Guide to Road Safety Part 2

Safe Roads

Austroads

Guide to Road Safety Part 2: Safe Roads

Austroads

Sydney 2021

Guide to Road Safety Part 2: Safe Roads

First edition prepared by: Kenn Beer, Jamie Robertson, Thuan Nguyen, Fahim Zafar, Dr. Tana Tan, Ash Mani and Dr. Tom Beer

First edition project manager: James Holgate

Abstract

Austroads *Guide to Road Safety* has been developed to provide an overview of road safety and road safety practices in Australia and New Zealand.

Part 2 of the guide is designed to help practitioners minimise the risk of road crashes including run-off-road, intersection and head-on crashes and to implement countermeasures to achieve a safe road system.

The guide contains practical, hands-on advice to help practitioners investigate and treat locations on the road system which are experiencing crashes, including identifying crash locations, diagnosing the crash problem and its causes, selecting a countermeasure which targets the problem, designing a safe remedial treatment and establishing its cost-effectiveness.

The guide also provides information on sources of road crash data and how engineering improvements fit into an overall road safety strategy.

This guide is intended for road authorities and road safety practitioners to use when considering potential road safety infrastructure improvements and should be read in conjunction with all other parts of the *Guide to Road Safety*.

Keywords

Crash, countermeasures, evaluation, hazards, road crash, safety, site investigation, statistics, run-off-road, road safety, crashes, clear zone, delineation, signs, line markings, raised reflective and non-reflective pavement markers, guide posts, barriers, wire rope barriers, flexible barriers, non-rigid barriers, rigid barriers, roadside hazards, roadside hazard management, forgiving roadside, regional, remote, safe system

Edition 1.0 published July 2021

ISBN 978-1-922382-60-3

Austroads Project No. SAG6145

Austroads Publication No. AGRS02-21

Pages 242

Publisher

Austroads Ltd.
Level 9, 570 George Street
Sydney NSW 2000 Australia

Phone: +61 2 8265 3300

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

Acknowledgements

This guide re-uses material from the previous version of the *Guide to Road Safety Part 8: Treatment of Crash Locations*, *Guide to Road Safety Part 9: Roadside Hazard Management* and *Guide to Road Safety Part 5: Road Safety for Rural and Remote Areas*. Acknowledgements of contributions to these source documents are made to the project teams, Phil Allan, Michael Tziotis, Philip Roper, Melissa Watts, Lisa Wundersitz, Peter Palamara, Kate Brameld, James Thompson, Simon Raftery, Matthew Govorko, Colin Brodie, Blair Turner, Michael Tziotis, Paul Hiller, David Beck and Tariro Makwasha. The authors would also like to acknowledge the input of the Austroads Safety Task Force for their contributions to these documents and previous editions.

Contents

Tables

Figures

1. Introduction

This *Guide to Road Safety* has been structured to reflect the Safe System which has been adopted by Australia and New Zealand as part of their overall road safety strategy. The Guide consists of the following parts:

Table 1.1: Parts of the Guide to Road Safety

Part	Title	Content
Part 1	Introduction and the Safe System	An overview of the Austroads *Guide to Road Safety* and the Safe System philosophy.
Part 2	**Safe Roads**	**Guidance on safe road planning, design and operation.**
Part 3	Safe Speed	Guidance on the application of safe speeds.
Part 4	Safe People	Information on safe people and communities.
Part 5	Safe Vehicles	Information on safe vehicles and vehicle safety features.
Part 6	Managing Road Safety Audits	Guidance on the procurement, management and conduct of road safety audits.
Part 6A	Road Safety Auditing	Guides practitioners through the practical implementation of road safety audits. (Part 6 and 6A will be consolidated.)
Part 7	Road Safety Strategy and Management	Guidance on road safety strategies and road safety management.

