SI (DSIs / injury crashes) – table a3-	Estimated no. of DSIs	H	1	0.15	0.15	K	1	0.10	0.10	D	2	0.20	0.40	Cyc	5	0.21	1.05	M/C	1	0.30	0.30		10		2
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M/C	1	0.30	0.30																										
	10		2																										
Personal risk:	<p>Using the main north/south flows of 14,387 and 9,261, and east / west flows of 5663 12016.</p> $PoF = ((14,387 + 9261) \times 0.5 \times (5,663 + 12,016) \times 0.5)^{0.4} = 1613$ <p>There are two main measures of collective risk reported risk of 2 F&S crashes / 2 = 1 or estimated risk of 1 DSI equivalents.</p> $\text{Personal risk} = \frac{1 \text{ DSI} \times 10^8}{1613 \times 5 \text{ years} \times 365 \text{ days} \times 1.7}$ <p>Personal risk = 20</p> <p>Comparing with table 4-2, Personal risk is medium–high.</p>																												

LoSS	Using the 5 injury crashes, the PoF of 1613, and looking up figure A5-7 in Appendix 5:
Estimated or predicted crashes	LoSS = IV. This shows that this intersection is in the worst 30% of urban 4 legged roundabouts. The expected 50%ile injury crash rate is about 2 so there is still potential to more than halve the injury crash rate.
Transformation potential	As a roundabout is likely to be the safest intersection form, transformation to another intersection type is unlikely to reduce DSIs. A typical 50%ile roundabout would have 0.3 DSIs.

(c) *Previous improvements*

The roundabout has had no improvements in the last ten years. It has standard signs and markings associated with a roundabout, including give way signs on the approach islands.

(d) *Treatment approach*

The high-risk metrics assessment shows that the intersection has medium collective risk and medium high personal risk. It is a high-risk intersection and should be investigated.

The LoSS IV category suggests that there is still the potential to save another 0.7 DSI in five years, so the intersection deserves a closer preliminary look to see if there are any crash characteristics and patterns that might suggest a promising approach to treatment.

A closer look at the crashes indicates that all but one of the entering vs circulating crashes have involved a driver entering the roundabout that collided with a cyclist or moped rider from the right. Another 2 crashes involved a collision with the same power pole located 50 metres south of the roundabout exit. This crash pattern suggests that it is highly likely that some low cost solutions that slowed down traffic on the approaches, such as increased deflection, eg by kerb protrusions, enlarging the main island, or pedestrian platforms, could be effective, along with removing a row of power poles from near the roundabout..

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 estimated DSI equivalents based on the 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 of all crash data and to visit the site in order to identify any 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 deaths and serious injuries. 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, ie 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, RCA deficiency databases, 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 crash 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. Caution should be given to drawing conclusions solely from the older data as site conditions may have changed, eg 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 did not slow sufficiently for intersection to give way, did not see other party, misjudged speed, distance size or position of another party, slippery surface, foreign drivers, impaired drivers.

Consideration also needs to be given to the traffic volumes and composition and an assessment made as to whether the appropriate intersection form and control is provided. The potential of a transformation approach to reduce DSIs is helpful in this assessment.

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 or delineation; poor signal visibility, or issues with 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.

5.2.1 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 DSI equivalent risk based on all injury crashes takes account of the higher severity of crashes involving, pedestrians, cyclists and motorcyclists.

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. As a result, proactive methods require local knowledge of where cycling and walking activity is focused, and identification of features that are known to be less safe for pedestrian and cyclists.

Section 6.5.5 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.

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, and motorcyclists. 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 raised 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 to 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 from 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 Treatment philosophy

As shown in figure 4–5 there are four key treatment philosophies for countermeasures for high-risk intersections. These are:

- **Safe System transformation treatments (section 6.6):** These treatments are likely to address sites with high collective and personal risk profiles. They are generally higher cost infrastructure countermeasures and are developed and implemented over a longer term, although they can also include aspects of safety management and safer intersections type treatments – especially as interim measures.
- **Safer intersection treatments:** These measures are medium to low cost and can be implemented in a relatively short time frame on busier intersections.
- **Safety management treatments:** These measures tend to be the lowest cost, and are most appropriate on lower volume roads where higher cost measures are not feasible.
- **Safety maintenance:** This involves maintaining the performance of the network by complying with general good practice as defined in standards, guidelines and specifications.

More detail on the types of countermeasures most appropriate to each of the above categories is contained in Appendix 6: table 14.

6.3 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:

- where the intersection fits within the local and national route hierarchy and wider area context
- whether the intersection form and control is appropriate to the hierarchy and traffic volumes
- whether the importance and function of the intersection is intuitive to users and whether it is consistent with others of similar strategic role
- 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
- whether the intersection crosses or forms part of a strategic route for key user groups. For example, where overdimension/overweight loads are transported certain changes to one intersection may affect these types of vehicles using the route, limiting access to certain locations. Similarly, other changes could affect the cycle network as defined by the RCA, or the intersection may be significant in the walking network.

Consideration of 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.

6.4 Wider network treatments

6.4.1 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 an 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 the 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.

In addition to reactive measures, proactive mass treatment could be considered. This would be the form of mass action of features with high-risk potential, such as rural crossroads.

6.4.2 Network-wide treatments

There may be some high-risk intersections which have been subject to previous improvement works but continue to have unresolved problems. 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, increasing 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, decreasing the use of other less suitable intersections. In these cases an assessment will need to be considered as to the adequacy of the other intersections and improvements to these may be necessary.

6.5 Countermeasure evaluation

6.5.1 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 crash reports contained in CAS.

Careful consideration needs to be given to some types of countermeasure and their suitability for the environment and types of road users. 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 through traffic. 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. In addressing issues, a wide range of road users should be considered. Further information can be sourced within a number of NZTA guides, including the *High-risk rural roads guide*, *Safer journeys for motorcycling on New Zealand roads*, *Pedestrian planning design guide* and *Cycle network and route planning guide* among others.



6.5.2 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. It should be noted that an RCA can introduce lower speeds limit under current legislation for particular roads. Refer to NZTA Traffic Note 61: Safe System approach to rural speed management for further information. Wider network or 'blanket' default urban and rural speed limits would require changes to the Speed Limits Rule.

The NZTA recognises that there is some merit in applying a safer operating speed limit or speed zones² for roads on which the standard rural speed limit is inappropriate. This also applies to intersections.

Another common proven technique employed in crash reduction is adding on or enhancing other existing traffic control devices. For example where speed management may be an issue, countermeasures may take the form of raising driver awareness on main road approaches to reduce through speeds with:

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 (2013)) method of setting speed limits, which is based primarily on the amount of frontage development.

- 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 used to types of signs, and over time this may reduce the overall benefit. Care should also be given to 'over-signing' a high-risk location as this may result in nearby intersections becoming relatively less visible.

Intelligent options have been developed for electronic warning signs that provide additional information so that a driver is more aware of the type of risk. The driver can then determine which risk they are facing at a specific site, such as approach speed, weather or presence of a vehicle on the side road. A trial of active warning signs setting reduced speeds limits on main road approaches to intersections when there is conflicting traffic present is producing very encouraging speed reductions.

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 upon in the following countermeasures section.

Further information on Safe System speeds in a rural context can be found in NZTA Traffic Note 61: Safe System approach rural speed management – information.

6.5.3 Intersection visibility

An intersection approach can suffer from too little visibility or too much visibility. The problem due to too much visibility arises at crossroads and roundabouts when a vehicle required to give way has visibility from too far back on the intersection approach. This can result in failing to slow sufficiently and looking too early with the result that less conspicuous vehicles – especially cyclists and motorcyclists are not seen. In these situations, balancing the visibility on all approaches to a more consistent and optimum level should be considered.

In the case of an intersection where site investigation has identified poor visibility from the side road as the issue, the problem is typically that a side road vehicle cannot see far enough down the main route to safely judge a gap. There are a number of potential measures that can be employed which will provide some improvement. These could include increasing visibility, 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 possibility 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 visibility improvement should be accompanied by risk mitigation through effectively managing through traffic speeds.

6.5.4 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 will be obvious when developing any countermeasure strategy. However whenever they are present their needs should also be considered, to ensure at least a satisfactory level of safety. 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.

There are particular issues and crash types that affect vulnerable road users.

- At traffic signals, it is rare for a pedestrian to be struck by a vehicle that did not stop for a red light. Where pedestrians were struck by vehicles travelling straight through at the lights, almost invariably the pedestrian has crossed against the signals.
- At traffic signals the hazard to legally crossing pedestrians is from turning vehicles, especially heavy vehicles with visibility constraints from the driver's seat being a major issue. This requires careful consideration of timing of pedestrian phases in relation to turning traffic especially where parallel pedestrian phases operate or filtered right turns are permitted. Early start of the parallel pedestrian phases is beneficial.

- Cyclists can have a similar issue alongside left turning vehicles, especially heavy vehicles. The provision of cycle lanes between through and left turning only lanes is beneficial (with or without splitter islands) as is coloured surfacing of cycle lanes.
- The road width to be crossed by pedestrians can be excessive due to over-generous kerb radii and provision for turning lanes, making it difficult to judge a crossing opportunity. Central refuges and high entry angle splitter islands help. Pedestrians crossing to splitter islands can be assisted by pedestrian platforms.
- Urban roundabouts typically operate at speeds that are higher than is comfortable or safe for pedestrians and cyclists. Recent research suggests that even multilane roundabouts can perform safely for pedestrians and cyclists provided speeds are well controlled by a mix of tight geometry, restricted visibility and vertical deflection to the extent that even zebra crossings across the entrances and exits can operate with relative safety.
- Both cyclists and motorcyclists are often not noticed by other drivers that fail to give way. Unlike cyclists, motorcyclists are likely to be travelling at above Safe System thresholds at impact. At signals this typically happens when drivers are turning right, so exclusive right turn phases are particularly beneficial to motorcyclists and cyclists.
- At rural intersections motorcyclists often get struck while attempting to overtake a vehicle slowing to turn right. Right turn bays are an effective countermeasure.

The development of countermeasures for main motor vehicle crash movement types will also need to consider their needs. For example:

- If a signalised intersection has a right turn against crash problem, the solution may be 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, and increase the number of pedestrians crossing against the lights. 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] In addition, where there is a significant volume of vulnerable road users using the intersection, consideration could be given to the use of overbridges or underpasses to protect them.
- If motorcyclist crashes are over-represented at intersections, consideration can also be given to other Safe System treatments, reduction in speeds, visibility triangles unobstructed by turning traffic, improved delineation, active speed warning signs and skid resistance. More information on motorcycle aspects can be found in the NZTA's *Safer journeys for motorcycling on New Zealand roads*.
- When designing new and retrofitted treatments it is important to determine whether the layout/treatment might create a hazard to other road users. For example, a new roundabout or kerb build-outs could create a hazard for cyclists.

Further information can be sourced within a number of guides, including the *Safer journeys for motorcycling on New Zealand roads*, the *Pedestrian planning and design guide*, *Cycle network and route planning guide*, *Cycling aspects of Austroads guides* and the draft *Non-motorised user review procedures* among others.

6.5.5 Road user responsibility

While the Safe System approach moves away from driver blame and recognises that the severity of inevitable errors must be managed, 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 also 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 at-risk groups. This may lead to better road user behaviour 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 and communicate with the school community so that improvements and behavioural issues are dealt with together. The parents will better understand how their behaviour is compromising the safety of their children, and the school authorities and designers may understand that parent's behaviour may be a response to inadequate parking provision or other issues.

Road safety messages identifying high crash rate sites and routes are useful to highlight 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 ongoing 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, it would be worth considering measures to manage the speed environment such as gateway features, enhanced signage and raised platforms.

6.6 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 ten years prior to this should also be reviewed to confirm there is a long-standing 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.

6.6.1 Safe System compliance of transformational works

Roundabouts have consistently good safety performance and are inherently Safe System compliant, so they are generally the preferred option considered for transformation treatments, subject to space considerations. Despite their often higher non-injury crash rates, their superior Safe System performance is achieved by controlling crash forces to occupants of motor vehicles to below Safe System thresholds. However, the outcome for motorcyclists and cyclists is not as favourable, as conflicts are still frequent, and impact speeds for them are still above their lower Safe System thresholds. Compared to urban crossroads, their performance was typically better than signals but similar on average to priority control, but with more consistent performance. Many existing rural roundabouts also suffer from poor clear zones on the exits, where over 60% of all DSIs happen in impacts with unyielding roadside objects. So there is still room for improvement in roundabout performance. New designs and improvements to existing roundabouts should aim for better speed control on approaches, consistent but not excessive visibility, appropriate provision for cyclists and to provide forgiving environments especially downstream of the exits.

Traffic signal controlled crossroads do not perform as well under Safe System criteria and their performance varies widely. In urban areas they overall perform worse than priority controls, despite substantially reducing crossing movement crashes, they perform much worse for right turn against and pedestrian crashes. So they should not be automatically considered as a Safe System transformation, and where they are needed for other reasons, their shortcomings should be carefully addressed in the design.

Rural traffic controlled crossroads, generally perform better than the very poor performing rural priority crossroads, due mostly to lower crash severities, but they have higher severities than roundabouts. While impact speeds and hence severities are lower than for priority control, they are still likely to exceed Safe System thresholds. So where traffic signals are required for other reasons than Safe System transformation, careful attention will be required to approach detection, and phasing sequences.

Traffic signals at urban T-junctions also show little advantage over priority control, despite being most effective at reducing crashes involving vehicles entering from the side road colliding with main road traffic. They however increase right turn against and pedestrian crash risk.

However at rural T-junctions controlled by traffic signals, the limited data from 26 sites shows none of the problems apparent at urban T-junctions, but rather the performance of rural sites is six times better than the urban sites. This may be partly due to an absence of pedestrians, but it is also likely that because of the higher speeds, much greater care is used in the detection of vehicles and the safe phasing of signal sequences is easy to achieve.

Channelised priority junctions theoretically improve safety as traffic islands provide a degree of separation between through and turning traffic, and they enable vehicles turning right to cross one direction of traffic at a time. However, in practice these layouts typically result in an elevated crash record. This is due to:

- the layout dictating a larger intersection area, divided by islands, making it difficult to observe and understand the whole layout
- driver confusion as to its use, especially by those unfamiliar with the site or tourists from countries that drive on the other side of the road
- higher through traffic speeds.

A number of studies worldwide show an average increase in injury crashes of 16% for full channelisation of T-intersections. [2] Seagull T-junctions are a particular case in point. Findings from a case study [46] which analysed three different forms of seagull design in operation at one intersection indicated that 'careful consideration should be given to the road environment, traffic volumes, turning patterns, sight distances, [crash factors] and possible counterintuitive elements when considering the most appropriate design for seagull treatment at T-junctions'. Seagull T-junctions are easily transformed to traffic signal control. This is likely to be very effective at achieving satisfactory Safe System performance.

Estimating benefits of transformation treatments

The potential crash reduction benefit of a transformational change can be quickly assessed by using the figures 6-1 to 6-4 to predict the DSI performance of a transformed intersection and compare it with the estimated DSI equivalents of the existing junction. These figures give similar results for urban intersections to the models in Appendix A6 of the NZ TA's *Economic evaluation manual* (EEM). There are also more detailed models for urban intersections in the EEM that take into account the operational and geometric characteristics of intersections. However the rural models used in this HRIG are based on a larger and more recent sample of NZ intersections, so it is recommended that they be used in the interim, until the rural EEM models are revised. Worked examples are included in section 0.

6.6.2 Comparing intersection form and control

Graphs showing the relationship between the product of the minor and major road flow and the expected number of fatal and serious crashes, and deaths and serious injury casualties, for a five-year period are provided below in figures 6–1 and 6–2 for urban intersections and figures 6–3 and 6–4 for rural intersections.

As discussed in section 6.6.1, the differences in safety performance of intersections is a product of the likelihood of an injury crash happening and the likelihood that the crash will result in deaths or serious injuries.

The number of crashes or casualties that there is a 50% probability of being exceeded for a particular intersection control and traffic volume is shown as a solid line. The band shaded in the same colour extends from the crash/casualty number with a 70% probability of being exceeded up to the number with a 30% probability of being exceeded. Because the data is skewed with much more variation above the 50%ile line than below it, the 50%ile is below the average or mean DSI risk. This means the 50%ile line represents the value likely to be achieved by a better than average intersection of the type and can be used with transformational assessments to predict the performance likely to be achieved by a good design standard.

These graphs can be used as a guide to the trends in intersection control safety among existing New Zealand intersections. The graphs are based on the injury crash rate and flow data used in the development of the level of safety service indicator, with the severity index factors contained in Appendix 3 applied to determine the likely deaths and serious injuries based on the injury crash numbers. The formulae for the 50%ile lines are contained in Appendix 4.

These graphs highlight the considerable variation between intersections with the same control and traffic flows. There is also overlap in crash rates between different intersection controls, as well as considerable potential for improvement.

Figure 6–1: Flow range and crash relationship for various methods of control at urban crossroad intersections

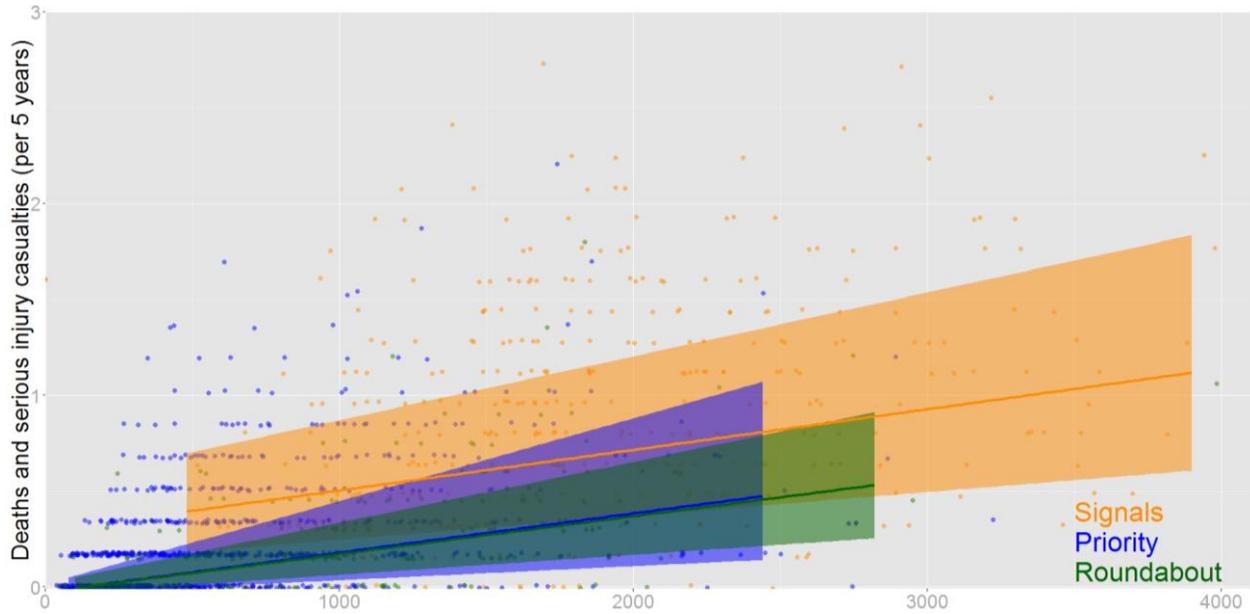
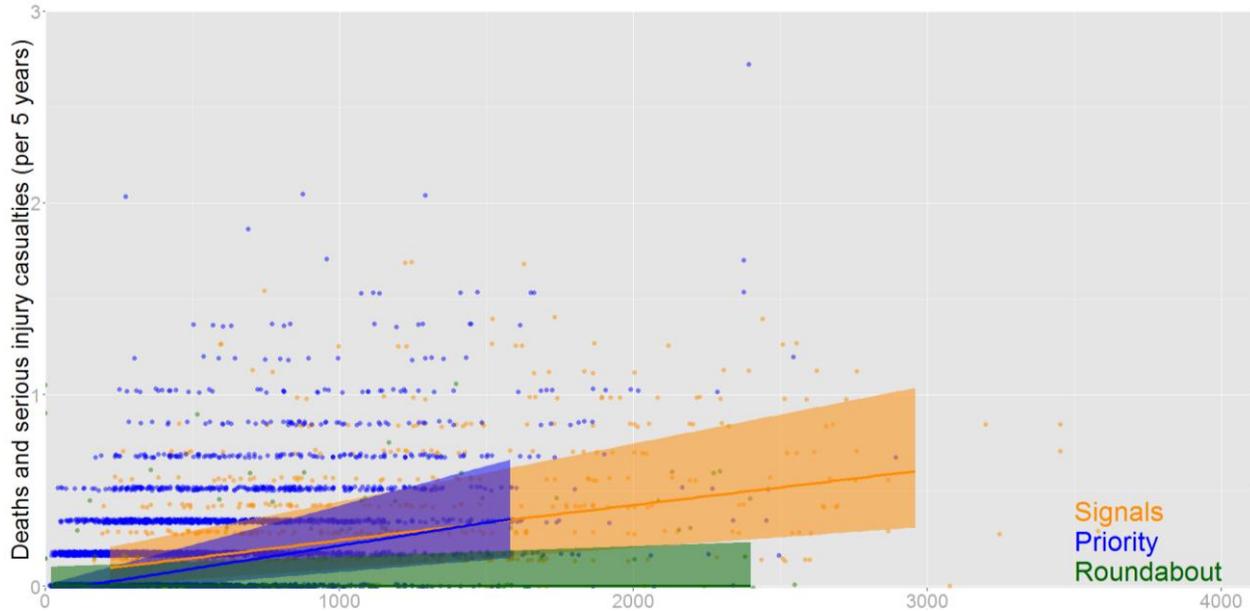


Figure 6–2: Flow range and crash relationship for various methods of control at urban T-intersections



Figures 6–1 and 6–2 show that the performance of urban intersections controlled by traffic signals is no better than with priority control, and in the case of crossroads is worse. As one of the reasons typically advanced for installing traffic signals is improved safety, this requires further investigation to understand why this should be so.

As expected the Safe System performance of urban roundabouts is superior to signals, but for urban crossroads it is surprising that the 50%ile line is similar to priority control. However, roundabouts perform more consistently, having few high-risk sites, whereas the performance of priority crossroads and traffic signals varies widely.