The four pillars of the Safe System are reflected in this Guide through the aforementioned structure and also through the contents of the Guide. It is noted that each pillar does not stand on its own but, rather, interlinks with other pillars to form the Safe System (Figure 1.1). As such, readers of this Guide are encouraged to refer to multiple pillars when reading this Guide, even though this AGRS Part focusses on Safe Roads (Figure 1.2).

Figure 1.1: AGRS Part 2 to Part 5 interlink with each other

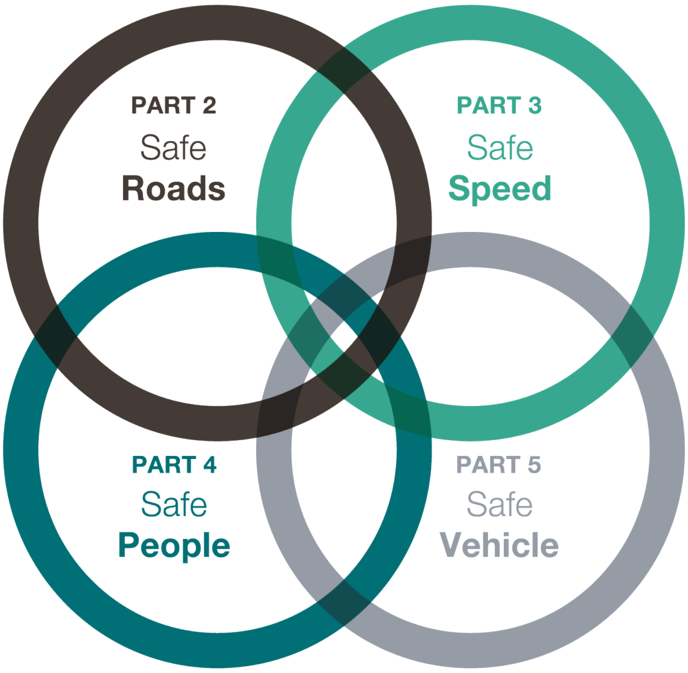
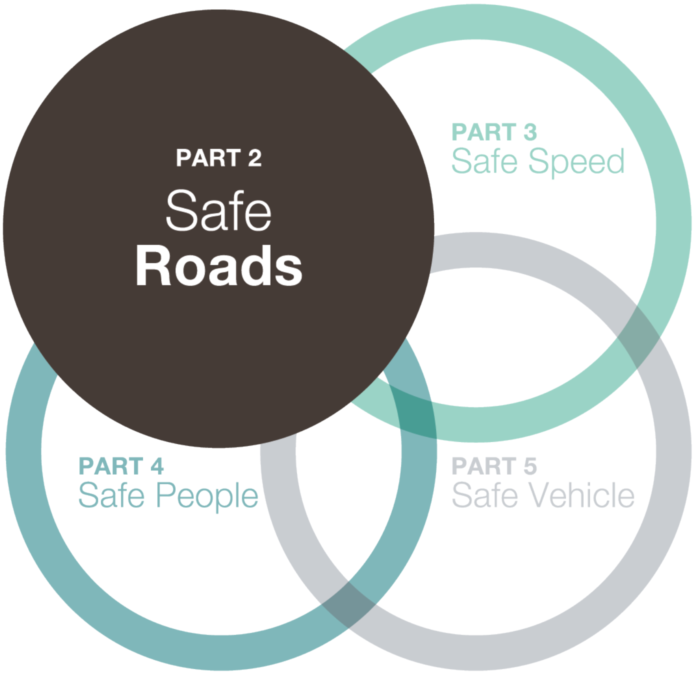


Figure 1.2: AGRS Part 2: Safe Roads



The *Guide to Road Safety*, in association with other key Austroads publications, will provide road safety practitioners with the knowledge and techniques that will enable the application of Safe System principles.