Figure 6–3: Flow range and crash relationship for various methods of control at rural crossroads intersections

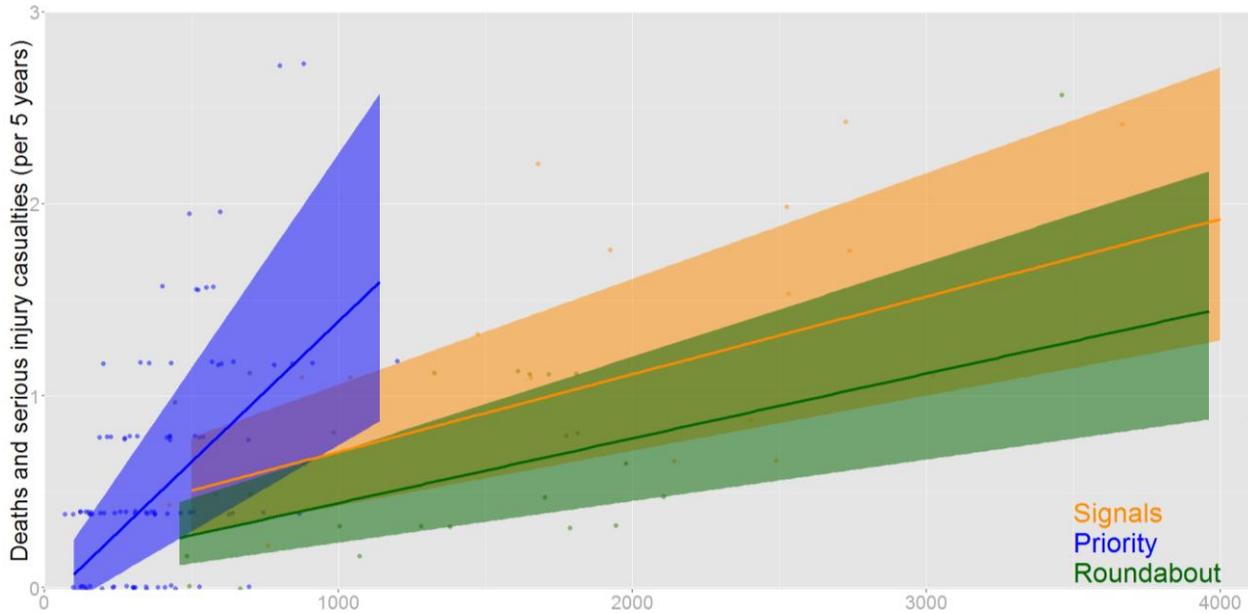
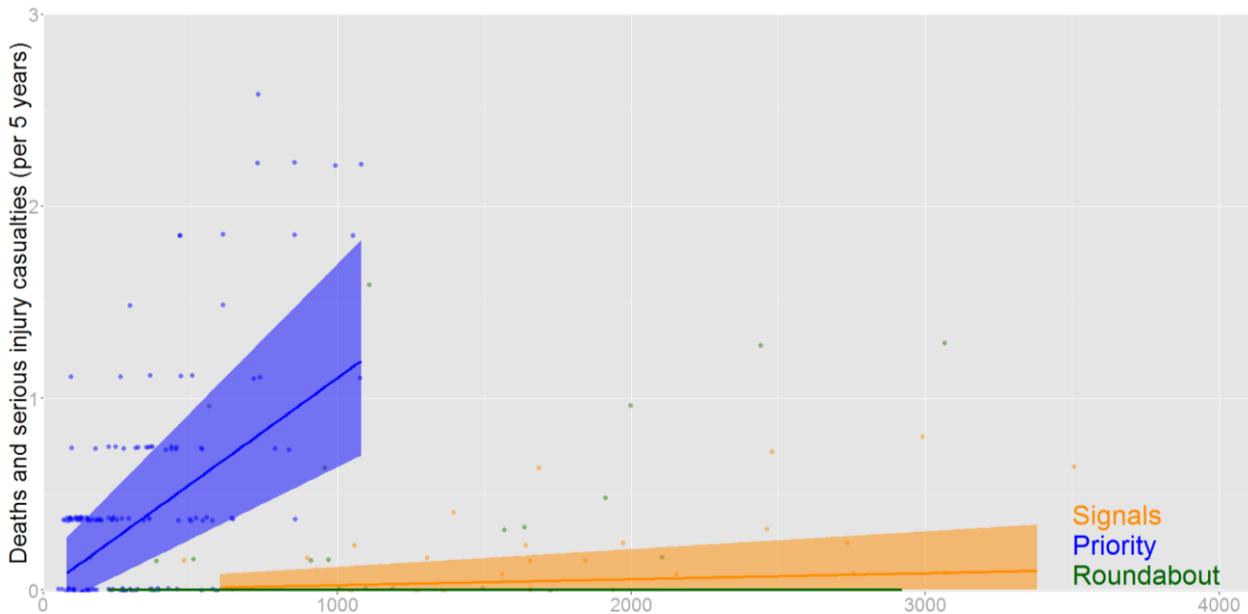


Figure 6–4: Flow range and crash relationship for various methods of control at rural T-intersections



Figures 6–3 and 6–4 show that the most common rural intersection type by far – priority control – is the worst performing. These intersections are typically over five times riskier for deaths and serious injuries than urban intersections with the same traffic flows. This would be expected from Safe System principles as the impact speeds are well above Safe System thresholds, and the risk of death and serious injury climbs rapidly with speed.

The rural roundabouts and traffic signals analysis is based on smaller samples of between 20 and 30 sites each, so are subject to more uncertainty than the priority control sites. However, the differences in safety performance between them and priority control are much larger than the margin of error.

The difference in performance of roundabouts between T-junctions and crossroads is also quite remarkable and deserves further study. It may be related to the excessive number of lost control on roundabout exit crashes in the rural roundabout data. This problem is simple to solve so a well designed rural roundabout at crossroads should aim for better performance than suggested by this historic data.

What is very clear is that transformational works should be much more effective at rural intersections than urban ones.

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

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

Table 6–1 and table 6–2 provide a guide to some of the potential site issues that may contribute to the key F&S crash movement types of both rural and urban intersections identified in section 3. The corresponding likely safety management and safer intersection countermeasures are also provided with further details of which are contained in the countermeasures section in Appendix 6.

Table 6–1: Rural countermeasures reference table by intersection form and crash movement type

Intersection form	Potential site issues	Countermeasure	Reference (Appendix 6)	
Rural signals	Vehicle lost control (CA/CB/CC/DA/DB/DC)			
	<ul style="list-style-type: none"> Poor or obscured signal head location 	7	Improve signal conspicuity	IS8
	<ul style="list-style-type: none"> Poor visibility of intersection due to alignment 	8	Rumble strips, enhanced signing, sight distance improvement	S2, S4, IS3
	<ul style="list-style-type: none"> Restricted inter-visibility from side road to main road traffic 	9	Sight distance improvement	IS3
	<ul style="list-style-type: none"> Associated street furniture can represent a collision risk 	10	Clear or safe zones	C1 S3
	<ul style="list-style-type: none"> Poor skid resistance 	11	Improve skid resistance	
	<ul style="list-style-type: none"> Poor drainage 	12	Improve drainage (maintenance)	
	Right turn against (LA/LB)			
	<ul style="list-style-type: none"> Poor or obscured signal head location 		Improve signal conspicuity	IS8
	<ul style="list-style-type: none"> No separate right turn phase 		Provide separate right turn phase	IS7
	<ul style="list-style-type: none"> Restricted or obscured forward visibility due to alignment, street furniture, signs, trees 		Sight distance improvement	IS3
	<ul style="list-style-type: none"> Opposing or left offset right turn bays resulting in turning vehicles restricting visibility of through traffic 		Align opposing right turns	IS9
	<ul style="list-style-type: none"> Excessive opposing through approach speed or differential through speeds where multiple opposing through lanes 		Intelligent electronic warning signs, enhanced signing, high friction coloured surfacing, speed and red light cameras	S1, S2, S3, E1

Intersection form	Potential site issues	Countermeasure	Reference (Appendix 6)
Rural Roundabout	Vehicle lost control (CA/CB/CC/DA/DB/DC)		
	<ul style="list-style-type: none"> Excessive visibility on roundabout approach leading to early decision making and higher entry speeds 	Geometry improvements	IS13
	<ul style="list-style-type: none"> Poor entry deflection leading to higher entry speeds, particularly when exit radius is tighter 	Geometry improvements	IS13
	<ul style="list-style-type: none"> Poor advance signing and poor delineation /lighting of approaches/ circulatory 	Transverse road markings, central lighting	S2, IS14
	<ul style="list-style-type: none"> Poor skid resistance on approach and/or circulatory 	High friction coloured surfacing,	S3
	<ul style="list-style-type: none"> Poor drainage 	Improve drainage (maintenance)	N/A
	<ul style="list-style-type: none"> Unforgiving roadside on exits 	Clear or safe zones	C1
Intersection form	Potential site issues	Countermeasure	Reference (Appendix 6)
Rural crossroads	Crossing (HA/JA/JC)		
	<ul style="list-style-type: none"> Poor visibility from intersection along major road, often results in re-start crashes 	Sight distance improvement	IS3
	<ul style="list-style-type: none"> View 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 	Intelligent electronic warning signs, enhanced signing, minor road central islands, Transform to staggered T, or roundabout	S1, S4, IS1, T1, T2
	<ul style="list-style-type: none"> Imbalance in left and right visibility along major road – leading to driver concentrating on restricted direction, often resulting in collision from other direction 	Sight distance improvement	IS3
	<ul style="list-style-type: none"> Poor visibility of intersection due to alignment 	Intelligent electronic warning signs, enhanced signing,	S1, S4
	<ul style="list-style-type: none"> Excessive approach speed on major or minor road 	Intelligent electronic warning signs, rumble strips, high friction coloured surfacing, transverse road markings, enhanced signing, speed and red light cameras	S1, S2, S3, S4, E1

Intersection form	Potential site issues	Countermeasure	Reference (Appendix 6)
Rural T/Y Intersections	Vehicle lost control (CA/CB/CC/DA/DB/DC)		
	<ul style="list-style-type: none"> Poor skid resistance 	High friction coloured surfacing	S3
	<ul style="list-style-type: none"> Lack of advance notice of intersection – poor forward visibility and advance signing 	Sight distance improvement, enhanced signing	IS3, S4
	<ul style="list-style-type: none"> Poor turning guidance, no minor road central island, lack of road markings 	Minor road central island	IS1
	<ul style="list-style-type: none"> Excessive approach speed on minor or major approaches 	Intelligent electronic warning signs, rumble strips, transverse roadmarkings, enhanced signing	S1, S2, S2, S4
	<ul style="list-style-type: none"> Poorly designed right turn bay facility 	Geometry improvements	IS2
	<ul style="list-style-type: none"> Poor drainage 	Improve drainage (maintenance)	N/A
	Crossing (HA/JA/JC)		
	<ul style="list-style-type: none"> Poor visibility from/to intersection. Obscured by geometric issues, left turn in deceleration lanes, fence line, street furniture, other traffic where two entry lanes (left & right) provided. 	Geometry improvements, sight distance improvement	IS2, IS3
	<ul style="list-style-type: none"> Poor turning guidance, no minor road channelisation, lack of roadmarkings 	Minor road channelisation	IS1
	<ul style="list-style-type: none"> Excessive approach speed on major or minor road 	Intelligent electronic (IE) warning signs, rumble strips, transverse road markings, enhanced signing, speed and red light cameras	S1, S2, S3, S4, E1
	<ul style="list-style-type: none"> Imbalance in left and right visibility along major road – leading to driver concentrating on restricted direction 	Sight distance improvement	IS3
	Intersection form	Potential site issues	Countermeasure
Rural uncontrolled intersection	Vehicle lost control (CA/CB/CC/DA/DB/DC)		
	<ul style="list-style-type: none"> Poor skid resistance 	High friction coloured surfacing	S3
	<ul style="list-style-type: none"> Poor turning guidance, no minor road channelisation, lack of road markings 	Minor road channelisation	IS1
	<ul style="list-style-type: none"> Excessive approach speed 	Intelligent electronic warning signs, rumble strips, transverse road markings, enhanced signing,	S1, S2, S2, S4
	<ul style="list-style-type: none"> Poor skid resistance 	High friction coloured surfacing	S3
	<ul style="list-style-type: none"> Imbalance in left and right visibility along major road – leading to driver concentrating on restricted direction 	Sight distance improvement	IS3
	<ul style="list-style-type: none"> Lack of advance visibility of intersection 	Intelligent electronic warning signs, enhanced signing, sight distance improvement	S1, S4, IS3
	<ul style="list-style-type: none"> Poor drainage 	Improve drainage (maintenance)	N/A
	<ul style="list-style-type: none"> Unyielding road side hazards, eg poles 	Clear or safe zones	C1

Table 6–2: Urban intersection issues and countermeasures

Intersection form	Potential site issues	Countermeasure reference	Reference (Appendix 6)	
Urban signals	Crossing (HA/JA/JC)			
	<ul style="list-style-type: none"> Poor or obscured signal head location 	13	Improve signal conspicuity	IS8
	<ul style="list-style-type: none"> Restricted inter-visibility from side road to main road traffic 	14	Sight distance improvement	IS3
	<ul style="list-style-type: none"> Short cycles times leading to frustration, short inter-green times and excessive approach speed all leading to red light running 	15	Speed discrimination equipment, speed and red light camera	IS6, E1
	Right turn against (LA/LB)			
	<ul style="list-style-type: none"> Poor or obscured signal head location 	16	Improve signal conspicuity	IS8
	<ul style="list-style-type: none"> Filtered turn with no separate right turn phase resulting in conflict 	17	Provide separate right turn phase	IS7
	<ul style="list-style-type: none"> Restricted or obscured forward visibility due to street furniture, signs, trees 	18	Sight distance improvement	IS3
	<ul style="list-style-type: none"> Opposing or left offset right turn bays resulting in turning vehicles restricting visibility of through traffic 	19	Align opposing right turns	IS9
	<ul style="list-style-type: none"> Excessive opposing through approach speed or differential through speeds where multiple opposing through lanes 	20	Speed discrimination equipment , provide separate right turn phase, align opposing right turns, speed and red light camera	IS6, IS7, IS9, E1
	<ul style="list-style-type: none"> Short cycles times leading to frustration, short inter-green times and excessive approach speed all leading to red light running 	21	Provide separate right turn phase	IS7
<ul style="list-style-type: none"> Where separate right turning phase is provided alongside filtering phasing may not be optimal 	22	Provide separate right turn phase	IS7	

Intersection form	Potential site issues	Countermeasure reference	Reference (Appendix 6)
Urban roundabout	Vehicle lost control (CA/CB/CC/DA/DB/DC)		
	<ul style="list-style-type: none"> Excessive visibility on roundabout approach leading to early decision making and higher entry speeds 	23 Geometry improvements	IS13
	<ul style="list-style-type: none"> Poor entry deflection leading to higher entry speeds, particularly when exit radius is tighter 	24 Reverse curves on approach to roundabout	IS12
	<ul style="list-style-type: none"> Poor advance signing and poor delineation/lighting of approaches/ circulatory 	25 Central lighting	IS14
	<ul style="list-style-type: none"> Poor skid resistance on approach and/or circulatory 	26 High friction coloured surfacing	S3
	<ul style="list-style-type: none"> Adverse camber or abrupt camber changes Poor drainage 	27 Adverse camber rectification	IS17
	<ul style="list-style-type: none"> Unyielding road side hazards, e.g. poles 	28 Clear or safe zone	C1
	Crossing (HA/JA/JC) – Entering vs circulating movements		
	<ul style="list-style-type: none"> Poor visibility around circulatory and to other arms often restricted by signage or planting 	Geometry improvements	IS13
	<ul style="list-style-type: none"> Imbalance in visibility to right at entry leading to differential entry speeds 	Geometry improvements	IS13
	<ul style="list-style-type: none"> Poor skid resistance on approach 	High friction coloured surfacing	S3
	Cyclist (All cycle movement types)		
	<ul style="list-style-type: none"> Differential speeds with motor vehicle traffic on larger roundabouts, particular issues when cyclist are passing exits 	Cyclist facilities	IS16
	<ul style="list-style-type: none"> Lack of continuous cycle routes through roundabouts – often stopping short on intersection 	Cyclist facilities	IS16
	<ul style="list-style-type: none"> Inadequate lane widths on approach to and through roundabout- particular issue where high truck usage 	Cyclist facilities	IS16

Intersection form	Potential site issues	Countermeasure reference	Reference (Appendix 6)
Urban crossroads	Crossing (HA/JA/JC)		
	<ul style="list-style-type: none"> Poor visibility from/to intersection. Obscured by fence line, street furniture, other traffic particularly where two entry lanes (left & right) provided. 	Enhanced signing	IS3
	<ul style="list-style-type: none"> Opposing side road arm gives impression of a straight through road particularly where fence lines or buildings restrict advance visibility of intersection. 	Minor road channelisation	IS1
	<ul style="list-style-type: none"> Poor turning guidance, no minor road channelisation, lack of road markings 	Minor road channelisation	IS1
	<ul style="list-style-type: none"> Excessive approach speed on major or minor road Difficulty in gap selection with high speeds and high through traffic volumes 	Intelligent electronic warning signs, transverse road markings, enhanced signing, speed and red light camera	S1, S2, S4, E1

Intersection form	Potential site issues	Countermeasure reference	Reference (Appendix 6)
Urban T/Y Intersections	Vehicle lost control (CA/CB/CC/DA/DB/DC)		
	<ul style="list-style-type: none"> Poor skid resistance 	High friction coloured surfacing	S3
	<ul style="list-style-type: none"> Lack of advance visibility of intersection 	Enhanced signing, sight distance improvement	S4, IS3
	<ul style="list-style-type: none"> Poor turning guidance, no minor road channelisation, lack of road markings 	Minor road channelisation	IS1
	<ul style="list-style-type: none"> Excessive approach speed on major or minor road Poor drainage 	Intelligent electronic warning signs, transverse road markings, enhanced signing,	S1, S2, S4
	<ul style="list-style-type: none"> Unyielding road side hazards, e.g. poles 	Clear or safe zone	C1
	Crossing (HA/JA/JC)		
	<ul style="list-style-type: none"> Poor visibility from/to intersection. Obscured by fence line, street furniture, and other traffic where two entry lanes (left & right) provided. 	Sight distance improvement, minor channelisation, move left turn deceleration lane,	IS3,IS2, IS1
	<ul style="list-style-type: none"> Poor turning guidance, no minor road channelisation, lack of road markings 	Minor road channelisation	IS1
	<ul style="list-style-type: none"> Excessive approach speed on major or minor road 	Intelligent electronic warning signs, transverse road markings, enhanced signing, speed and red light camera	S1, S2, S4, E1
	Right turn against (LA/LB)		
	<ul style="list-style-type: none"> Poor visibility of opposing traffic 	Minor road channelisation, turning bays	IS1, IS2
	<ul style="list-style-type: none"> Poor turning guidance, lack of road markings 	Minor road channelisation	IS1
	<ul style="list-style-type: none"> Excessive approach speed 	Intelligent electronic warning signs, transverse road markings, enhanced signing, speed and red light camera	S1, S2, S4, E1
	<ul style="list-style-type: none"> Difficulty in achieving gaps to turn leading to risk taking or acceptance of smaller gaps 	Sight distance improvement	IS3
	<ul style="list-style-type: none"> Unexpected delay entering the side road caused by activity in immediate vicinity of intersection from accesses, driveways, parking or bus stops 	Consider rationalisation of parking and accesses etc. if creating safety concerns	N/A

Intersection form	Potential site issues	Countermeasure reference	Reference (Appendix 6)
Urban uncontrolled	Vehicle lost control (CA/CB/CC/DA/DB/DC)		
	<ul style="list-style-type: none"> Poor skid resistance 	High friction coloured surfacing	S3
	<ul style="list-style-type: none"> Lack of advance visibility of intersection 	Enhanced signing, geometry improvements	S4, IS13
	<ul style="list-style-type: none"> Poor turning guidance, no minor road channelisation, lack of road markings 	Minor road channelisation	IS1
	<ul style="list-style-type: none"> Excessive approach speed on major/minor road 	Intelligent electronic warning signs, transverse road markings, enhanced signing,	S1, S2, S4
	<ul style="list-style-type: none"> Poor drainage 	Improve drainage (maintenance)	N/A
	<ul style="list-style-type: none"> Unyielding road side hazards, e.g. poles 	Clear or safe zone	C1
	Pedestrian (all pedestrian movements)		
	<ul style="list-style-type: none"> Lack of crossing facilities, dropped kerb, tactile paving, refuge 	Pedestrian facilities	IS2
	<ul style="list-style-type: none"> Poor inter-visibility at crossing points. Obstructed by fence lines, street furniture/signs 	Pedestrian facilities	IS2
	<ul style="list-style-type: none"> Excessive crossing width 	Pedestrian facilities	IS2
	<ul style="list-style-type: none"> Large entry radii allowing higher entry speeds 	Pedestrian facilities	IS2

7 Implementation, monitoring and evaluation

7.1 Introduction

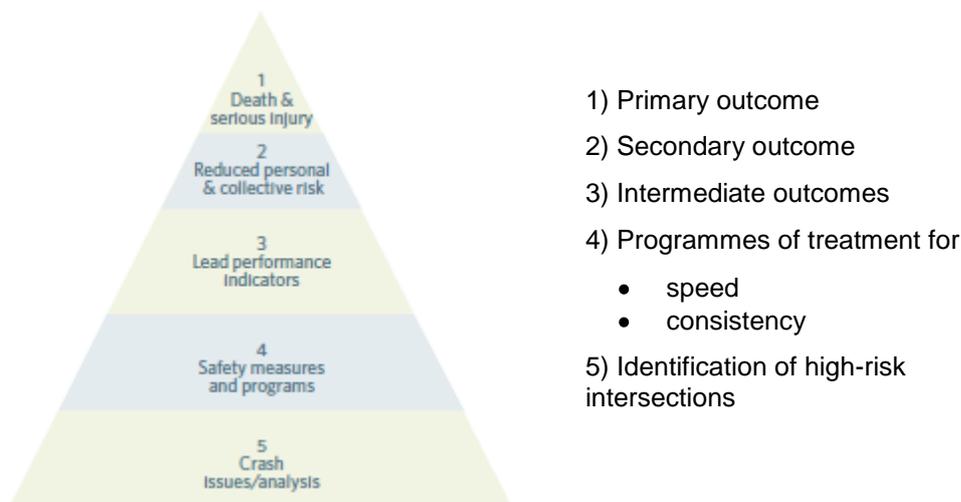
This section covers the implementation, monitoring and evaluation of countermeasures at high-risk intersections with the emphasis on reducing fatal and serious injury crashes. These process areas are significant for both the individual crash site and the assessment of the effectiveness of counter measures 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:

- identify the benefits or rather the effectiveness of the various treatments
- identify the most effective packages of treatments
- assess the levels of funding that may be required to achieve various levels of crash reduction
- 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



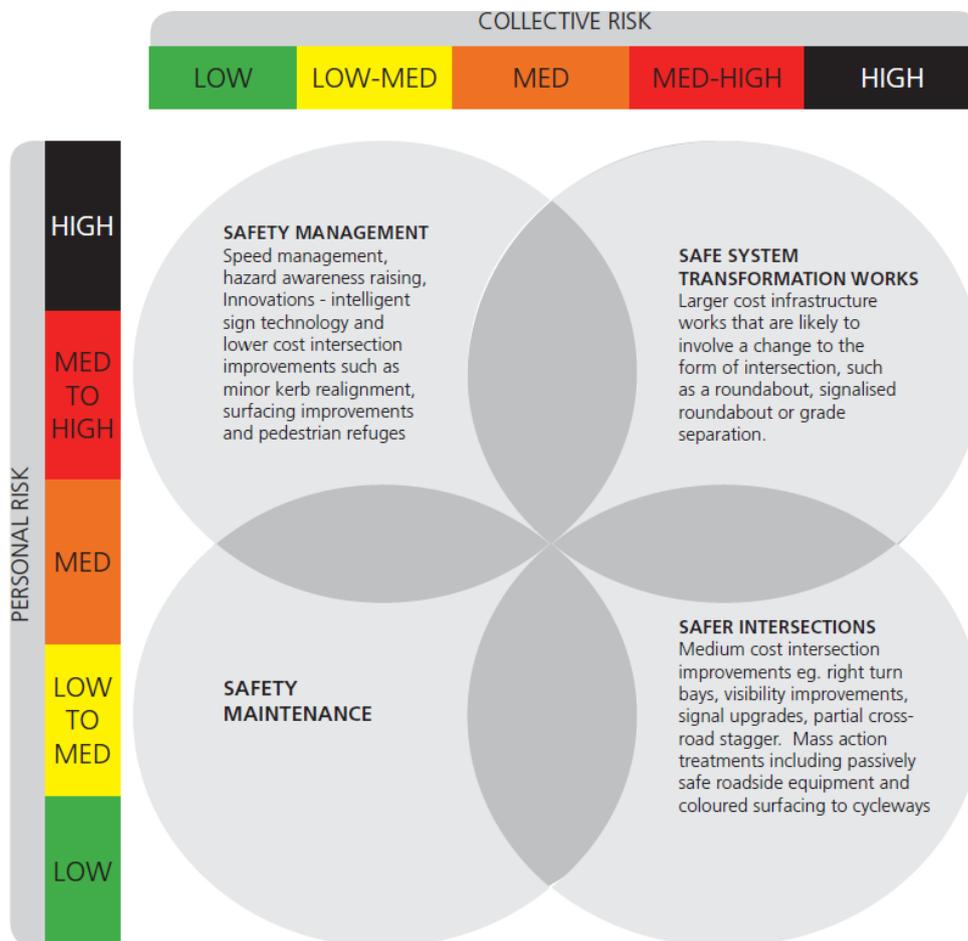
Having identified our sites/routes and clarified our safety concerns, this guide discusses some possible treatments or strategies to improve the safety of our high-risk intersections, with particular emphasis on the primary outcome of reducing fatal and serious injury.