1.1 Purpose of the Guide

These guidelines specifically relate to the Safe Roads pillar of the Safe System. They are designed to help practitioners in road agencies ensure that road safety underpins the planning, design and management of their infrastructure assets. This includes proactive and systematic approaches to reducing death and serious injury, and the reactive treatment of locations on the road system which experience a 'high' number of casualty crashes. When these locations (i.e. intersections, routes or road segments and areas of road network) are effectively treated by applying the appropriate engineering solutions, the number and severity of the crashes can be reduced or, preferably, eliminated.

These guidelines provide an overview of contemporary research and practices associated with the Safe System approach to road safety, of which providing safe road infrastructure is an integral part. An explanation of the Safe System approach can be found in *Guide to Road Safety Part 1: Introduction and the Safe System* (Austroads 2021a).

The details of road safety processes and practices in road system management are presented in these guidelines. They are generally categorised into proactive and reactive methods to address road safety risk. Reactive approaches have been a longstanding, significant approach to road safety, historically referred to as 'blackspot' engineering, and falls within the crash investigation and prevention function of road agencies. To apply engineering treatments to a crash location, the causes of the crashes must first be identified and then an effective treatment can be applied. There is a step-by-step process for achieving this, described in Section 5. While reactive approaches to road safety management remain valid at specific locations of high crash numbers, there is inherent risk across most of the road network and to address this risk requires a proactive and systematic process. The principles, processes and tools for proactive road safety management are newer than those of reactive processes, however the emergence of road risk rating methodologies and tools has transformed the approaches to infrastructure investment. These proactive methods are detailed in Section 8 and Section 9 and further explained in Section 1.8 below.

1.2 Road Safety in the Road System Management Process

Road safety is an integral part of all phases of a road's lifecycle. From the early strategic planning through to construction and management of the roads, there are tool and resources available to ensure that best practice road safety underpins all aspects of the road system.

Figure 1.3 represents the road system management process from network and corridor planning through to network operations. It then identifies key tools and processes for road safety assurance and directs readers to the Austroads Guides that provide the details.

Figure 1.3: Road safety in the road system management process

Sections 1.3 to 1.7 below expand on the project phases and provide reference to additional Austroads research reports and other material.

1.3 Network and Corridor Planning

A road network comprises corridors, links (within a corridor) and places which are defined as follows:

- A corridor is defined as a major area of travel between two points. It may include more than one link and more than one form of transport.
- A link is a segment of road which forms part of a corridor and has homogenous characteristics relating to land use, urban or rural location, divided or undivided carriageways, geometry, speed limits and traffic volumes.
- A place is an area where people stay, play, connect, interact and congregate. Many of our public places have evolved around the road network and have fostered prosperity and identity through the road. However often the mix of traffic has undesired impacts.

A high level of alignment with Safe System principles can be achieved for each of these road segmentations but requires understanding of the categorisation of the area within a Movement and Place context and the risk profile of the area.

The Movement and Place Framework is being increasingly applied by jurisdictions to guide the development of a more integrated transport system. Better integration supports a range of customer and user group outcomes. The emergence of the Movement and Place concept has been driven by transport planners needing to give greater weighting to the multiple values of Place than in the past. Integration of Safe System principles and treatments within the Movement and Place concept will lead to environments that better cater for all road users thus, enabling lasting road safety benefits from the outset. Guidance for contextualising the Safe System in the Movement and Place Framework is documented in *Integrating Safe System with Movement and Place for Vulnerable Road Users* (Austroads 2020e).

An important part of the network design process is the identification of homogeneous sections of road infrastructure within a corridor (i.e. links) so that an appropriate risk profile can be established. Network safety planning is a newly formalised process of understanding risk throughout a corridor and determining appropriate and sustainable design standards. Guidance for network safety planning is documented in *Network Design and Road Safety (Stereotypes for Cross-sections and Intersections)* (Austroads 2020f).

1.4 Program Development

Road safety infrastructure investment programs are evolving from reactive programs, such as 'blackspot' programs, to proactive programs based on network safety planning, infrastructure risk profiling and mass action. Many tools are emerging to assist program developers and managers to maximise safety benefits from investments. Guidance for best practice in the development of road safety infrastructure programs can be found in *Best Practice in Road Safety Infrastructure Programs* (Austroads 2018b).