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

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 may 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 on-going safety improvements at these locations, just that these improvements should be proportional to the problem. The level of safety service indicator is particularly useful for identifying sites that, although lower risk, are performing worse than would be expected (section 4.3.2). 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 roadmarkings.

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. It may be that the treatment is no longer appropriate or that another treatment would be better.

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. The BCR will need updating along with the estimated DSIs expected to be saved.

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 maintain a focus on 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 balancing risks. 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 road 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 planning and developing projects in order to create a common sense of purpose, draw on and learn from others' 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 a 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 (ie those that include road users and stakeholders) and internal stages (ie those that include employees of the road agency only)
 - is iterative in nature (ie part of an on-going 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 between stages that involve the community with stages that require 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 to 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 *Road safety audit procedures for projects 2013* provides further guidance, having been updated to 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. See the draft procedures on the NZTA website.

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 7.4.1 and 7.4.2).

- An evaluation analyses the results of monitoring and determines the results and effectiveness of the types of treatments used (section 0).

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 whether it is likely to achieve its aims. A stage 4 safety audit should not be considered 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 (essentially an observation of traffic behaviour), and obtaining 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 term 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. In addition, monitoring of road user behaviour could be undertaken to further define any issues.

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** (figure 7-4 and figure 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 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

Site of Interest Entry

Page 1

Study Name [dropdown]
Type Sites of Interest ID [text box]
Owner [text box]
User [text box] Status Public [dropdown]
Road Type [checkbox] 1=Local 2=SH Transit NZ Region No. [checkbox]
Site Implemented Date [text box] YYYYMMDD

Local Authorities [dropdown] [dropdown] [dropdown]

Urban/Rural [checkbox] U/R

Data Checks Save Cancel/Exit Help

Entering New Site

Figure 7-4: Monitoring site data entry screen 1

Monitoring Site Entry

Page 1 | PDR

Study name: [dropdown]
 Study Period (years): Injury Data [] - [] Non-Injury Data [] - []
 Location name: [dropdown]
 Location no.: [] Report Date: [] (YYYYMM)
 Road type: Local road State highway TNZ region: [dropdown]
 Local Authorities: [dropdown]
 Location type: Intersection Non-intersection Route Area
 Site specific location type: [dropdown] Other: []
 Speed limit: []
 Road classification: [dropdown]
 Roadside development: Rural Residential Industrial Commercial Recreational School Other
 Environmental changes/unusual conditions: []
 Buttons: Data Checks Save Cancel/Exit Help
 Status bar: Entering New Site

Figure 7-5: Monitoring site data entry screen 2

Monitoring Site Entry

Page 1 | PDR

PROBLEM CODING			RECOMMENDATIONS				LINKING		IMPLEMENTATION	
Prob No	Crash Type	Details Optional	Action No	ACTION Code	OBJECT Code	Traffic Sign Code	Effect	Links to Problem(s)	Status	Date YYYYMM
1	[]	[]	1	[]	[]	[]	1 Major	[]	[]	[]
2	[]	[]	2	[]	[]	[]	2 Minor	[]	[]	[]
3	[]	[]	3	[]	[]	[]	3 None	[]	[]	[]
4	[]	[]	4	[]	[]	[]		[]	[]	[]
5	[]	[]	5	[]	[]	[]		[]	[]	[]
			6	[]	[]	[]		[]	[]	[]
			7	[]	[]	[]		[]	[]	[]
			8	[]	[]	[]		[]	[]	[]
			9	[]	[]	[]		[]	[]	[]
			10	[]	[]	[]		[]	[]	[]
			11	[]	[]	[]		[]	[]	[]
			12	[]	[]	[]		[]	[]	[]
			13	[]	[]	[]		[]	[]	[]
			14	[]	[]	[]		[]	[]	[]
			15	[]	[]	[]		[]	[]	[]

COSTINGS
 Estimated \$ []
 Actual \$ []

CRASH DATA
 Injury: [] Non-Injury: []
 Total Crashes: []
 Crashes Addressed: []
 Crash Savings: []
 Description of addressed crashes: []
 Stop Monitoring Date: [] (YYYYMM) Date Entered: [] Date Last Edited: []
 Buttons: Delete Problem Data Checks Save Cancel/Exit Help
 Status bar: Entering New Site

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 *Guide to road safety part 2*, details basic categories of evaluation of traffic safety 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.

Changes in the minor injury record can also be an indicator, although this 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 includes:

- 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 DSIs 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 aims for sites to fall out of the high-risk category. Therefore determination of 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.

8 References

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10	Austrroads Guide to Road Design Part 6: Roundabouts.	www.Austrroads.co.au
11	NZTA: (Transfund/Traffic Design Group) 'The ins and outs of roundabouts'	www.nzta.govt.nz/resources/ins-and-outs-of-roundabouts/index.html
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22	Austrroads Guide to road design Part 6A: Pedestrian and cyclist path.	www.Austrroads.co.au
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36	Austrroads Roads Safety Engineering Toolkit	www.engtoolkit.com.au/default.asp?p=issue&i=20
37	Austrroads Roads Safety Engineering Toolkit	www.engtoolkit.com.au/default.asp?p=treatment&i=23
38	Austrroads Roads Safety Engineering Toolkit	www.engtoolkit.com.au/default.asp?p=treatment&i=51
39	Austrroads Roads Safety Engineering Toolkit	www.engtoolkit.com.au/default.asp?p=treatment&i=16
40	Austrroads Roads Safety Engineering Toolkit	www.engtoolkit.com.au/default.asp?p=treatment&i=43
41	Austrroads Roads Safety Engineering Toolkit	www.engtoolkit.com.au/default.asp?p=treatment&i=59
42	Austrroads Roads Safety Engineering Toolkit	www.engtoolkit.com.au/default.asp?p=treatment&i=51
43	Austrroads Roads Safety Engineering Toolkit	www.engtoolkit.com.au/default.asp?p=treatment&i=23
44	Austrroads Roads Safety Engineering Toolkit	www.engtoolkit.com.au/default.asp?p=treatment&i=72
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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

(a) Reported 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 four-year period 2006–10. The analysis should not be considered to be 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 that 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

Signalised intersections

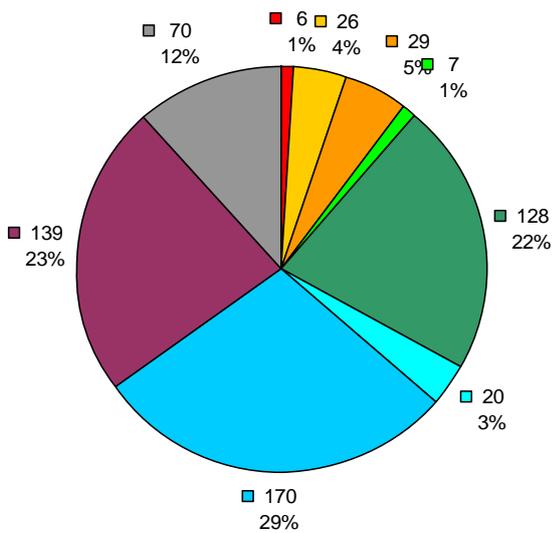
Urban

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

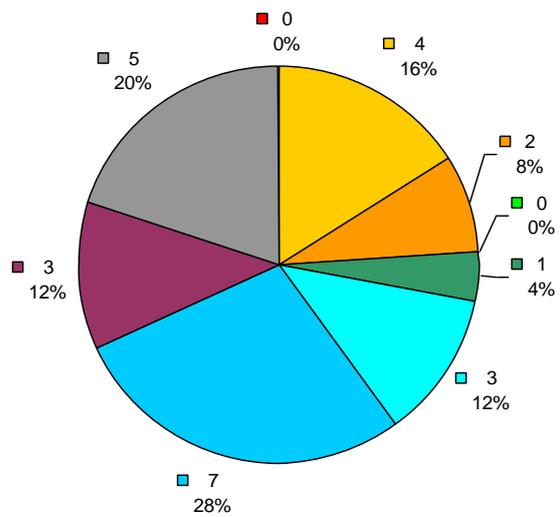
Rural

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.

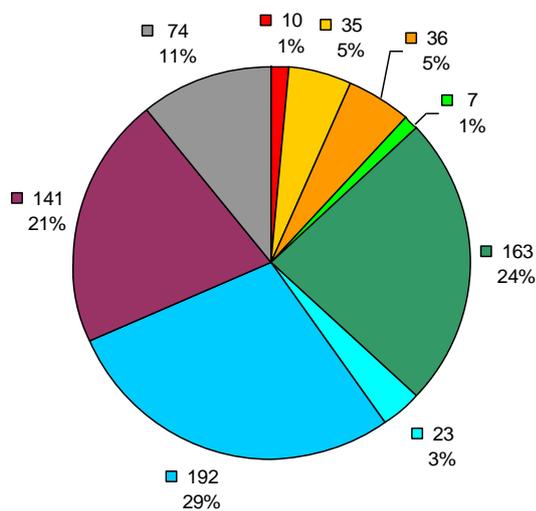
Urban F&S crashes



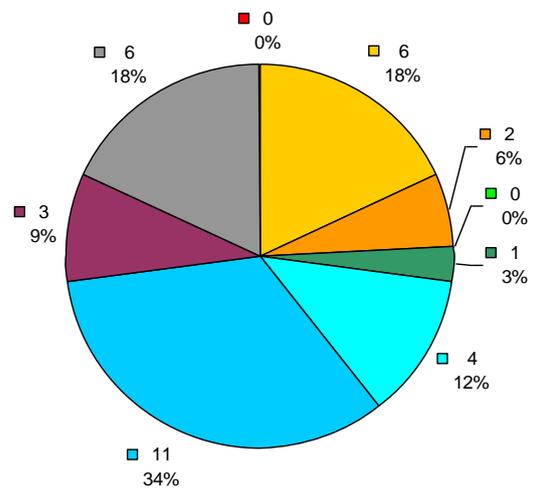
Rural F&S crashes



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

At roundabouts the crash types for right turn against, crossing (no turns), and crossing (turning) are similar so should be considered together as entering vs circulating crashes.

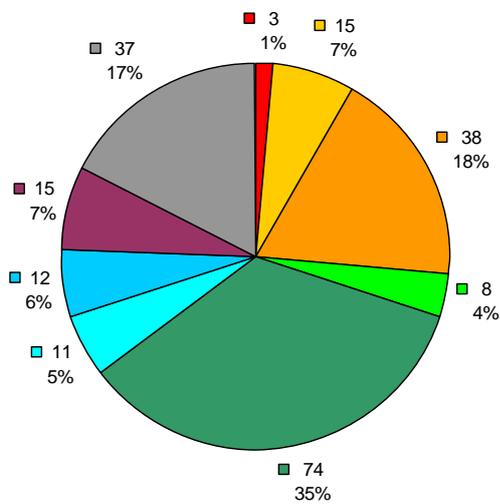
Urban

The main F&S crash and casualty crash movement types at urban roundabouts are entering versus circulating, and loss of control while negotiating the roundabout.

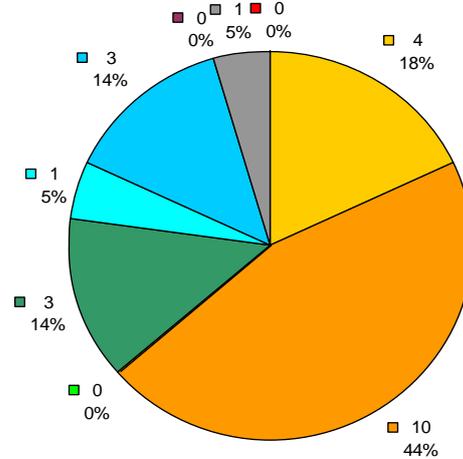
Rural

The main F&S crash and casualty crash movement type at rural roundabouts is single vehicle loses control, negotiating the roundabout, typically colliding with a roadside object on the roundabout exit. However conclusions drawn from the rural data should be treated with caution because of the small sample size.

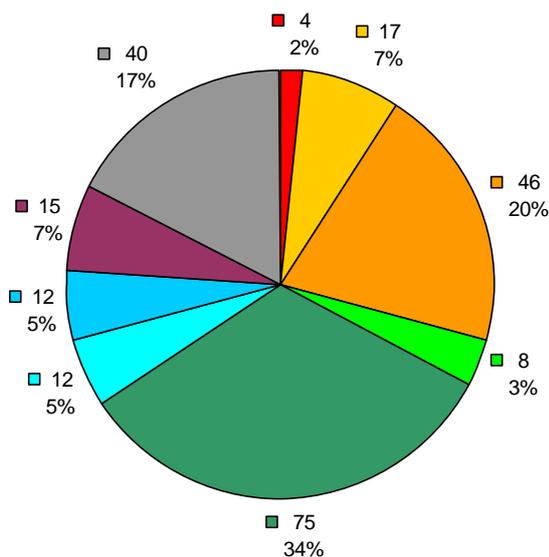
Urban F&S crashes



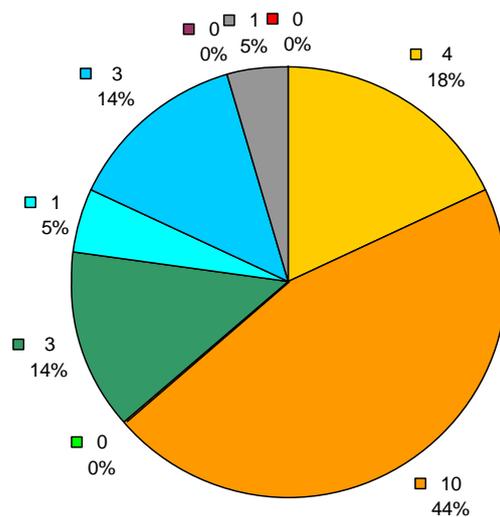
Rural F&S crashes



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

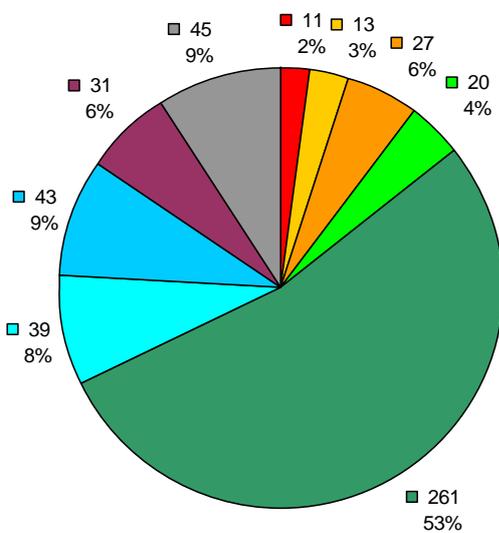
The main F&S crash and casualty crash movement type at urban priority controlled crossroads is overwhelmingly crossing (no turning).

Rural

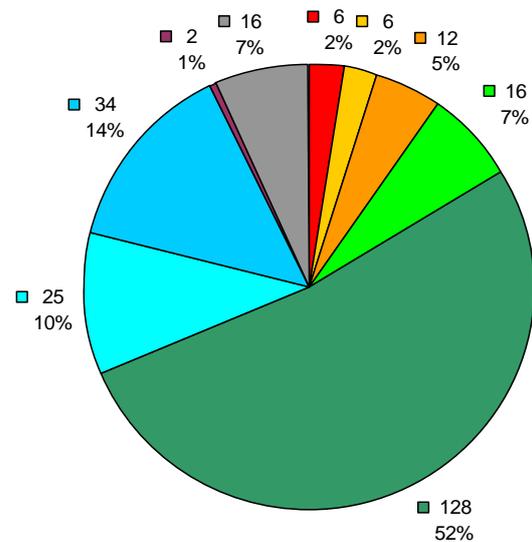
As with urban crashes, the main F&S crash and casualty crash movement type at rural priority controlled crossroads is overwhelmingly crossing (no turning).

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

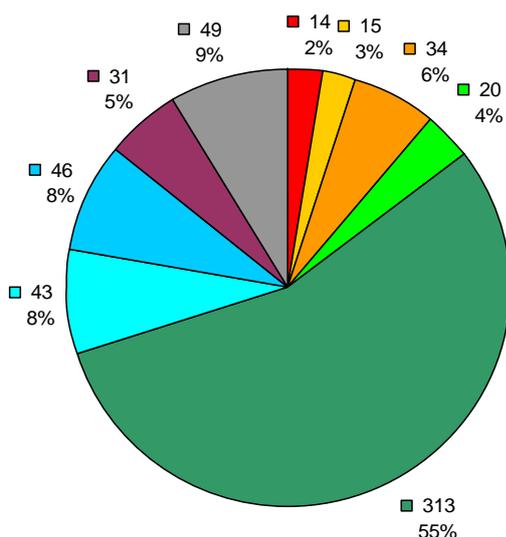
Urban F&S crashes



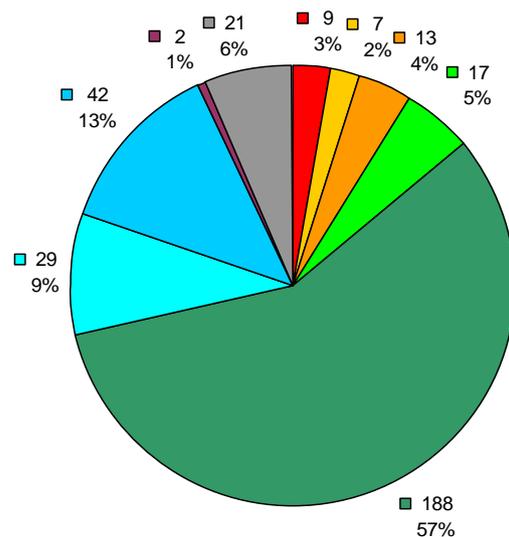
Rural F&S crashes



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

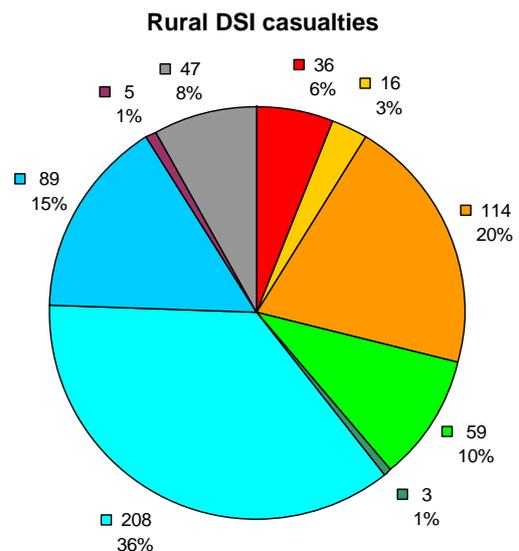
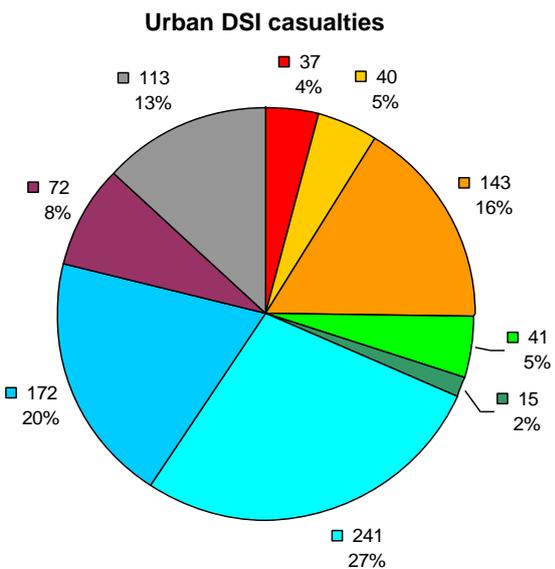
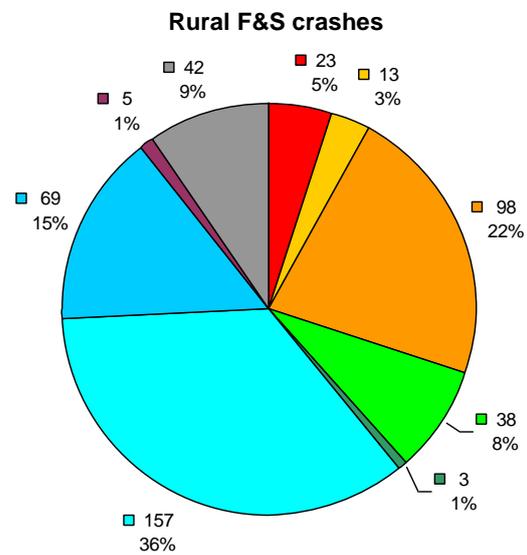
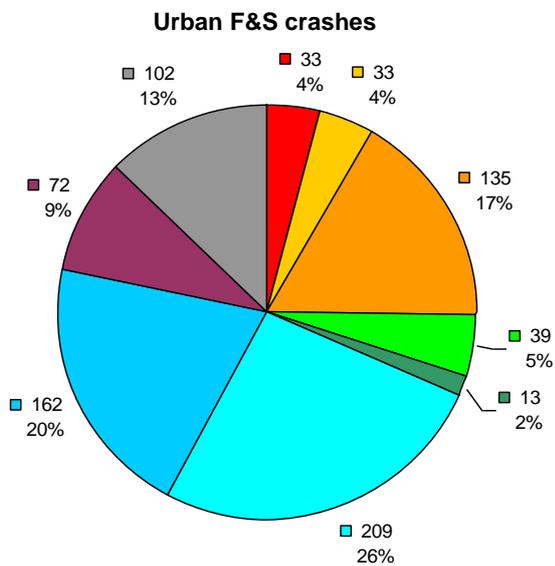
Urban

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 an F&S crash due to the impact being in the driver's side door.



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

Uncontrolled intersections consist of low volume T junctions.