The Safe System assessment framework provides a systematic methodology for assessing and quantifying any infrastructure investment on its alignment with Safe System principles. Not only does this framework aid in ensuring safety infrastructure programs maximise safety benefits, it also provides a method for comparing options and investment scenarios in other infrastructure programs where safety is not the main driver (e.g. congestion easing or public transport programs). Guidance on undertaking Safe System assessments can be found in *Safe System Assessment Framework* (Austroads 2016b).

1.5 Project Scoping and Development

After the network and corridor planning and development of a program of works, the individual projects are scoped and planned. Following this, business cases may be developed for the works that may be contained within a larger program business case. In most cases the general treatment selection has taken place and the scoping, planning and designing refines the details of the project. These aforementioned steps should also consider the local context of the project. Road safety audits provide safety assurance during the design of these projects; however, the audit should refer to the network safety plans and Safe System assessments that underpinned the expected safety outcomes of the project. Guidance on managing and undertaking road safety audits undertaking can be found in *Guide to Road Safety Part 6: Managing Road Safety Audits* (Austroads 2019a) and *Part 6A: Implementing Road Safety Audits* (Austroads 2019b).

1.6 Project Implementation and Review

Safety assurance for both road workers and the travelling public during construction is achieved through a combination of occupational health and safety procedures, practices and regulations, and traffic management planning and implementation.

In 2019 Austroads published Edition 1.0 of the Guide to Temporary Traffic Management (AGTTM). The ten parts of the Guide detail contemporary temporary traffic management practice for application in Australia and New Zealand. It provides guidance for the planning, design and implementation of safe, economical and efficient temporary traffic management designs. Additionally, it recognises the level of variability of the road environments for which guidance is provided. The guidance is intended to encourage a consistent level of planning that supports the streamlined safe progress of work. It applies to all works on roads and near roads, in addition to off road development and other activities that interact with and impact on the road environment.

During construction and pre and post opening, road safety audits provide independent safety assessments.

Ensuring that safety benefits are realised from investments is a vital, but often missed, part of the lifecycle of a road. A sound evaluation program and framework should be an integral part of any road safety or other infrastructure program.

1.7 Network Operation

The operation of the road network consists of a wide variety of safety initiatives through infrastructure and via other elements of the Safe System. The management of traffic (vehicles, pedestrians and cyclists), the maintenance and upkeep of the roads and roadsides, and the road safety interventions at an operational level all interact to deliver safety outcomes on the roads.

The management of vehicle speeds via speed limits continues to be the subject of much contention; however, is acknowledged as a key element of achieving significant gains in the safety of the road network. Austroads Guide to Road Safety Part 3: Safe Speeds addresses many of the issues associated with speed limits and explores ways to achieve safe speeds and the complex interactions between infrastructure, vehicles and people.

Monitoring the safety situation on the network and addressing crash clusters and emerging risks continues to play an important role in achieving safe roads. Existing conditions road safety audits and road safety reviews are used alongside other road risk rating methods to address spot risks on the network.

A process for the assessment of benefits realisation completes the circle of safety within the lifecycle of a road. This provides the ability to assess lead and lag performance indicators and determine if the operation is aligned with the objectives set out in the Network and Corridor Planning.

1.8 How to Use this Guide

There are several ways to use this guide and they are presented below:

Reactive treatment of crash locations (explained further in Section 2)

1. If there is one problematic crash location which requires investigation and treatment:
   - refer to Section 2.4 to understand the steps in the process
   - refer to Sections 5.1 to 5.4 to diagnose the problem
   - refer to Section 5.5 to develop countermeasures
   - refer to Section 5.7 which discusses countermeasure designs
   - refer to Section 6 to determine countermeasure costs and benefits
   - refer to Section 8 which discusses problems, solutions and expenditure justification.