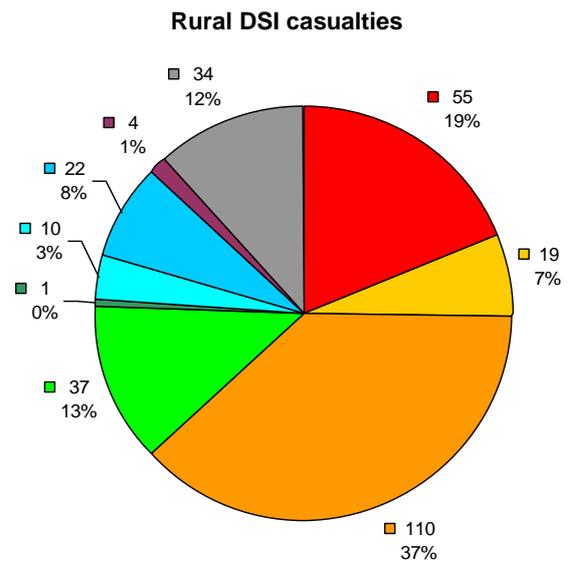
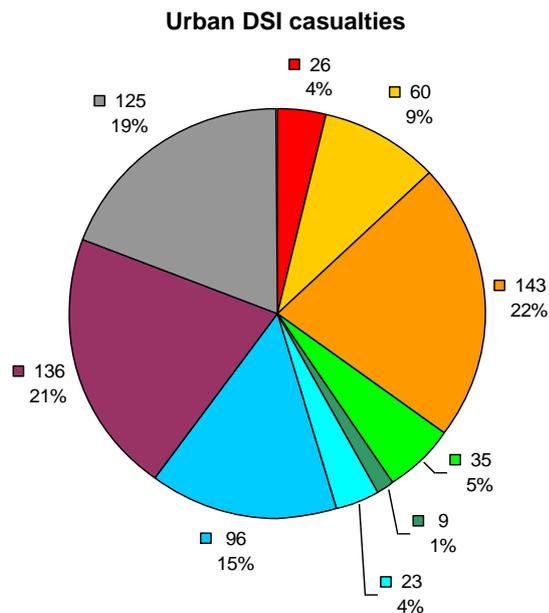
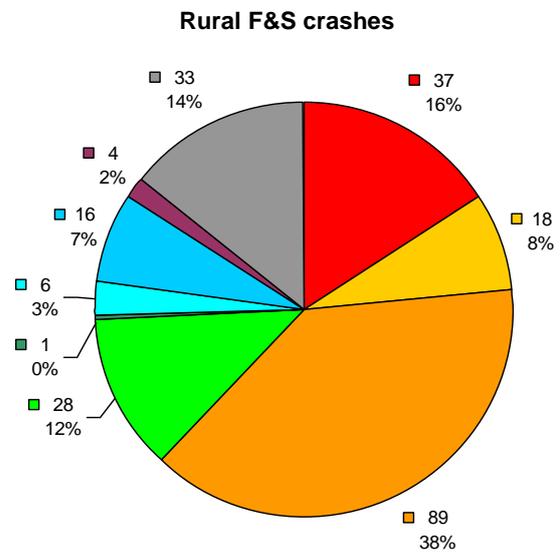
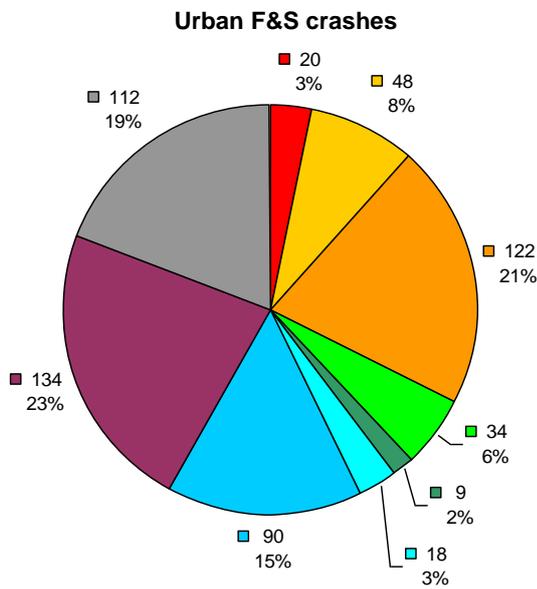
Urban

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

(b) Using CAS to identify intersections within a network

Process

- Using the front query screen of CAS, select:
 - area of study, ie Hauraki District Council
 - year of study, ie 10 years = 2003-2012
 - severity of crashes = fatal and injury crashes.
- Using the location tab, select:
 - either state highway or local roads only if required (do not click on 'intersection' as the grouping radius for this only extends to 30m default value. You will need to select specific intersections and group crashes – see instructions below)
- Using the environment tab select:
 - either urban or rural (or leave blank if you want both)
 - Junction type = roundabout, X-type, Y-type, T-type and multi road join (note you can select driveways here as well if you want to include them).
- Query and create list with the above information.
- Using created list, select 'group' then group all and the same radius and use 50m.
- Using the grouped list (ends with _gp), select Query and then 'remove small and/or large sites'.
- Select 'make size limited list' and then enter the minimum number you would want to remove, ie if you only want sites of 4 or more crashes at each site then type in sites with '> 3 crashes'. Create name for new list.
- To view the sites – can either use the map function or under 'reports' use coded or English lists. Click on 'group site' tab and use the new list name you created above.

After these intersections have been identified and you wish to analyse them further you will need to separately select all the crashes within 50 metres of each intersection and make a crash list for each intersection. This should pick up any crashes missed by the above method. . and can then process specific sites to determine whether they are high risk or not.

Appendix 3: Severity index tables

Development of severity index tables

The main use of these tables is for estimating the expected number of Deaths and Serious injury equivalents based on all injury crashes at a site. This is the method recommended to estimate collective risk in section 4.1 and 4.2.

The severity outcome of any crash is known to vary substantially depending on the type of movement, 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 DSIs 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 DSI equivalents at the site as detailed in section 4.1 with worked examples in section 0, the SI should be based on the *adjusted DSIs column. This column was adjusted where the sample size for that movement type was too small to give a reliable estimate of the SI. Adjusted DSIs have been estimated based on the movements at similar intersection forms and control types. This method allows us to estimate the underlying DSI 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. Motorcycle and cyclist severities are more severe and a separate severity index is most often appropriate. For cyclist crashes the data shows that urban cyclist crashes are consistently more severe than for most other road users. An analysis of the severity index of injury crashes involving cyclists suggests a SI value of 0.21 is appropriate in urban areas. There are not sufficient cyclist casualties to reliably provide a separate SI for different movements and intersection types. However surprisingly the data shows that at rural intersections, cyclist severity index is similar to other road users.

Likewise motorcycle crashes are well known to be the most severe of all. An analysis of the severity index of injury crashes involving motorcyclists suggests a severity index of 0.3 for urban crashes and 0.5 for rural crashes.

Use of SI tables

As an example, consider an urban priority crossroads intersection in an urban environment. The site has eight reported injury crashes in the past five years. The movement types comprise 3 x Type F (rear end), 2 x Type H (crossing – no turning) and 2 x Type N (pedestrian crossing road) injury crashes and one cyclist crash. We can use this individual crash movement type information and 'Adjusted DSI casualties / all injury crashes' in the SI table A3-3 for an urban priority crossroads intersection to estimate the DSI risk.

Appendix Table A3- 1: Example of SI tables

Crash movement type	Number of recorded injury crashes (5 years)	Adjusted severity index	Estimated DSI equivalents
F	3	0.08	$(3 * 0.08) = 0.24$
H	2	0.17	$(2*0.17) = 0.34$
N	2	0.21	$(2*0.22)= 0.44$
Cyclist	1	0.21	$(1* 0.21) = 0.21$
			Total = 1.15

Urban severity index tables

Notes:

- 1) For cyclists at urban intersections use severity ratio of 0.21 for all types.
- 2) For motorcyclist crashes at urban intersections use 0.3 for all types
- 3) Use the 'Adjusted DSI casualties / all injury crashes' column for the calculations (highlighted)

Table A3-2: Urban signalised crossroad: 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	Adjusted DSI casualties / All Injury crashes
A	56	5	5	0.09	0.11
B	30	2	2	0.07	0.12
C	89	12	15	0.17	0.18
D	106	13	17	0.16	0.17
E	23	3	3	0.13	0.13
F	386	21	24	0.06	0.06
G	78	7	7	0.09	0.10
H	727	113	140	0.19	0.19
J	90	8	9	0.10	0.10
K	48	10	10	0.21	0.15
L	851	113	125	0.15	0.15
M	31	6	6	0.19	0.19
N	423	94	97	0.23	0.23
P	3	0	0	0.00	0.31
Q	5	2	2	0.40	0.25
Total (for crash prediction use only)	2946	409	462	0.16	

Table A3-3: Urban priority controlled crossroad: 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	Adjusted DSI casualties / All Injury crashes
A	17	5	6	0.35	0.25
B	42	9	11	0.26	0.25
C	77	13	15	0.19	0.19
D	139	22	29	0.21	0.21
E	13	3	3	0.23	0.11
F	106	8	9	0.08	0.08
G	106	21	21	0.20	0.20
H	1697	239	283	0.17	0.17
J	239	34	38	0.16	0.16
K	129	15	16	0.12	0.13
L	278	46	49	0.18	0.18
M	31	6	7	0.23	0.19
N	158	33	35	0.22	0.22
P	12	4	4	0.33	0.31
Q	6	1	1	0.17	0.25
Total (for crash prediction use only)	3050	459	527	0.17	

Table A3-4: Urban signalised T-intersection: 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	Adjusted DSI casualties / All Injury crashes
A	28	3	3	0.11	0.11
B	24	2	4	0.17	0.12
C	41	8	16	0.39	0.18
D	79	12	14	0.18	0.17
E	9	0	0	0.00	0.11
F	224	8	8	0.04	0.06
G	31	1	1	0.03	0.07
H	19	1	1	0.05	0.10
J	140	13	14	0.10	0.10
K	25	2	2	0.08	0.10
L	266	40	48	0.18	0.18
M	12	2	2	0.17	0.19
N	144	33	34	0.24	0.24
P	6	2	2	0.33	0.31
Q	2	1	1	0.50	0.25
Total (for crash prediction use only)	1050	128	150	0.14	

Table A3-5: 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	Adjusted DSI casualties / All Injury crashes
A	55	11	15	0.27	0.25
B	158	27	30	0.19	0.21
C	179	38	46	0.26	0.25
D	638	132	149	0.23	0.24
E	51	4	4	0.08	0.1
F	344	17	21	0.06	0.07
G	340	34	35	0.10	0.11
H	79	14	16	0.20	0.18
J	1431	186	213	0.15	0.15
K	336	39	40	0.12	0.13
L	885	153	162	0.18	0.18
M	109	12	12	0.11	0.14
N	317	72	72	0.23	0.24
P	18	5	6	0.33	0.31
Q	9	2	2	0.22	0.25
Total (for crash prediction use only)	4949	746	823	0.17	

Table A3-6: 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	Adjusted DSI casualties / All Injury crashes
A	40	5	5	0.13	0.1
B	20	4	6	0.30	0.16
C	56	13	16	0.29	0.27
D	225	37	46	0.20	0.2
E	9	1	1	0.11	0.11
F	172	6	6	0.03	0.05
G	73	11	11	0.15	0.13
H	538	75	76	0.14	0.15
J	72	10	11	0.15	0.15
K	158	14	16	0.10	0.1
L	106	15	15	0.14	0.15
M	12	1	1	0.08	0.09
N	63	14	14	0.22	0.23
P	11	1	1	0.09	0.22
Q	6	3	3	0.50	0.25
Total (for crash prediction use only)	1561	210	228	0.15	

Rural severity index tables

Notes:

- 1) there are no corrections for cyclists at rural intersections
- 2) For motorcyclist crashes at rural intersections use 0.5 for all crashes
- 3) Use the adjusted DSI casualties / all injury crashes for the calculations

Table A3-7: Rural signalised crossroads: death and serious casualty analysis

Primary	Number of	Number of	Number of	Adjusted	
Crash	Injury	F + S	DSI	DSI Casualties	
Type	Crashes	Crashes	Casualties	All Injury Crashes	
				DSI casualties / All Injury crashes	
A	1		0	0.00	0.22
B	1		0	0.00	0.40
C	2	2	4	2.00	0.30
D	4	1	1	0.25	0.30
E	1	1	1	1.00	0.19
F	18	1	1	0.06	0.09
G	1		0	0.00	0.14
H	11		0	0.00	0.27
J	5	1	2	0.40	0.20
K	2	1	2	1.00	0.23
L	28	3	4	0.14	0.18
M	1		0	0.00	0.23
N	2	2	2	1.00	0.60
P	1		0	0.00	0.60
Q			0	0.00	0.50
Total (for crash prediction use only)	78	12	17	0.22	

Table A3-8: Rural priority controlled crossroads: death and serious casualty analysis

Primary	Number of	Number of	Number of	Adjusted	
Crash	Injury	F + S	F + S	DSI Casualties	
Type	Crashes	Crashes	Casualties	All Injury Crashes	
				DSI casualties / All Injury crashes	
A	9	3	4	0.44	0.40
B	13	6	11	0.85	0.70
C	32	10	11	0.34	0.30
D	50	12	13	0.26	0.30
E	3	1	1	0.33	0.33
F	19	3	3	0.16	0.10
G	87	16	17	0.20	0.25
H	367	127	180	0.49	0.50
J	86	25	31	0.36	0.36
K	29	4	6	0.21	0.25
L	116	31	41	0.35	0.35
M	9	3	3	0.33	0.30
N	3	2	2	0.67	0.60
P	2	0	0	0.00	0.60
Q	1	0	0	0.00	0.50
Total (for crash prediction use only)	826	243	323	0.39	

Table A3-9: Rural signalised T-intersection: death and serious casualty analysis

Primary	Number of	Number of	Number of	Adjusted	
Crash	Injury	F + S	F + S	DSI Casualties	
Type	Crashes	Crashes	Casualties	All Injury Crashes	
				DSI casualties / All Injury crashes	
A	1		0	0.00	0.22
B			0	0.00	0.40
C	6	1	1	0.17	0.30
D	9	1	1	0.11	0.26
E			0	0.00	0.15
F	23	1	1	0.04	0.08
G	2		0	0.00	0.11
H	1		0	0.00	0.11
J	7	1	1	0.14	0.13
K	3		0	0.00	0.11
L	20	1	1	0.05	0.11
M			0	0.00	0.27
N	1	1	1	1.00	0.60
P			0	0.00	0.60
Q			0	0.00	0.50
Total (for crash prediction use only)	73	6	6	0.08	

Table A3-10: Rural priority controlled T-intersections: death and serious casualty analysis

Primary	Number of	Number of	Number of	Adjusted	
Crash	Injury	F + S	Dsi	DSI Casualties	
Type	Crashes	Crashes	Casualties	All Injury Crashes	
				DSI casualties / All Injury crashes	
A	16	5	6	0.38	0.38
B	54	20	33	0.61	0.61
C	55	13	20	0.36	0.36
D	335	97	114	0.34	0.34
E	5	1	1	0.20	0.33
F	56	5	5	0.09	0.10
G	162	49	69	0.43	0.41
H	14	3	3	0.21	0.37
J	486	136	182	0.37	0.37
K	64	17	22	0.34	0.32
L	220	65	89	0.40	0.40
M	15	4	4	0.27	0.30
N	6	4	5	0.83	0.60
P	2	1	1	0.50	0.60
Q	4	2	2	0.50	0.50
Total (for crash prediction use only)	1494	422	556	0.37	

Table A3-11: Rural roundabouts: death and serious casualty analysis

Primary	Number of	Number of	Number of	Adjusted	
Crash	Injury	F + S	Dsi	DSI Casualties	
Type	Crashes	Crashes	Casualties	All Injury Crashes	
				DSI casualties / All Injury crashes	
A	5	0	0	0.00	0.10
B				0.00	0.16
C	11	3	3	0.27	0.27
D	47	11	11	0.23	0.25
E	2	0	0	0.00	0.11
F	24	1	1	0.04	0.06
G	8	0	0	0.00	0.13
H	35	3	3	0.09	0.16
J	7	2	2	0.29	0.16
K	7	0	0	0.00	0.11
L	11	5	5	0.45	0.19
M		0	0	0.00	0.11
N			0	0.00	0.30
P	1	0	0	0.00	0.30
Q	2	0	0	0.00	0.25
Total (for crash prediction use only)	160	25	25	0.16	

Appendix 4: Level of safety service predicted crash rates

This section gives a means of predicting post-transformation crash rates for a reasonably good implementation of a particular intersection control.

This is based on New Zealand intersection crash data. Negative binomial regression has been used to fit crash probability distributions to the data for each intersection form and control combination at different flow rates.

Note that the formulas are based on the data in the graphs in appendix 5. Their use should take into account the range of traffic flows used to derive them.

The equation below gives the line where there is a 50% probability of having more crashes, and 50% probability of having fewer crashes. This is a smaller number than the mean because the distribution of intersections is asymmetrical; there are many low crash rate intersections and a long tail of high crash rate intersections. There are different m and c values for each speed environment and control combination.

The basic form of the equation is:

$$\text{crashes} = m * PoF + c$$

where *crashes* is the number of injury crashes in a five year period,

PoF is the Product of Flow for the intersection with major and minor leg daily two-way flows Q_{major1}, Q_{major2} and Q_{minor1}, Q_{minor2} (In the case of a T intersection $Q_{minor2} = 0$)

$$PoF = \left(\text{avg}(Q_{major1}, Q_{major2}) * \text{avg}(Q_{minor1}, Q_{minor2}) \right)^{0.4}$$

m is a coefficient and c is a constant, both from the appropriate table below.

To convert from *injury crashes per 5 years* to deaths and serious injuries (DSI equivalents) multiply by the severity factor given in the right most column below.

$$DSI \text{ equivalents} = \text{injury crashes} * DSI \text{ per inj crash}$$

Table A4-1: Urban (speed < 80km/h)

Intersection form	m	c	Proportion F&S	Avg DSI casualties per injury crash
Signalised X	0.00132	1.826	0.14	0.16
Signalised T	0.00132	0.402	0.13	0.14
Roundabout 3- and 4-leg	0.00073	0.046	0.14	0.15
Roundabout 3-leg	0.00000	0.000	0.14	0.15
Roundabout 4-leg	0.00131	-0.167	0.14	0.15
Priority X	0.00120	-0.147	0.15	0.17
Priority T	0.00141	-0.159	0.15	0.17

Appendix Table A4-2: Rural (speed \geq 80km/h)

Intersection form	m	c	Proportion F&S	Avg DSI casualties per injury crash
Signalised X	0.00184	1.385	0.15	0.22
Signalised T	0.00039	-0.081	0.08	0.08
Roundabout 3- and 4-leg	0.00129	0.435	0.16	0.16
Roundabout 3-leg	0.00000	0.000	0.16	0.16
Roundabout 4-leg	0.00211	0.655	0.16	0.16
Priority X	0.00375	-0.197	0.31	0.39
Priority T	0.00299	0.002	0.27	0.37

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, plus a breakdown of roundabouts into those 3 legs and 4 or more legs. . The LoSS band definitions are shown in table 4-3. To use these charts you need to determine the:

- product of flow as described in 4.2.2 and Appendix 4.
- reported injury crashes for the last 5 years (within 50m radius).

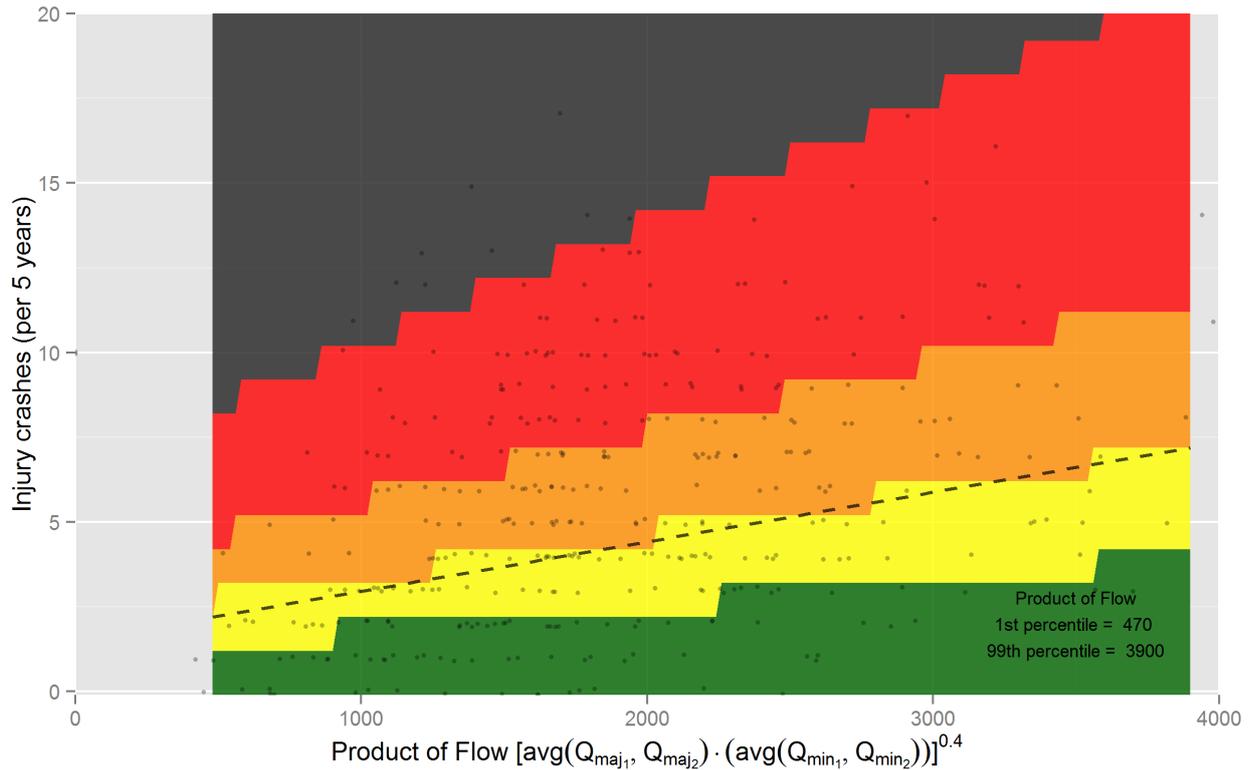
Level of safety service	Safety performance	Definition
LoSS V	90–100 th percentile	The observed injury crash rate is in the worst 10% band – higher (worse) than that expected of 90% of similar intersections.
LoSS IV	70–90 th percentile	The observed injury crash rate is in the worst 30%, lower (better) than that expected of 90% of similar intersections, and higher (worse) than that of 70%.
LoSS III	50–70 th percentile	The observed injury crash rate is lower (better) than that expected of 70% of similar intersections, and higher (worse) than that of 50%.
LoSS II	30–50 th percentile	The observed injury crash rate is lower (better) than that expected of 50% of similar intersections, and higher than that of 30%
LoSS I	0–30 th percentile	The observed injury crash rate is lower (better) than that expected of 30% of similar intersections.

Intersections classified as 'LoSS I' have a safety performance that is in the best category, when compared to the safety expected of 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 being in the worst ten percent group when compared to the performance expected from similar intersections.

On the LoSS charts the boundaries of the zones increase in a series of steps. This is because crashes only happen in whole numbers.

The 50% line shows the expected crash performance of a typical intersection. Use this line for comparison when assessing the potential for improvement with existing control.