   A detailed case study is included in Appendix D.
2. If there is a need to set up a crash location treatment program (also known as a blackspot treatment program) covering a network of roads:
   - refer to Section 2.2 on developing a program
   - refer to Section 2.4 to understand the steps in the process
   - refer to Section 3 to determine which locations should be included in the program.
3. To assess the effectiveness of a treatment program:
   - refer to Section 2.4 to understand the steps in the process
   - refer to Section 7 on how to evaluate the effectiveness of treatment programs.
4. If the intention is to apply for blackspot treatment funding for a problem site:
   - perform the steps for Item 1, in particular, Section 2.4 to understand the steps in the process. Also refer to Section 6 to determine the costs and benefits of the countermeasure(s).
5. If there are several potential remedial projects and prioritisation methods are needed:
   - refer to Section 2.4 to understand the steps in the process
   - refer to Section 6 to determine the costs and benefits of each treatment, including Section 6.3 on task prioritisation.

For all the above cases, Section 1 and Section 3 provide background information which is also useful for understanding the processes described in Sections 4 to 8. The practical examples provided in Appendix C help explain how the step-by-step process in Section 2.4 works.

1.8.1 Proactive crash prevention

For new roadworks projects, or where there are known risks that have not yet translated to crashes, it is desirable to implement treatments that eliminate, or at least minimise, the potential for fatal and serious injuries due to road crashes. In these cases, road managers must take all reasonable steps to minimise the potential for harm to road users. Section 9 and Section 10 provide details and supporting evidence for contemporary measures to minimise harm as a result of intersection crashes and high speed lane departures respectively. It is noted that proactive crash prevention is discussed in more detail in Section 2.

2. Reactive and Proactive Road Safety Approaches

2.1 Risk Assessment and Management: Linking 'Reactive' and 'Proactive' Safety Approaches

Previous crash history, whether at points on the road, on routes, or across areas, has been used for many years to predict locations where crashes are most likely to happen in future. This approach is very useful where there are high concentrations of crashes. Over time there have been substantial improvements in safety, and in some cases the number of crash locations has decreased, making it harder to identify potential crash locations based on this information. In both Australia and New Zealand, the majority of crashes are estimated to occur outside what would traditionally be classified as 'blackspots'. Conversely, a large proportion of more serious crashes occur at locations where there is no existing crash history. As an example, in New Zealand 56% of fatal and serious crashes occur at locations on roads with no other injury crashes recorded in the previous five years (New Zealand Transport Agency 2013a). Particularly on lower volume roads, crash locations tend to be more scattered making it harder to identify the location for future potential crashes. This is especially the case when considering fatal and serious crash locations – the reduction of which is the key focus of the Safe System approach.

Methods for identifying potential crash locations have evolved with new approaches developed to complement the crash based, or 'reactive' approach. 'Proactive' tools and approaches are also used, and some of these do not rely on knowledge of crash locations to identify high risk locations. As an example, road safety review (or audit) of existing roads assesses risk, based on knowledge about the road and roadside factors that contribute to risk. These tools and approaches are important, as they are able to identify locations where there is a high risk of severe crash outcomes, and to address these before serious injury does occur.

Years of experience in crash analysis and treatment of crash locations has improved understanding of the road and roadside elements that contribute most to crash risk, and the amount that each of these elements contribute to that risk. For example, Austroads (2010a) provides information on road design elements and contributions to risk. Austroads (2012c) provides information on the effect of different infrastructure treatments on safety outcomes. This knowledge has led to the development of tools to identify risk locations, regardless of whether crash data is available. Programs such as the Road Safety Risk Manager, and the Australian and New Zealand Road Assessment Programs (i.e. AusRAP and kiwiRAP), can be used to identify and treat high risk locations before crashes occur (i.e. in a proactive manner) with estimates of risk based on road and roadside elements. Further tools are being developed in New Zealand (e.g. Urban KiwiRAP, SafetyNET and KAT – the KiwiRAP Assessment Tool).