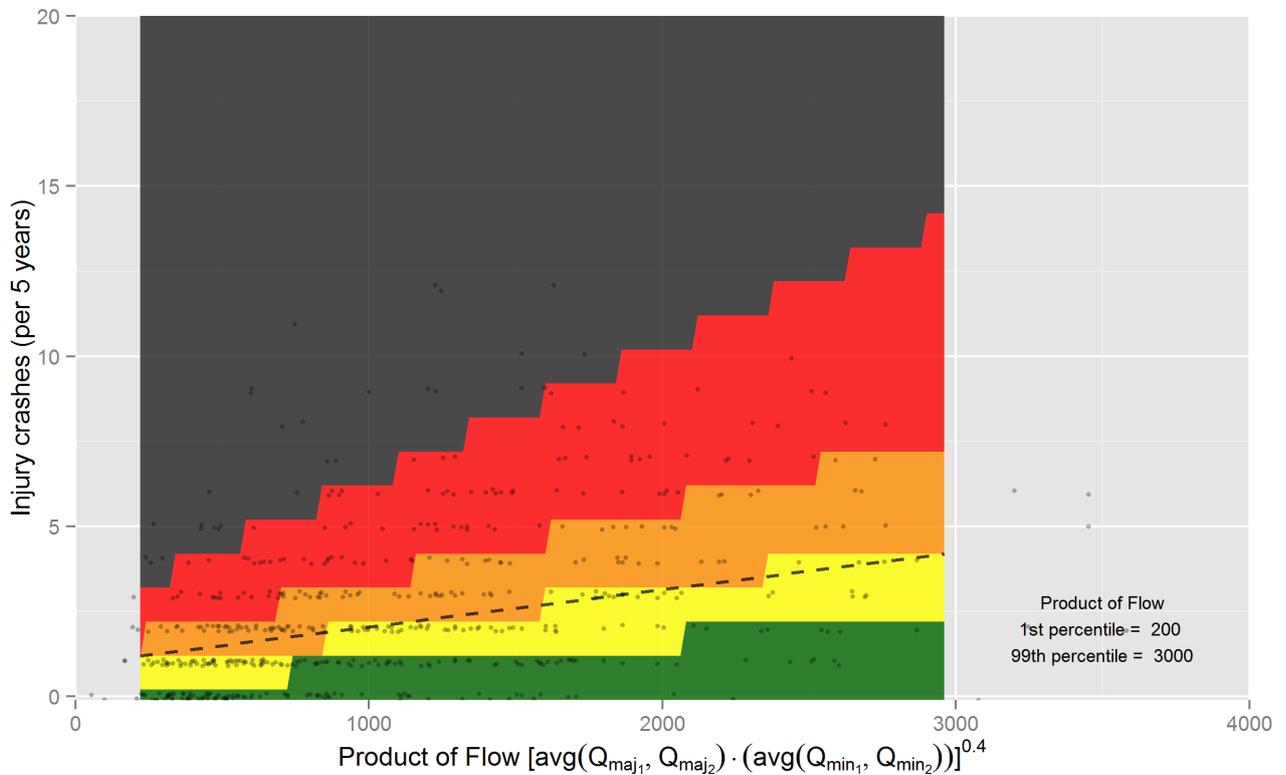
Figure A5-1: LoSS bands for urban signalised crossroad intersections



Note: Based on a sample size of 372 intersections.

The dashed line shows the expected 50%ile. Use this line to assess the potential for improvement with existing control.

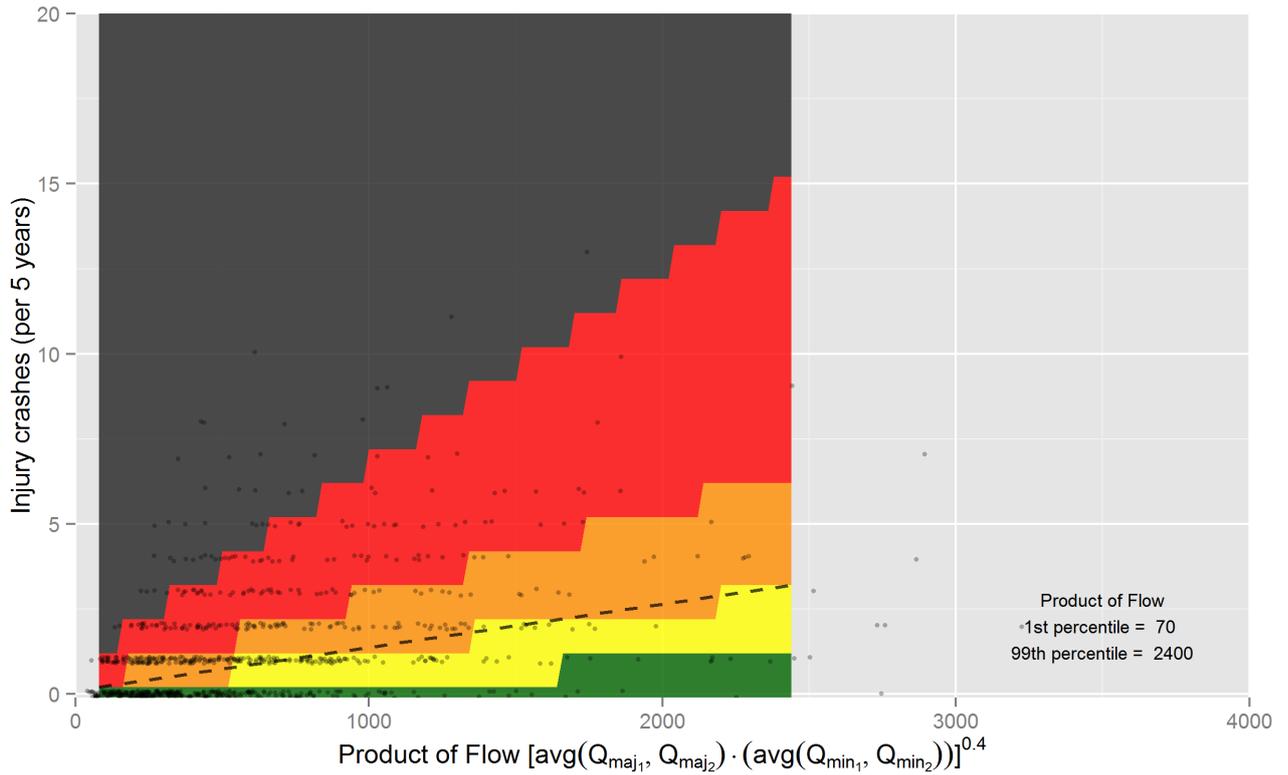
Figure A5-1: LoSS bands for urban signalised T/Y intersections



Note: Based on a sample size of 552 intersections

The dashed line shows the expected 50%ile. Use this line to assess the potential for improvement with existing control.

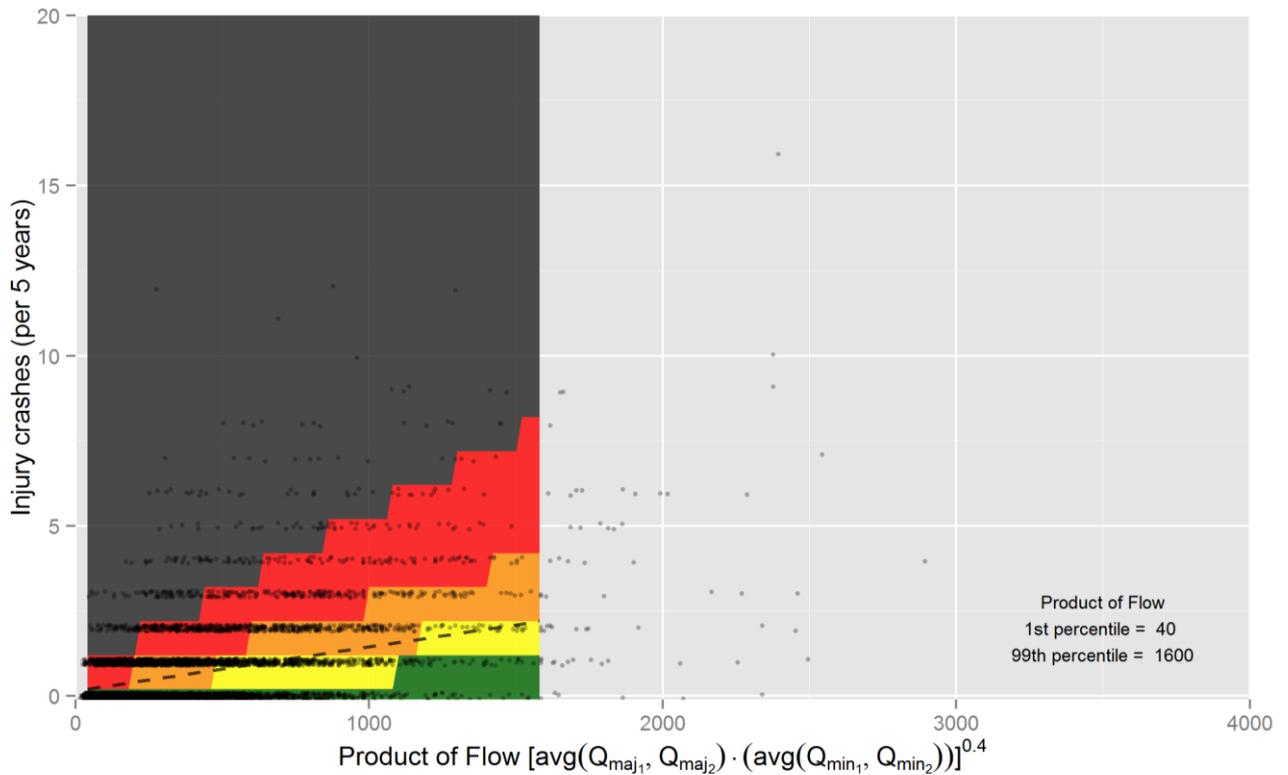
Figure A 5-2: LoSS bands for urban priority controlled crossroad intersections



Note: Based on a sample size of 860 intersections.

The dashed line shows the expected 50%ile. Use this line to assess the potential for improvement with existing control.

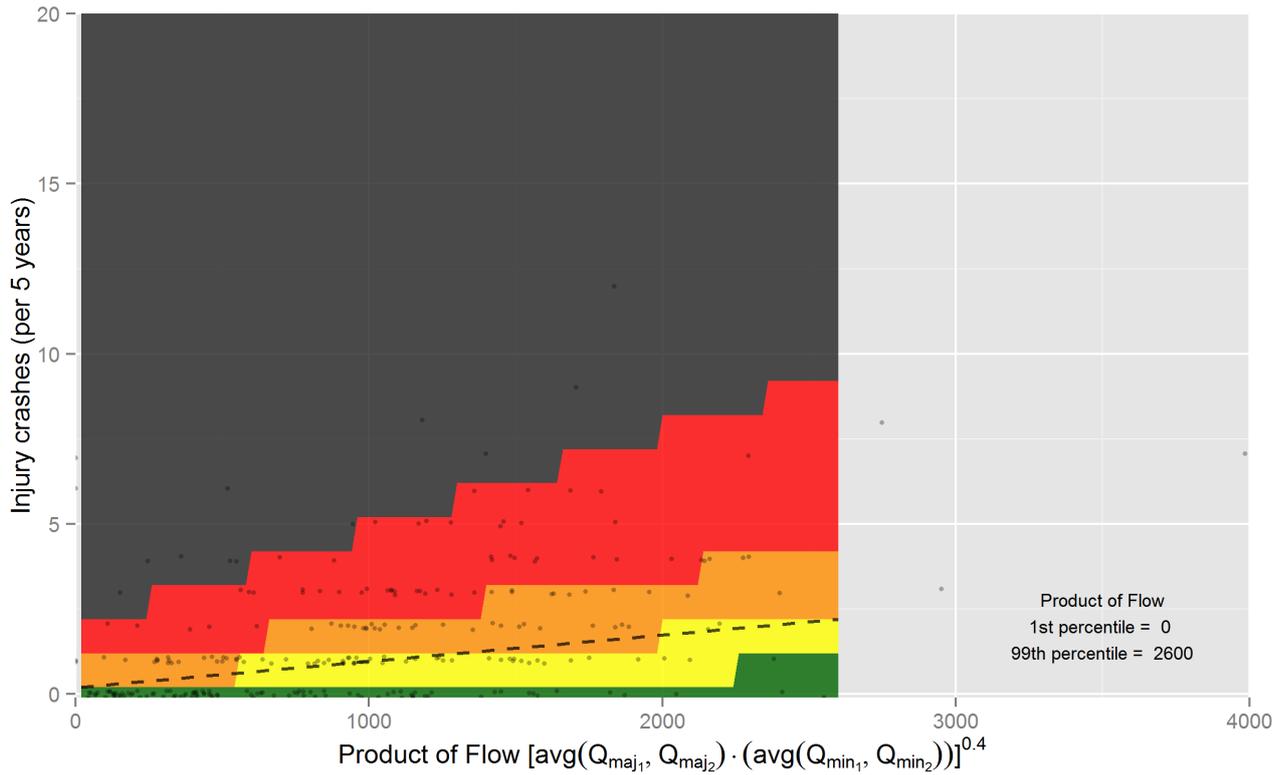
Figure A5-3: LoSS bands for urban priority controlled T/Y intersections



Note: Based on a sample size of 6,537 intersections.

The dashed line shows the expected 50%ile. Use this line to assess the potential for improvement with existing control.

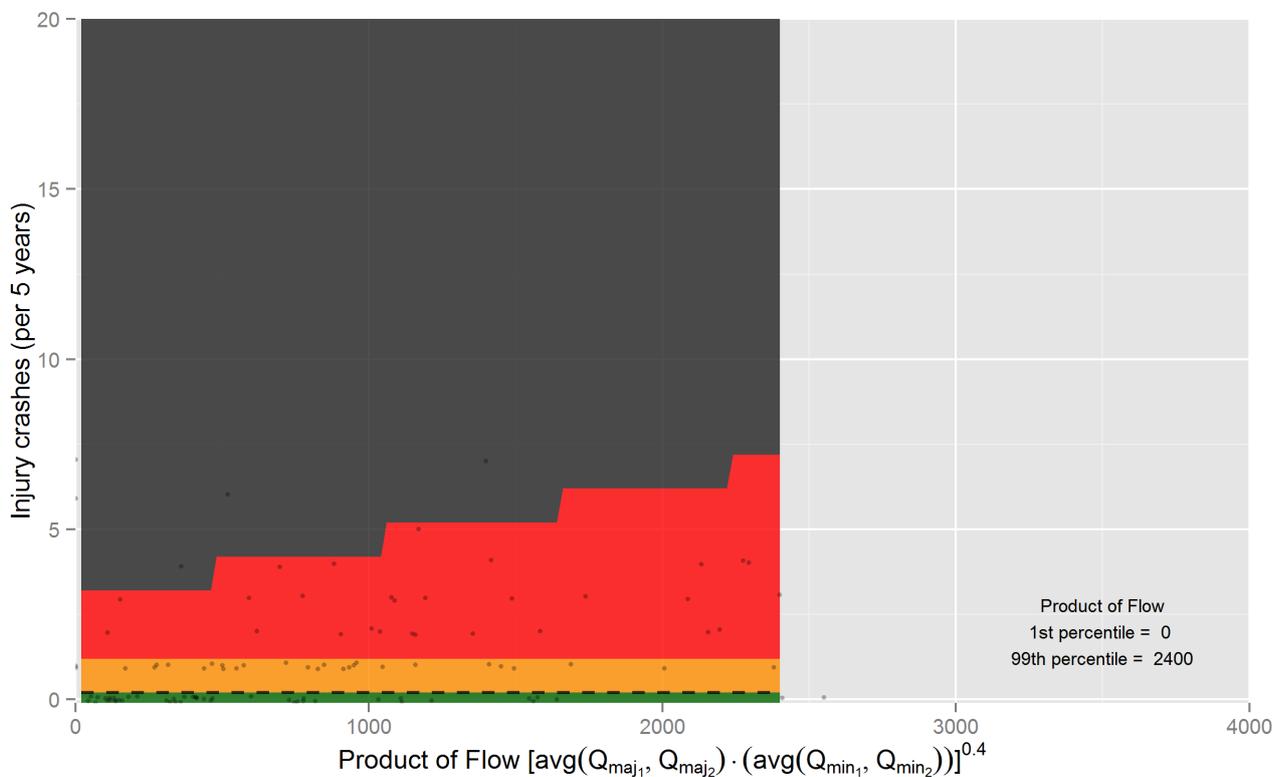
Figure A5-5: LoSS bands for urban three- and four-leg roundabout intersections



Note: Based on a sample size of 271 intersections.

The dashed line shows the expected 50%ile. Use this line to assess the potential for improvement with existing control.

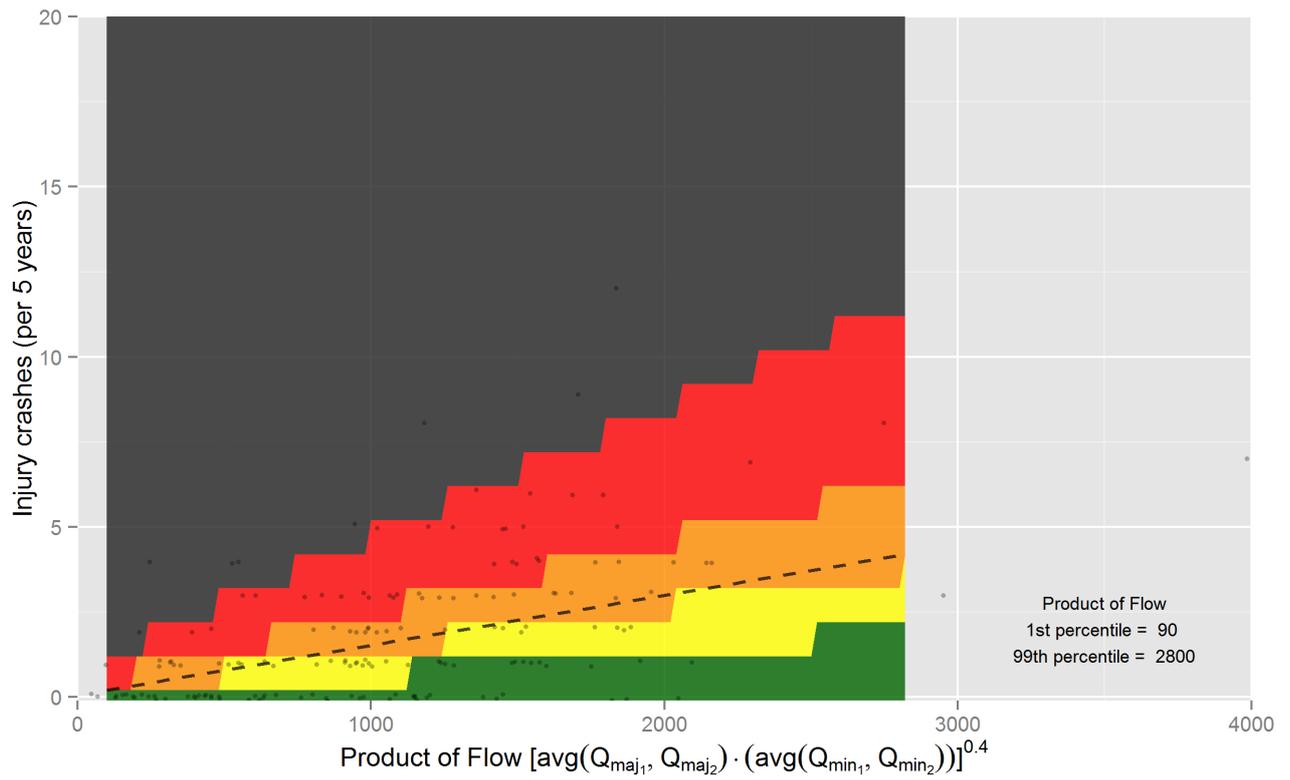
Figure A5-6: LoSS bands for urban three-leg roundabout intersections



Note: Based on a sample size of 106 intersections.

The dashed line shows the expected 50%ile. Use this line to assess the potential for improvement with existing control.

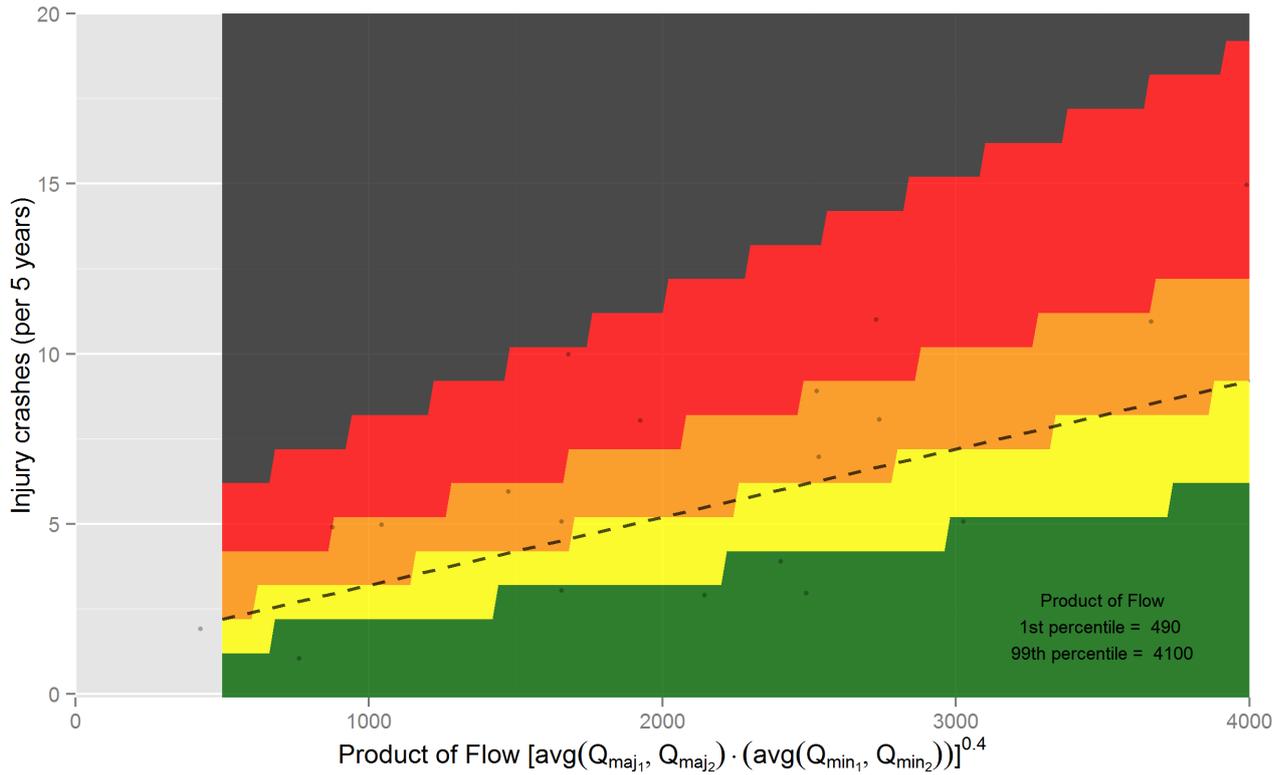
Figure A5-7: LoSS bands for urban four-leg roundabout intersections



Note: Based on a sample size of 165 intersections.

The dashed line shows the expected 50%ile. Use this line to assess the potential for improvement with existing control.

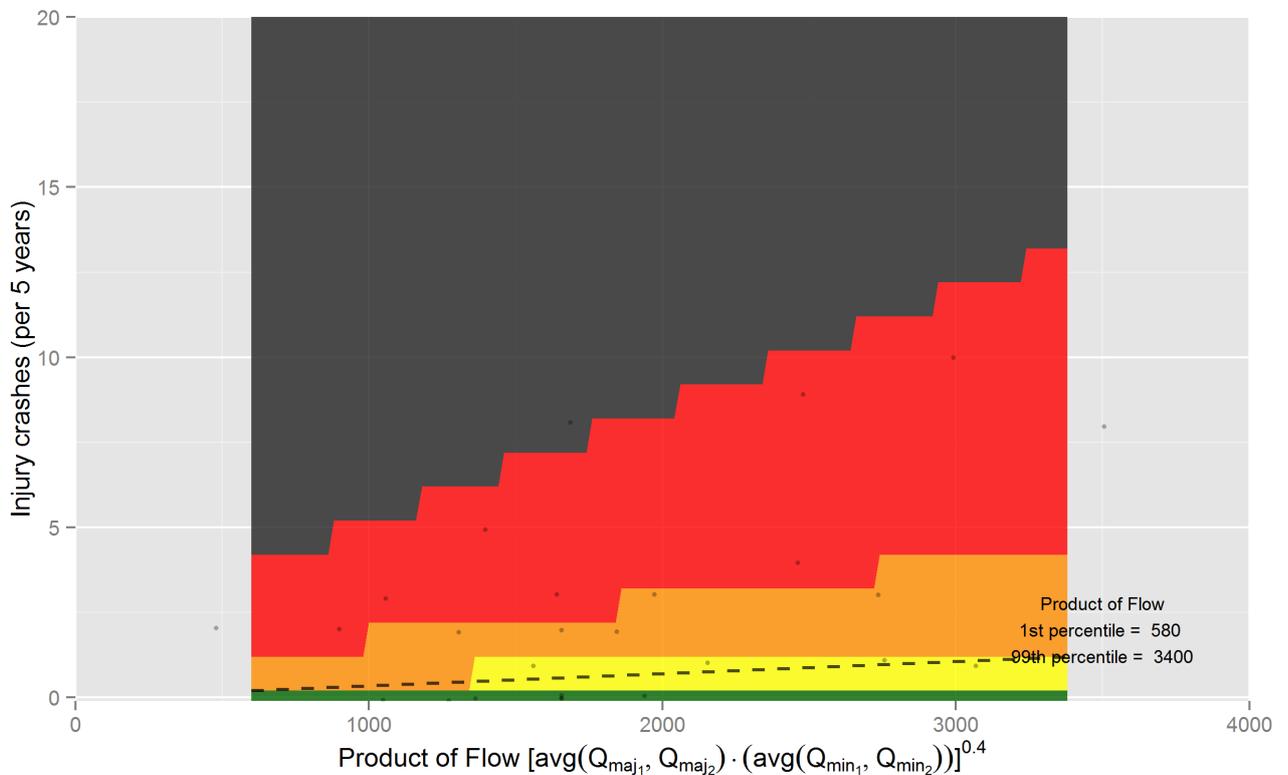
Figure A5-8: LoSS bands for rural signalised crossroad intersections



Note: Based on a sample size of 20 intersections

The dashed line shows the expected 50%ile. Use this line to assess the potential for improvement with existing control.

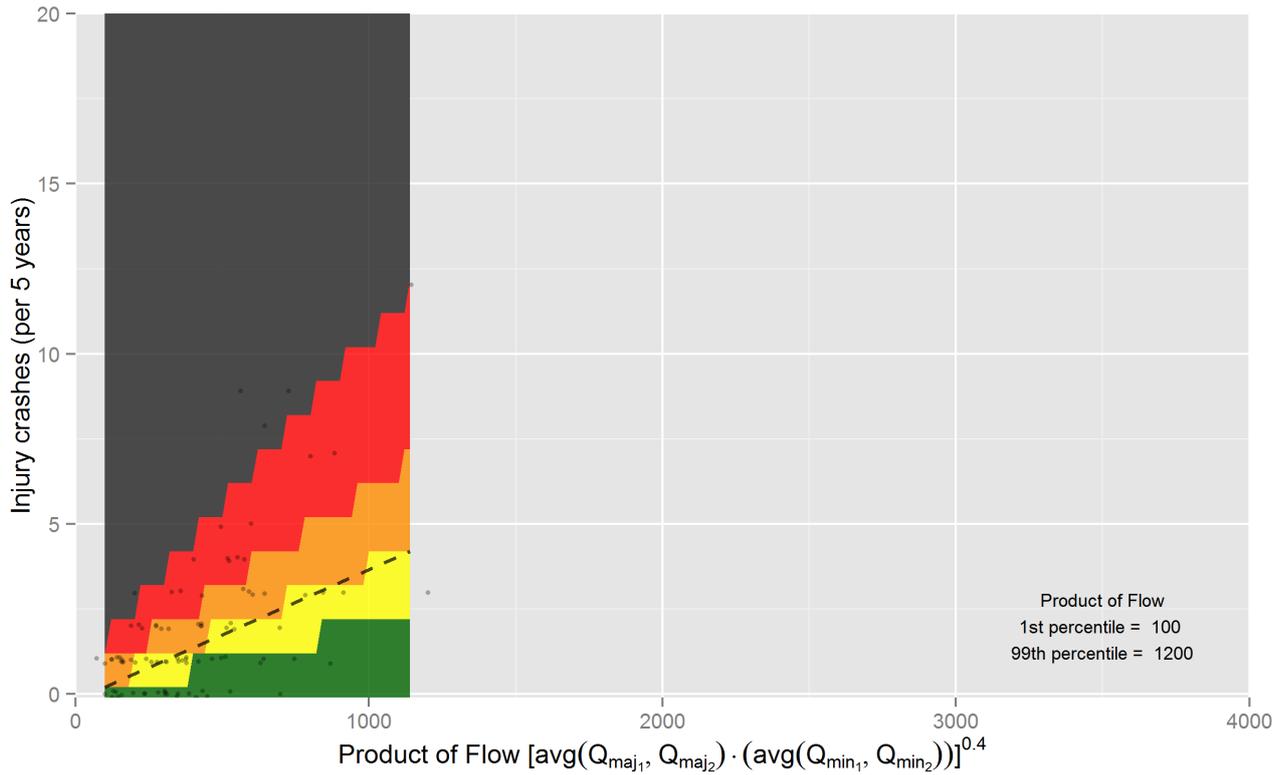
Figure A5-9: LoSS bands for rural signalised T/Y intersections



Note: Based on a sample size of 26 intersections.

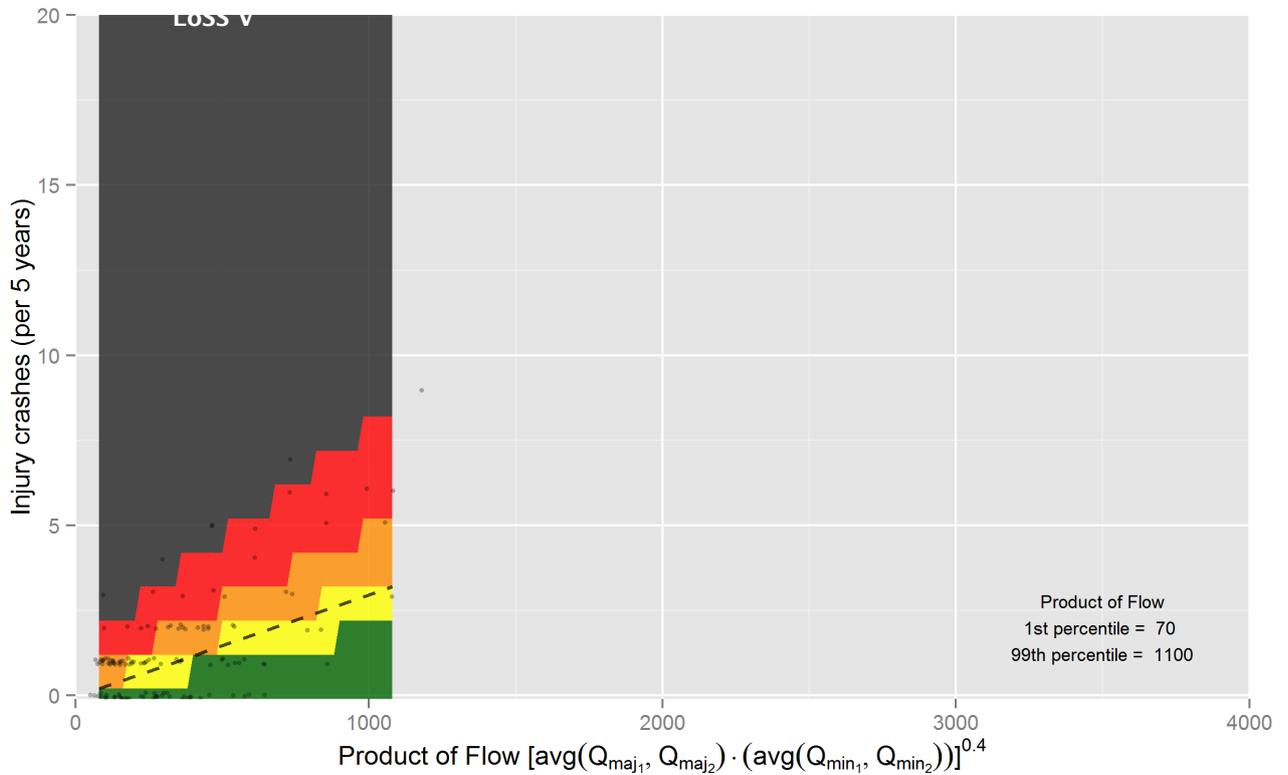
The dashed line shows the expected 50%ile. Use this line to assess the potential for improvement with existing control.

Figure A5-10: LoSS bands for rural priority controlled crossroad intersections



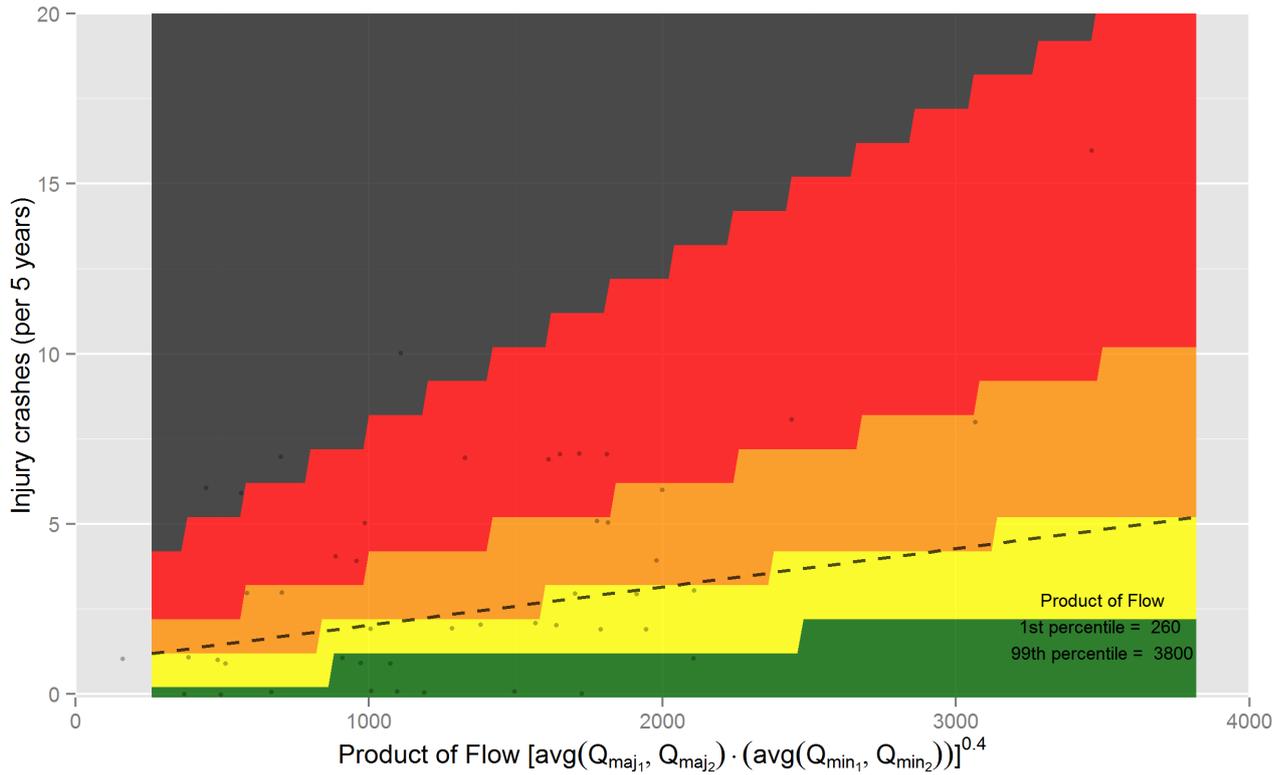
Note: Based on a sample size of 93 intersections.
 The dashed line shows the expected 50%ile. Use this line to assess the potential for improvement with existing control.

Figure A5-11: LoSS bands for rural priority controlled T/Y intersections



Note: Based on a sample size of 131 intersections.
 The dashed line shows the expected 50%ile. Use this line to assess the potential for improvement with existing control.

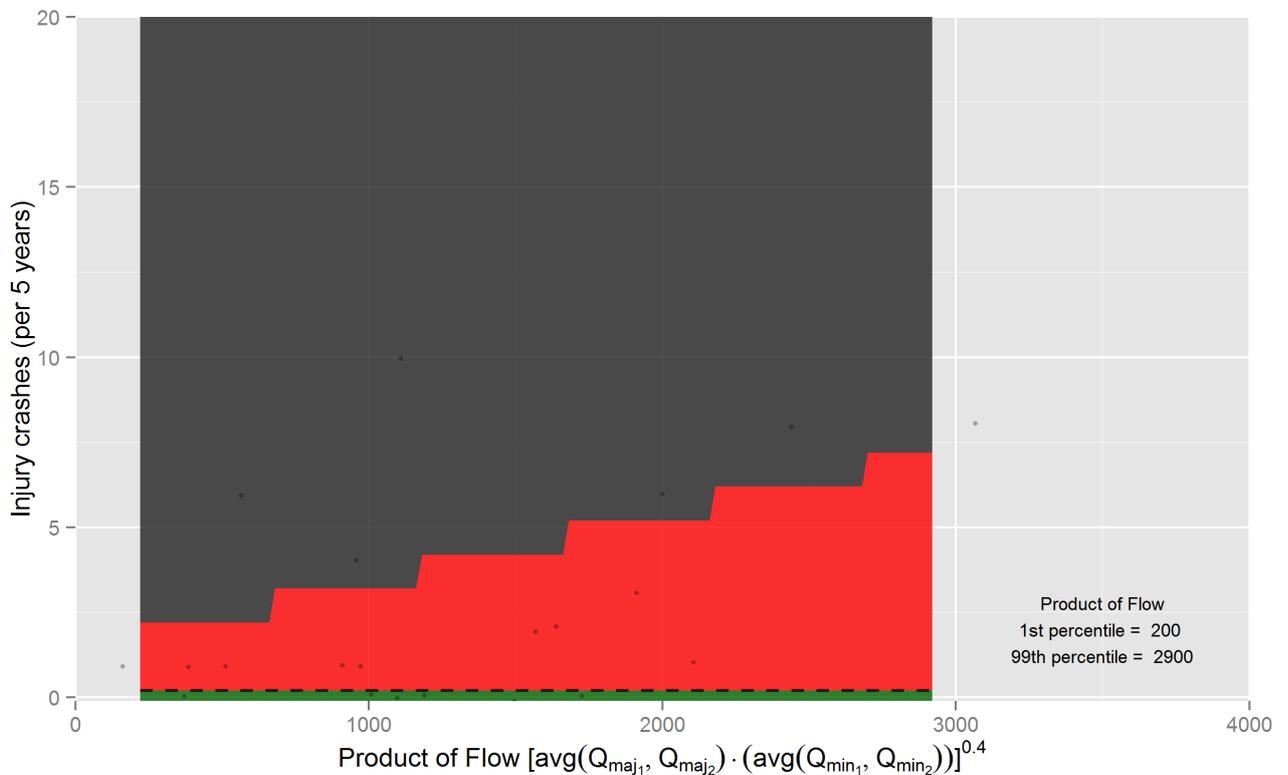
Figure A5-12: LoSS Bands for rural three- and four-leg roundabout intersections



Note: Based on a sample size of 48 intersections.

The dashed line shows the expected 50%ile. Use this line to assess the potential for improvement with existing control.

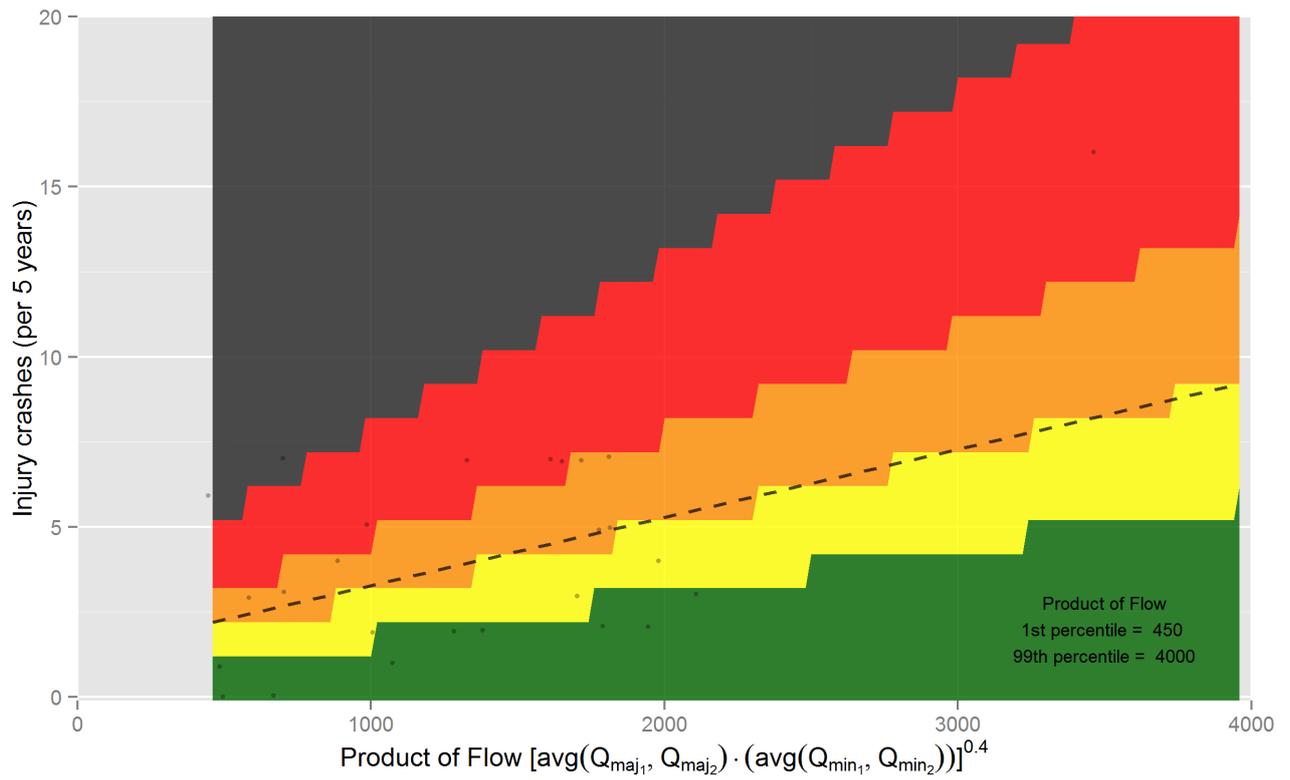
Figure A5-13: LoSS Bands for rural three-leg roundabout intersections



Note: Based on a sample size of 21 intersections.

The dashed line shows the expected 50%ile. Use this line to assess the potential for improvement with existing control.

Figure A5-14: LoSS Bands for rural four-leg roundabout intersections



Note: Based on a sample size of 27 intersections.

The dashed line shows the expected 50%ile. Use this line to assess the potential for improvement with existing control.

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 table a6-1. 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.

Table A6-1: High-risk countermeasures details sheet

Countermeasure	Ref	Safe System treatment philosophy	Rural high speed >= 80km/h						Urban <= 70km/h					
			Signalised intersection	Roundabout	Priority crossroads	T intersection	Staggered T	Y intersection	Signalised intersection	Roundabout	Priority crossroads	T intersection	Staggered T	Y intersection
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 and intersection awareness														
Intelligent electronic warning signs	S1		x	x	x	x	x	x	x	x	x	x	x	x
Rumble strips/transverse road markings	S2		x	x	x	x	x	x						
High friction/coloured surfacing	S3		x	x	x	x	x	x	x	x	x	x	x	x
Enhanced signing	S4		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/give way	IS2				x	x	x	x			x	x	x	x
Cyclist facilities at uncontrolled/give way	IS4				x	x	x	x			x	x	x	x
Lighting	IS18		x	x	x	x	x	x	x	x	x	x	x	x

		Rural high speed >= 80km/h							Urban <= 70km/h						
		Safe System treatment philosophy	Signalised intersection	Roundabout	Priority crossroads	T intersection	Staggered T	Y intersection		Signalised intersection	Roundabout	Priority crossroads	T intersection	Staggered T	Y intersection
Countermeasure	Ref														
Signals															
Speed discrimination equipment	IS6	Yellow	x							x					
Separate right turn bays	IS7	Red	x							x					
Improve signal conspicuity	IS8	Yellow	x							x					
Align opposing right turns	IS9	Red	x							x					
Pedestrian facilities at signals	IS10	Orange	x							x					
Cyclist facilities at signals	IS11	Orange								x					
Roundabouts															
Reverse curves on approach to roundabout	IS12	Red		x											
Geometry improvements	IS13	Red		x							x				
Central lighting	IS14	Orange		x							x				
Pedestrian facilities	IS15	Orange		x							x				
Cyclist facilities	IS16	Orange		x							x				
Adverse camber rectification	IS17	Red		x							x				
Collision severity mitigation															
Clear or safe zones	C1	Red	x	x	x	x	x	x		x	x	x	x	x	x
Enforcement															
Speed and red light camera's	E1	Orange	x	x	x	x	x	x		x	x	x	x	x	x

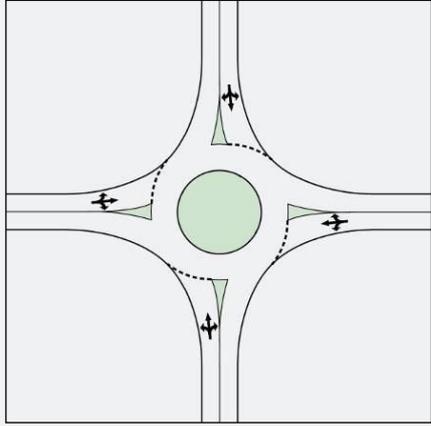
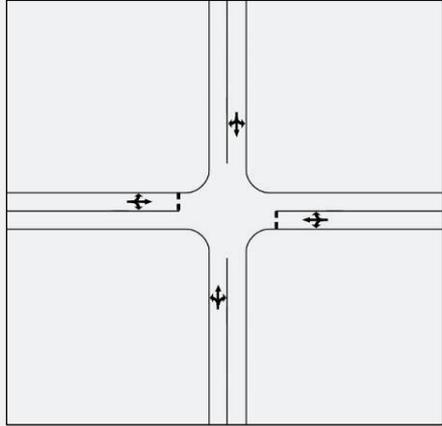
Key to Safe System countermeasure treatment philosophy

	Safe System transformation
	Safer intersections (medium cost)
	Safety management
	Safety maintenance

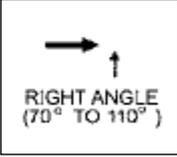
Transformational works

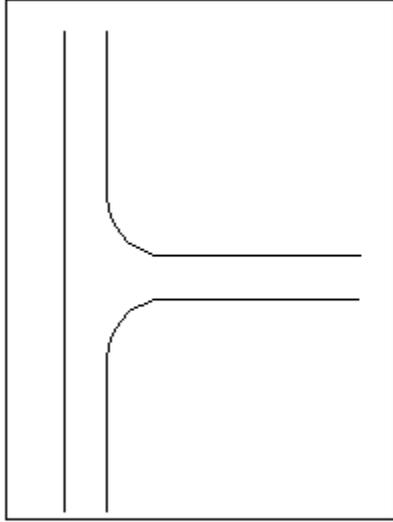
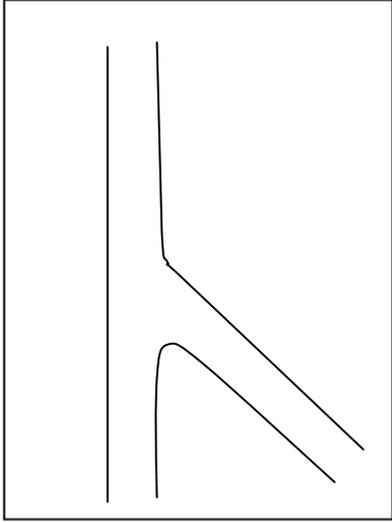
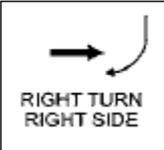
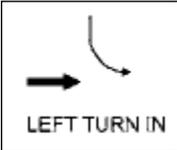
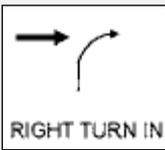
Roundabout from 'T' or crossroads intersection

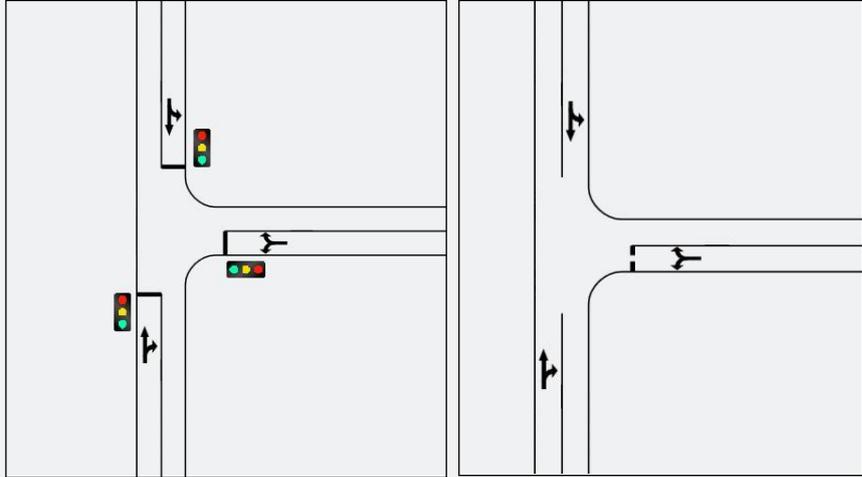
T1

<p>Description</p>	<p>Roundabouts are an effective method of reducing both the number and severity of injury crashes. This is due to the reduced number of conflict points and lower relative impact speeds when compared with other layouts.[10]</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p>Roundabout</p>  </div> <div style="text-align: center;"> <p>Crossroads</p>  </div> </div>
<p>Application</p>	<p>At T junctions and crossroads.</p>
<p>Issues</p>	<p>Larger footprint than other simple junction forms.</p> <p>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]</p> <p>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]</p> <p>Management of speed at entry is critical and can be achieved using a combination of geometry, visibility and in urban areas, vertical deflection.</p> <p>Two thirds of DSIs at rural roundabouts involve loss of control, colliding with roadside objects downstream of the exit. So clear zones in these areas are crucial.</p>
<p>Crash reduction</p>	<p>10–40% reduction in injury crashes. [2]</p> <p>90% reduction in serious and fatal crashes. [34]</p> <p>25–80% reduction in all crashes from uncontrolled intersection. [5]</p> <p>25–50% reduction in all crashes from traffic signals. [5]</p>
<p>Other benefits</p>	<p>Improved flow – with reduced delays for side road traffic.</p>
<p>Cost</p>	<p>High</p>
<p>Treatment life</p>	<p>25-30 years</p>
<p>Applicable key high-risk crash movement types</p>	<p>Most crash movement types with the exception of pedestrian and cyclist crashes.</p>
<p>References</p>	<p>[2] [5][7][10][11][12][14][34]</p>

<p>Description</p>	<p>Changing a crossroad to a staggered T-intersection involves providing offset between opposite side road legs to decrease conflict points. There are two types of staggers, a right-left and left-right.</p> <p>The left-right stagger has limited space for right-turn bays, but allows drivers travelling from one side road to the other to turn left then right and so cross the main road in two movements. The right-left stagger has plenty of space for right-turn bays, but drivers travelling from one side road to the other must turn right then left, so must generally find a gap in traffic in both directions.</p> <p>Right-left stagger [23]</p>  <p>Left-right stagger [23]</p> 
<p>Application</p>	<p>Usually applied to rural crossroads where there is a history of overrun crashes and sufficient land available to accommodate.</p> <p>A right-left staggered T-intersection treatment may be selected where [23]:</p> <ul style="list-style-type: none"> the potential for high-speed right angle overrun crashes at a basic crossroad needs to be eliminated the intersection could be expected to operate below capacity throughout the intended design life of the treatment. <p>A left-right staggered T treatment may be selected where [23]:</p> <ul style="list-style-type: none"> Analysis shows that a right-left staggered treatment would not have a satisfactory design life in terms of intersection capacity (and hence safety), and there is room to provide for right turn bays between the staggered side roads.
<p>Issues</p>	<p>As the problem is mostly over-run crashes due to the straight through appearance of the side roads, at lower volume intersections, most safety benefits are achieved with a quite modest right - left offset.</p> <p>Where the volume of traffic means that a staggered T may run into capacity issues, a roundabout option should also be considered.</p>
<p>Crash reduction</p>	<p>25–35% where minor road flows +15% of main road. [23]</p> <p>35% – where minor traffic flows <15% of main road. [23]</p> <p>40–95% reduction in injury crashes. [5]</p>

Other benefits	<p>A staggered T requires less land than a roundabout.</p> <p>A staggered T is likely to provide a better return on investment at lower side road volumes than is required to warrant a more expensive roundabout.</p>
Cost	High
Treatment life	25 years
Applicable key high-risk crash movement types	
References	[2][5][10][23]

<p>Description</p>	<p>Changing a Y intersection into a T gives the main advantage 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.</p> <div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p>T intersection</p>  </div> <div style="text-align: center;"> <p>Y intersection</p>  </div> </div>
<p>Application</p>	<p>At unsignalised Y–intersections.</p>
<p>Issues</p>	<p>May not be appropriate where minor road flows are high. Likely to require additional land acquisition.</p>
<p>Crash reduction</p>	<p>15-50% reduction in all crashes. [5] 87% reduction in injury crashes. [16]</p>
<p>Other benefits</p>	<p>Improved flow – with reduced delays for side road traffic.</p>
<p>Cost</p>	<p>Medium/high</p>
<p>Treatment life</p>	<p>25 years</p>
<p>Applicable key high-risk crash movement types</p>	<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;">  <p>RIGHT TURN RIGHT SIDE</p> </div> <div style="text-align: center;">  <p>LEFT TURN IN</p> </div> <div style="text-align: center;">  <p>RIGHT TURN IN</p> </div> </div>
<p>References</p>	<p>[5][16]</p>

<p>Description</p>	<p>Upgrading an uncontrolled or priority (give way or stop) intersection to traffic signals can be an effective method of managing conflicting traffic flows and user types.</p> <p>Signals T-intersection</p> 
<p>Application</p>	<p>At crossroads in urban locations, and at T-junctions.</p> <p>Can be used to manage vehicular, pedestrian and cycle modes.</p>
<p>Issues</p>	<p>Requires careful consideration of layout and phasing, including particular attention to opposing right turns, cycle and pedestrian facilities.</p> <p>In urban areas conflict between turning vehicles and pedestrians, requires careful phasing.</p> <p>Right turn against crashes on multi-lane roads – requires exclusive turn phases.</p> <p>Rural signals require high standard of vehicle detection and careful phasing.</p>
<p>Crash reduction</p>	<p>15–30% reduction in all crashes from uncontrolled intersection. [5]</p> <p>However figures 6-1 to 6-4 indicate that performance is typically not this good, so design and operation must be best practice.</p>
<p>Other benefits</p>	<p>Improved flow – with reduced delays for side road traffic.</p>
<p>Cost</p>	<p>Medium/high</p>
<p>Treatment life</p>	<p>25 years</p>
<p>References</p>	<p>[5][10]</p>

Description	<p>A grade separated interchange improves traffic operation and safety at a site by removing conflict between major traffic movements and by controlling conflict associated with minor traffic movements.</p> 
Application	<p>Generally for high speed, high through flow motorway intersections, although can be used in other lower speed environments.</p>
Issues	<p>Larger footprint than other simple junction forms.</p> <p>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.</p> <p>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.</p> <p>Structures and ramps can be hazards can present collision risk if unprotected.</p>
Crash reduction	<p>50% reduction in injury crashes when replacing crossroads. [2]</p>
Other benefits	<p>Improved flow – with reduced delays for side road traffic.</p>
Cost	<p>High</p>
Treatment life	<p>25 years</p>
References	<p>[2][10]</p>

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 active warning signs

S1

Description	<p>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.</p> 
Application	<p>To reduce speeds and raise awareness of an intersection with deficiencies or crash problems where transformational works are not appropriate or possible.</p>
Issues	<p>If overused can result in drivers becoming habituated to them.</p> <p>Sufficient permanent signing as a back-up to sign failure may be necessary.</p>
Crash reduction	<p>35% reduction in injury crashes. [3]</p>
Other benefits	<p>Very effective speed reduction.</p> <p>Some signs can collect speed data for monitoring.</p>
Cost	<p>Low/medium</p>
Treatment life	<p>25 years</p>
Applicable key high-risk crash movement types	<p>All crash movement types.</p>
References	<p>[3][13]</p>

<p>Description</p>	<p>Transverse markings or rumble strips are changes in surface, usually raised which lead to vibration or noise within a vehicle, and the markings provide an enhanced visual sense of speed.</p>  <p>Source: [20]</p>
<p>Application</p>	<p>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.</p> <p>To raise awareness of an intersection with deficiencies or crash problems where transformational works are not appropriate or possible.</p>
<p>Issues</p>	<p>Not suitable near residential property due to noise.</p> <p>Subject to wear, requiring regular refurbishment.</p>
<p>Crash reduction</p>	<p>33% reduction in injury crashes. [3]</p> <p>17–50% reduction in total crashes. [5]</p> <p>24–54% reduction in crashes. [5]</p>
<p>Other benefits</p>	<p>Can reduce speeds of vehicles a distance away from the intersection depending on the layout.</p>
<p>Cost</p>	<p>Low</p>
<p>Treatment life</p>	<p>1-3 years depending on traffic volumes.</p>
<p>Applicable key high-risk crash movement types</p>	<p>All crash movement types.</p>
<p>References</p>	<p>[3][5][6][20]</p>

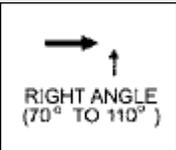
Description	<p>Surface with a high skid resistance which can be combined with change in colour of surface to raise driver awareness. A change in speed limit or reminder can be marked on the coloured surface.</p>  <p>(source: www.colourgripsurfacing.co.nz)</p>
Application	<p>To reduce speeds and raise awareness.</p> <p>To reduce stopping distances on approaches to intersection.</p>
Issues	<p>Can lose effectiveness due to colour fade.</p> <p>More expensive to maintain than standard surfacing.</p>
Crash reduction	<p>18–74% reduction in injury crashes due to improved skidding resistance. [5]</p> <p>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.</p> <p>40% reduction in rear-end crashes. [14]</p>
Other benefits	<p>Can reduce/restrict inappropriate driver behaviour at intersection (eg wheel spin by boy racers).</p>
Cost	<p>Low</p>
Treatment life	<p>25 years</p>
Applicable key high-risk crash movement types	<p>All crash movement types.</p>
References	<p>[5][14]</p>

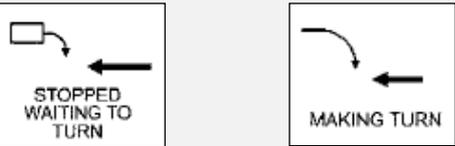
Description	<p>Improvement to signing including gating (placement on both sides of road), larger signs and providing coloured backing boards.</p>  <p>Example of a gateway entry feature. Source MOTSAM.</p>
Application	To reduce speeds and raise awareness on both main and minor road approaches to intersections, most useful for high speed locations.
Issues	<p>Less benefit in urban locations due to visually eventful environment.</p> <p>A change in speed limit may also be marked on the roadway.</p>
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]

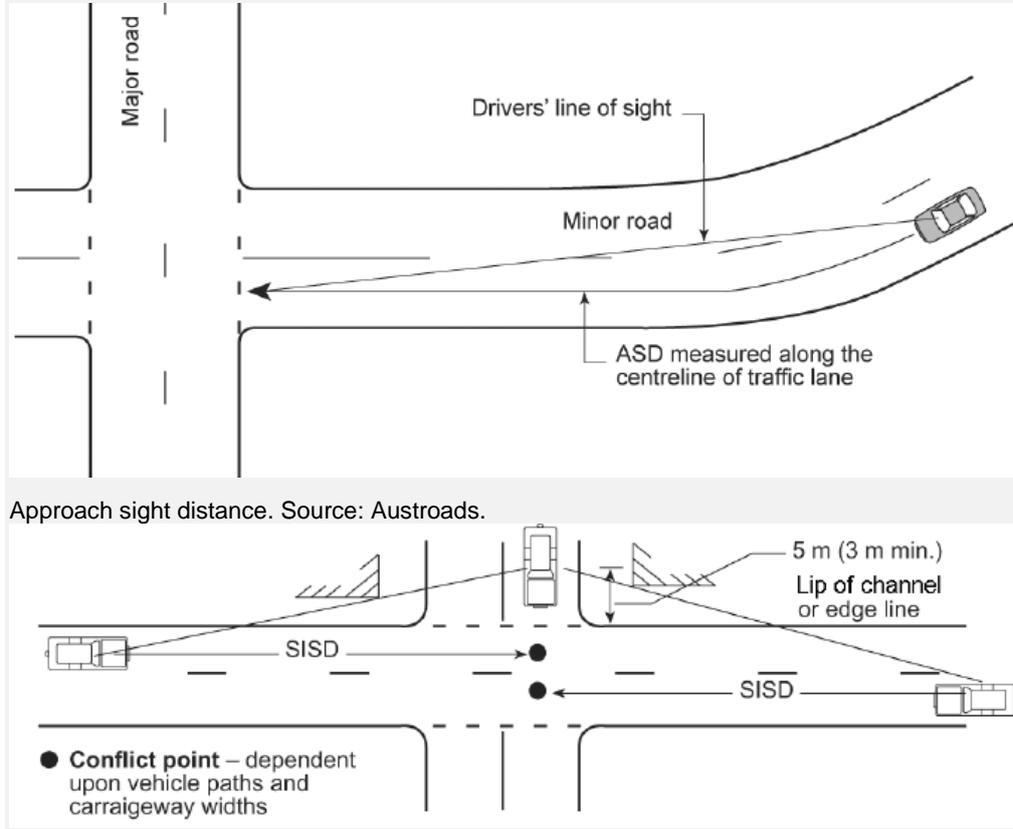
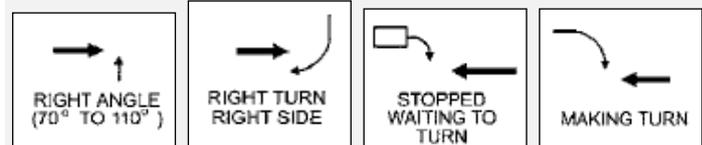
Intersection improvement

Minor road central islands

IS1

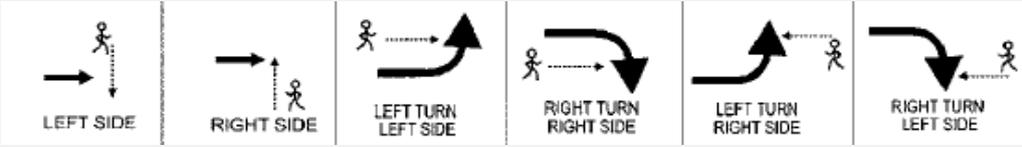
Description	<p>Central/splitter raised islands installed on the side road approaches. Used mostly to channelise traffic, reduce speeds and increase visibility and safety of all road users.</p>  <p>Source: Austroads Engineering Toolkit [35]</p>
Application	<ul style="list-style-type: none"> • Where there are issues with vehicles failing to stop or give way on the side road approach. • As a method for separation of traffic turning. • Reduce speed of turning traffic • In urban situations to aid pedestrian crossing.
Issues	<p>Traffic islands at intersections should be designed to allow turning by the appropriate design vehicle for the type of road (eg service vehicle for a local access lane, a semi-trailer for most arterial roads). Occasionally, this means that part of an island may need to be made mountable to accommodate all desired turns.[35]</p>
Crash reduction	<p>17–35% reduction in injury crashes at crossroads. [2]</p> <p>39% reduction in total crashes. [5]</p> <p>In the minor road – 40% at cross intersections and 45% at T intersections.[35]</p> <p>In the major road – 15% if mountable, 25% if not mountable.[35]</p>
Other benefits	
Cost	Low
Treatment life	10-15 years
Applicable key high-risk crash movement types	
References	[2][5]

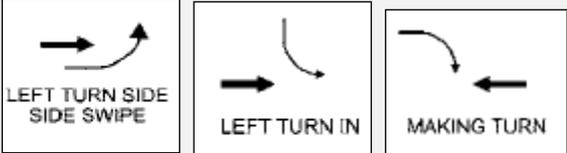
<p>Description</p>	<p>Right turn and left turn (diverge) bays on the main road to remove turning traffic from conflict with through traffic.</p> 
<p>Application</p>	<p>At T, Y and crossroads intersections where there are high turning volumes leaving the main road or difficulty turning due to high through traffic volume on the major road.</p>
<p>Issues</p>	<p>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.</p> <p>Right turn bays:</p> <ul style="list-style-type: none"> • can result in increased crossing crashes at crossroads, as it is more difficult to anticipate oncoming traffic due to the widened intersection, and poorly aligned right turn bays can block visibility of opposing through traffic • when introduced on rural curves can result in poor geometry for the through traffic lane, so length of tapers needs to be carefully considered. <p>Left turn bays:</p> <ul style="list-style-type: none"> • can result in left-turning traffic masking faster moving through traffic to traffic emerging from the side road. This happens on typical straight main road approaches and is greater on approaches where the side road is on the inside of a curve) • where this is likely to be an issue the left turn bays must be aligned to prevent it, e.g offset further left, or the left turn lanes not provided. <p>Both require larger footprint than other simple junction forms.</p>
<p>Crash reduction</p>	<p>33% reduction in injury crashes. [15] 35% reduction in injury crashes. [3] However these are low severity rear end crashes that are saved. Fatal and serious crash risk may increase.</p>
<p>Other benefits</p>	<p>Improved through flow.</p>
<p>Cost</p>	<p>Medium/high</p>
<p>Treatment life</p>	<p>25 years</p>
<p>Applicable key high-risk crash movement types</p>	
<p>References</p>	<p>[3][15][23]</p>

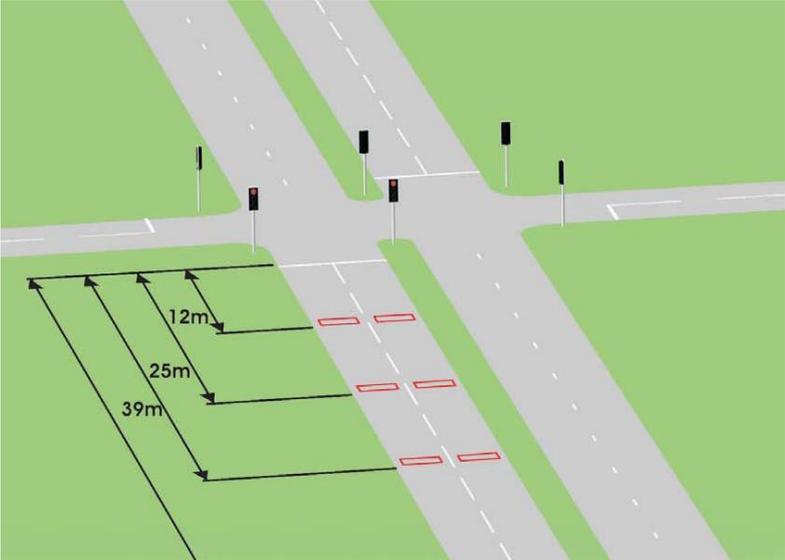
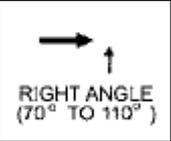
<p>Description</p>	<p>Sight distance improvements mitigate insufficient, excessive, or unbalanced visibility from the side road. There are three key sight distances that need to be considered; the approach sight distance (ASD) on the minor road, the safe intersection site distance (SISD) measured along the major road from the side road and the set-back distance from the edge line from which this should be achieved.</p>  <p>Approach sight distance. Source: Austroads.</p> <p>Safe intersection sight distance. Source: Austroads.</p>
<p>Application</p>	<p>For intersections where side road sight distance is not consistent with design guidance and speed environment.</p>
<p>Issues</p>	<ul style="list-style-type: none"> • Full visibility which is available too far back from the limit line can result in early decision making, potentially resulting in failure to see less conspicuous users such as cyclists and motorcyclist. • 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 imbalance in sight distance left and right along the major road can result in drivers concentrating too much on one direction.
<p>Crash reduction</p>	<p>30% reduction where sight distance is improved. [3]</p>
<p>Other benefits</p>	
<p>Cost</p>	<p>Low to moderate</p>
<p>Treatment life</p>	<p>1-25 years (vegetation maintenance required annually).</p>
<p>Applicable key high-risk crash movement types</p>	

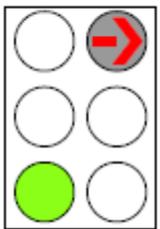
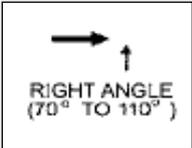
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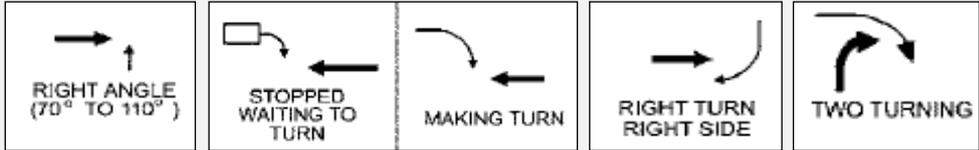
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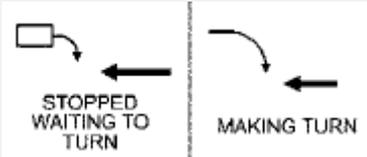
<p>Description</p>	<p>There are a number of measures that can improve safety for pedestrians including:</p> <ul style="list-style-type: none"> pedestrian refuges on side roads and on the adjacent major road (ideally to the right of side road to avoid pedestrians being obscured by vehicles turning right into the side road) 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).  <p>Raised pedestrian platform at free left turn</p>
<p>Application</p>	<p>For all intersections where there is significant pedestrian movement or difficulty crossing due to traffic speed or volume.</p> <p>Where the existing level of pedestrian facilities may no longer be sufficient to manage the increased pedestrian and vehicular movements (e.g. pedestrian refuges may need to be replaced by signals), or the type of pedestrians (eg the children from a new school nearby). [36]</p>
<p>Issues</p>	
<p>Crash reduction</p>	<ul style="list-style-type: none"> 15% for pedestrian refuge islands. [37] 20% at intersections with pedestrian-only phases. [38] No reduction at intersections with phases permitting conflicting pedestrian/vehicle movements (eg left turn or right turn filtering). [38]
<p>Other benefits</p>	<p>Overall improvement to the visibility of the intersection for all roads users.</p>
<p>Cost</p>	<p>Low/medium</p>
<p>Treatment Life</p>	<p>5–25 years</p>
<p>Applicable key high-risk crash movement types</p>	
<p>References</p>	<p>[21][22] [37]</p>

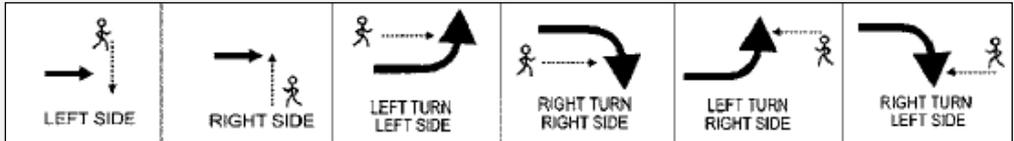
<p>Description</p>	<p>There are a number of measures that can improve safety for cyclists including:</p> <ul style="list-style-type: none"> • coloured surfacing of cycle lane through intersection • tightening radius of the junction to slow turning traffic.  <p>Coloured surfacing of cycle lane through intersection</p>
<p>Application</p>	<p>To raise driver awareness of cyclists at intersections and reduce likelihood of cycle/vehicle conflict.</p>
<p>Issues</p>	<p>Surface life reduced due to concentrated turning movements at intersection.</p>
<p>Crash reduction</p>	<p>50% reduction in cyclist injuries with green lane surfaces at signals. (Austroads research report)</p>
<p>Other benefits</p>	<p>Overall improvement to the visibility of the intersection for all roads users.</p>
<p>Cost</p>	<p>Low/medium</p>
<p>Treatment life</p>	<p>5–25 years</p>
<p>Applicable key high-risk crash movement types</p>	
<p>References</p>	<p>[39]</p>

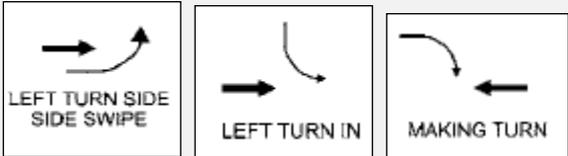
<p>Description</p>	<p>Induction loops fitted in advance of high speed signals (80km/h+) which will increase the all red time when a vehicle is detected within the 'dilemma' zone at speeds where a vehicle is unlikely to be able to stop.</p>  <p>Source: Department for Transport [17]</p>
<p>Application</p>	<p>When traffic signals change away from green, drivers have to decide whether they can safely stop, at an acceptable deceleration rate, or continue and clear the stop line before the start of red. On high-speed roads the decision becomes more difficult with increasing vehicle speeds. 'High-speed' for signal controlled intersections is taken to mean a road where the 85th percentile approach speeds at an intersection are 56km/h or above. [17]</p>
<p>Issues</p>	<p>May not be compatible with all signal controller types.</p>
<p>Crash reduction</p>	<p>No current research data.</p>
<p>Other benefits</p>	<p></p>
<p>Cost</p>	<p>Medium</p>
<p>Treatment life</p>	<p>10–15 years</p>
<p>Applicable key high-risk crash movement types</p>	 <p>RIGHT ANGLE (70° TO 110°)</p>
<p>References</p>	<p>[17]</p>

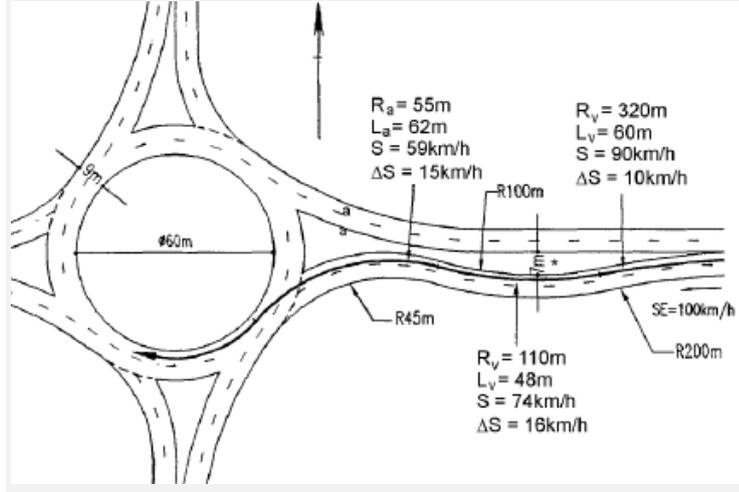
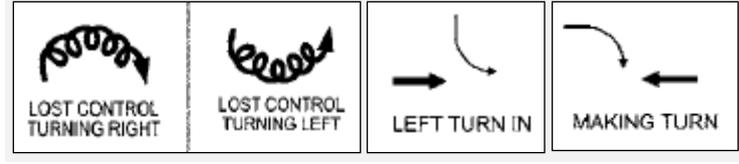
<p>Description</p>	<p>Fully controlled right turn phases are provided at signalised intersections to eliminate right turn filtering. [40]</p> <p>A separate turn phase to isolate conflicting traffic flows.</p> 
<p>Application</p>	<p>Where opposing right turning traffic restrict visibility and on multi-through lane intersections where gaps are difficult to judge.</p> <p>Can also be considered where there is a history of right turners conflicting with the pedestrians crossing the road being entered by the right turners. [40]</p>
<p>Issues</p>	<p>Will increase signal cycle times.</p> <p>Apart from increasing the length of the right turn lanes, median works may be necessary to increase the intersection size to accommodate the 'diamond' phase. Provision of a double right turn may also be considered to reduce the queuing. [40]</p>
<p>Crash reduction</p>	<p>35% reduction in injury crashes. [3]</p> <p>27% reduction in injury crashes. [16]</p> <p>45%</p>
<p>Other benefits</p>	<p>Reduction in severity of crashes throughout the intersection. [40]</p>
<p>Cost</p>	<p>Medium</p>
<p>Treatment life</p>	<p>10–15 years</p>
<p>Applicable key high-risk crash movement types</p>	 <p>Reduction in vehicle-pedestrian conflict potential. [40]</p> <p>Removal of conflict between right turners and pedestrians crossing the intersecting road. [40]</p>
<p>References</p>	<p>[3][16][40]</p>

<p>Description</p>	<p>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.</p> 
<p>Application</p>	<p>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.</p>
<p>Issues</p>	<p>Additional equipment can provide additional collision hazard risk which will need to be protected or passively safe (particularly in higher speed locations).</p>
<p>Crash reduction</p>	<p>25%, based on one US study on the benefits of installing mast arms. [41]</p>
<p>Other benefits</p>	<ul style="list-style-type: none"> • Assist drivers to see signal displays earlier, thus increasing the time available to comply with their message. [41] • Improve overall compliance with the signal messages. [41] • Increase the effective sight distance to the traffic signals. [41] • Increase the visual presence of the entire intersection. [41] • Reduce consequences of driving against the sun. [41]
<p>Cost</p>	<p>Medium</p>
<p>Treatment life</p>	<p>10–15 years</p>
<p>Applicable key high-risk crash movement types</p>	
<p>References</p>	<p>[18][41]</p>

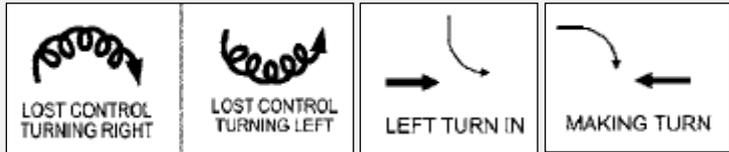
Description	<p>Ensuring opposing right turns are either opposite or offset to the right to allow visibility of oncoming through traffic.</p>  <p>Right turn lanes offset to the left. Note: opposing right turning vehicles will restrict visibility of oncoming through traffic.</p>
Application	All traffic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

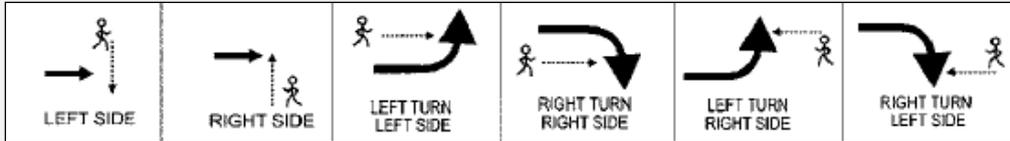
<p>Description</p>	<p>Typical measures:</p> <ul style="list-style-type: none"> • Provision of separate crossing phase without conflict with traffic. Can be pedestrian or shared with cycle crossing phase. • Provision of early start for pedestrians so they are visible to turning traffic. This is especially important where heavy vehicles turn. • Provision of pedestrian refuge islands where there is a large crossing distance or multiple lanes to cross. These refuges areas should have a signal call up button. • 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.  <p>Tactile paving at signalised crossing</p>
<p>Application</p>	<p>Where high urban pedestrian demand or where pedestrians are likely to cross high flow or speed signals (all environments).</p>
<p>Issues</p>	<p>Extended phase times necessary where children and elderly or mobility impaired are likely, resulting in increased traffic delay.</p>
<p>Crash reduction</p>	<ul style="list-style-type: none"> • 30% reduction in crashes. [4] • 20% at intersections with pedestrian-only phases [42] • No reduction at intersections with phases permitting conflicting pedestrian/vehicle movements (e.g. left turn or right turn filtering).[42]
<p>Other benefits</p>	<ul style="list-style-type: none"> • Higher level of service to pedestrians. [42] • Providing equal access to the road network for pedestrians with disabilities. [42]
<p>Cost</p>	<p>Low/medium</p>
<p>Treatment life</p>	<p>25 years</p>
<p>Applicable key high-risk crash movement types</p>	
<p>References</p>	<p>[4] [18][42]</p>

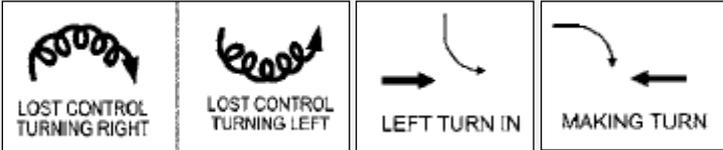
<p>Description</p>	<p>Typical measures:</p> <ul style="list-style-type: none"> • Hook turns for right-turning cyclists, particularly on multi-lane approaches. • Shared use cycle crossing – can be combined with hook turns. • Ensure refuge islands are of sufficient width for cyclists. • Advance cycle stop 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. <p>Other measures for consideration:</p> <ul style="list-style-type: none"> • Blindspot mirrors fixed to street furniture for left-turning trucks at intersections.  <p>Advance cycle stop line with approach lane and coloured surfacing. Note centrally located to remove conflict with left turning vehicles.</p>
<p>Application</p>	<p>Predominantly in urban/peri-urban areas or for crossing of high speed or high flow roads.</p>
<p>Issues</p>	<p>Facilities often require additional road space.</p> <p>Inadequate formal provision such as narrow cycle lanes and disjointed routes/failure to consider cycle routes as a whole can be counterproductive for safety.</p>
<p>Crash reduction</p>	<p>10-15% reduction in crashes for marked crossing at signals. [5]</p> <p>35% reduction in crashes for advanced cycle stop box. [5]</p>
<p>Other benefits</p>	
<p>Cost</p>	<p>Low/medium</p>
<p>Treatment life</p>	<p>25 years</p>
<p>Applicable key high-risk crash movement types</p>	
<p>References</p>	<p>[5][11]</p>

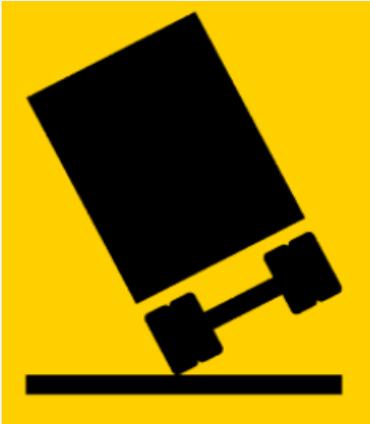
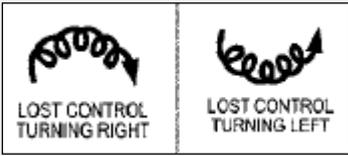
<p>Description</p>	<p>Typically a pair of curves on approach to a roundabout designed to reduce approach speeds.</p> 
<p>Application</p>	<p>Roundabouts with high speed approaches.</p>
<p>Issues</p>	<p>Additional road space required.</p> <p>Curves can result in trucks overrunning cycling space resulting in conflict.</p>
<p>Crash reduction</p>	<p>No current research, however, a reduction in approach and therefore through speeds significantly improves safety.</p>
<p>Other benefits</p>	
<p>Cost</p>	<p>High</p>
<p>Treatment life</p>	<p>25 years</p>
<p>Applicable key high-risk crash movement types</p>	
<p>References</p>	<p>[12]</p>

Description	<p>These include:</p> <ul style="list-style-type: none"> • 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	<p>Facilities often require additional road space.</p> <p>Curves can result in trucks overrunning cycling space resulting in conflict.</p>
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]

<p>Description</p>	<p>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.</p>  <p>Example of central lighting of roundabout. Source: Austroads.</p>
<p>Application</p>	<p>All roundabouts.</p>
<p>Issues</p>	<p>Ensure that the lighting/pole/lamp does not create a hazard if a collision occurs.</p>
<p>Crash reduction</p>	<p>40% reduction in injury crashes for improving lighting (all intersection forms). [3]</p>
<p>Other benefits</p>	<p>Enhance street scape.</p>
<p>Cost</p>	<p>Medium</p>
<p>Treatment life</p>	<p>25 years</p>
<p>Applicable key high-risk crash movement types</p>	
<p>References</p>	<p>[3]</p>

<p>Description</p>	<p>There are a number of considerations for improvement of pedestrian facilities at roundabouts including:</p> <ul style="list-style-type: none"> • ensure motor vehicle entry and exit speeds are well managed • the use of barriers to protect pedestrians from out of control vehicles – especially downstream of exits • use of kerb line protection devices (barriers, sight rails etc.) 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 on platforms may be considered provided speeds are less than 40km/h.  <p>Crossing point adjacent to roundabout</p>
<p>Application</p>	<p>All roundabouts where pedestrians are likely.</p>
<p>Issues</p>	<p>Raised tables may result in rear-end collisions on roundabout. Zebra crossings may lead to queuing into the roundabout.</p>
<p>Crash reduction</p>	<p>15% if raised pedestrian refuge island. [43] 20% if pedestrian fencing used. [44] 70% reduction in injury crashes for grade separation.</p>
<p>Other benefits</p>	<p>Use of kerb build-outs, platforms, fencing, refuges creates a narrowing effect and therefore reduction in overall speeds improving safety.</p>
<p>Cost</p>	<p>Low–medium</p>
<p>Treatment life</p>	<p>25 years</p>
<p>Applicable key high-risk crash movement types</p>	
<p>References</p>	<p>[43][44]</p>

Description	<p>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:</p> <ul style="list-style-type: none"> • ensure motor vehicle entry speeds are particularly well managed • provide cycle bypass or segregation (preferable in high speed environments) • ensure inter-visibility is equal, not excessive, uninterrupted to/from crossing point • grade separation • raised table across entry/exit (some urban situations only) • ensuring the refuges are wide enough to accommodate cycles.
Application	All roundabouts where cyclists are likely.
Issues	<ul style="list-style-type: none"> • 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. • Generally existing roundabout performance for cyclists is worse than signals, so where cyclists are present roundabout speed management must be best practice. [45]
Crash reduction	<p>Can cause increase in low severity crashes if not designed accordingly.</p> <p>Any improvements to roundabout designed to assist cyclists usually provide crash reductions for most road users.</p>
Other benefits	
Cost	Medium/high
Treatment life	25 years
Applicable key high-risk crash movement types	
References	[11][19][45]

Description	<p>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.</p> 
Application	<p>Where visual inspection of moving vehicles identifies lurching or rolling and particularly where losing control crash record.</p>
Issues	<ul style="list-style-type: none"> • 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 – so exit geometry should be easier than on entry.
Crash reduction	<p>No current research available.</p>
Other benefits	
Cost	<p>Medium/high</p>
Treatment life	<p>25 years</p>
Applicable key high-risk crash movement types	
References	<p>[10][11]</p>

Description	<p>Lighting intersections (whether flag lighting or full lighting), reduces the likelihood of a crash by an errant vehicle by improving the visibility of the intersections and other road users.</p>  <p>Source: [33]</p>
Application	All intersections.
Issues	<p>Street lighting provides an additional roadside hazard that can result in high severity crashes if installed incorrectly in high speed environments. An adequate clear zone needs to be provided and frangible designs used. Provision of guard railing (or other adequate protection) may be required in some environments. [33]</p> <p>The installation of street lights may cause problems with glare if installed incorrectly. Similarly, lighting 'pollution' may also be an issue in some circumstances. [33]</p> <p>Street lighting needs to be maintained, including clearance of vegetation, especially in urban environments. [33]</p>
Crash reduction	<p>40% reduction in injury crashes for improving lighting (all intersection forms). [3]</p> <p>Install lighting – intersections 50% of night time crashes. [33]</p> <p>Install lighting – rural intersection 40% of night time crashes. [33]</p> <p>Install lighting – urban intersection 20% of night time crashes. [33]</p> <p>Improve lighting – intersection 40% reduction in night time crashes. [33]</p>
Other benefits	Personal security, crime reduction
Cost	Low–medium
Treatment life	25 years
Applicable key high-risk crash movement types	All movements
References	[3], [33]

Collision severity mitigation

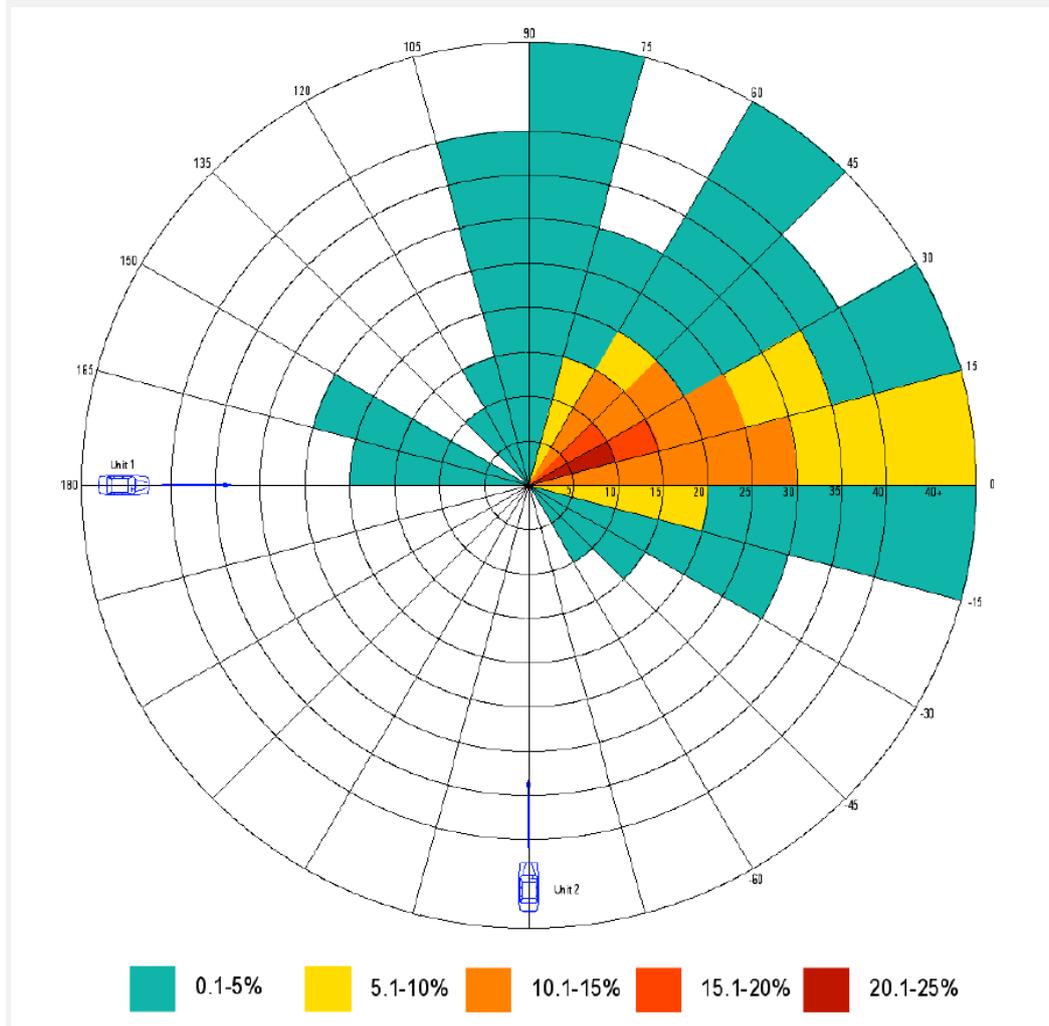
Clear or safe zones

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/or 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.

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

	<p>they do not present a serious collision risk</p> <ul style="list-style-type: none"> • use of frangible posts for signage, lighting columns and traffic signals or protect with a vehicle restraint system (VRS) or safety barrier.
Application	<p>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.</p> <p>Removal of unnecessary signing/objects – good practice in all locations.</p> <p>Use of weaker posts designed to yield on impact– good practice in all locations.</p> <p>Bending/ passively safe posts – generally good practice on roads with speeds of 80km/h and above. [8]</p> <p>Vehicle restraint systems – to protect from collision with immovable roadside objects or features.</p>
Issues	<p>Sign/signal siting – care needs to be taken when re-siting equipment that it meets the operational visibility requirements in order to be effective.</p> <p>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.</p> <p>Vehicle restraint systems – can present an issue for motorcyclists, additional protection may be necessary in high-risk locations.</p>
Crash reduction	<p>Widely acknowledged to reduce crash severity although overall number of crashes unlikely to reduce.</p> <p>30% reduction in injury crashes where frangible sign posts used. [5]</p>
Other benefits	
Cost	Low
Treatment life	10–15 years
Applicable key high-risk crash movement types	All movements where collision with a roadside object is possible.
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	<p>Speed cameras</p> <p>Where there is a particular history of excess speed which is either not treatable (or not responding) by other measures, speed cameras can be used for both the short term (interim) and long term.</p> <p>Red light cameras</p> <p>Red light cameras are one option to reduce related intersection crashes, but under a Safe System framework alternatives should be considered too. These include physical improvements to the intersection, understanding why people run red lights at particular intersections (eg it could be a problem with the phasing, poor visibility because of obstructions such as billboards, or just impatience), and raising awareness with road users. Red light cameras have safety benefits but we need to be sure they are the best and most cost-effective solution under different circumstances.</p>
Issues	<p>Speed cameras</p> <p>Potential to result in sudden braking if they are unexpected by drivers which has potential for rear-end crashes; however, as the number of HA type crashes reduces the overall severity is likely to reduce</p> <p>Red light camera</p> <p>Will only have an effect on the approach it is situated on.</p>
Crash reduction	<p>23% reduction in fatal and serious crashes at urban speed camera sites. [27]</p> <p>11% reduction in fatal and serious crashes at rural speed camera sites. [27]</p> <p>69% reduction in red light running crashes at red light camera sites. [28]</p>
Other benefits	
Cost	Medium
Treatment life	5–15 years
Applicable key high-risk crash movement types	Most crash movement types.
References	[5] [27] [28]