The reactive and proactive approaches are often used in combination. As an example, for a rural route with high numbers of run-off-road crashes, it is desirable that all potential high severity locations be treated, regardless of whether crashes have happened there yet or not (the route-based approach is described in later sections of this guide). This is in contrast to a crash-based analysis that addresses just those points on the road where crashes have previously occurred. Equally risky locations (in terms of road and roadside features) should not be ignored. The benefits of reactive and proactive approaches are highlighted in Table 2.1.

Table 2.1: The contrast between proactive and reactive processes

Proactive Processes - Road Assessments	Reactive Processes - Crash Data Based
Relies on a valid assessment process, but does not require accurate crash data	Relies on valid crash data, including accurate location data and severity data
Is dependent on road features alone to predict crashes	Is able to accommodate crash history being affected behavioural factors as well as road features (such as proximity to a hotel, or a 'fatigue zone' some hours from a major city
Road engineering features may interact with safety levels of the vehicle mix to create undetected variations in crash risk and crash severity	Variations in crash risk and severity due to the vehicle fleet are accommodated through the use of actual crash data
May be applied to new or re-engineered roads	Can only be applied to a road after usage when crash data is available
Is independent of statistical variations in crash occurrence	May be vulnerable to variations in crash occurrences
Is seen as more closely connected to safe system principles	Not seen as closely connected to safe systems, since crashes must occur before this process can operate
Evaluations based on re-assessment of the road rely on the validity of the assessment method and its correspondence to crash risk	Evaluations may be placed by category shift and/or regression to the mean, though methods for reducing these risks exist (Elvik 2006; Job & Sakashita 2006)

Source: Austroads (2018a)

There is a growing realisation amongst road authorities that only using reactive approaches is no longer optimal for road safety and additional approaches are required to prioritize treatments and treatment locations. While reactive approaches can still be important where sufficient crash history exists, many prioritization identification processes are now combining both crash history and risk assessments based on network design attributes.

The Australian National Risk Assessment Model (ANRAM) combines the proactive approach with crash data to provide an objective assessment of potential risks (see Austroads 2014c).

This guide provides details of the processes used to identify and treat high risk locations based on crash data. Generally regarded as a reactive approach, the approach uses crash data to identify and address risk, but as in the example provided above on rural run-off-road crashes, this does not mean that a crash needs to have occurred at a specific location before improvements can be made.

There are strong linkages between reactive and proactive approaches, and this guide should be used in parallel to other parts of the Austroads guides in this series on risk assessment, particularly Part 6, Part 6A and Part 7 of the *Guide to Road Safety*.

Guide to Road Safety Part 6: Managing Road Safety Audits (Austroads 2019a) and *Part 6A: Implementing Road Safety Audits* (Austroads 2019b) deals with road safety in a proactive manner whereby potential safety problems are identified. Different stages of design audit are discussed (e.g. feasibility, preliminary design, detailed design, pre-opening) as are other types of audit (e.g. of road works, land use development, audits for different road user groups, and review of existing roads). The audit process is discussed, as are the procedures for responding to audit recommendations.

Guide to Road Safety Part 7: Road Safety Strategy and Management (Austroads 2021c) discusses road network crash risk assessment and management. The tools explained in that guide assist practitioners in:

- identifying and prioritising risks that require treatment
- comparing and assessing available treatment options
- monitoring and reviewing the treatment process to ensure that continual improvement is made.

Part 7 of the Guide provides case studies that give an overview of a range of risk based tools used in road safety across Australia, New Zealand and the UK. These tools include:

- Austroads Safe System Assessment Framework
- Queensland TMR and the LGAQ Roads Alliance Road Network Safety Assessment Tool
- AusRAP
- UK SafeNet
- New Zealand RISA
- Main Roads WA CRASHtool
- ALCAM.

Austroads (2016b) provides an assessment framework to help road agencies methodically consider Safe System objectives in road infrastructure projects. The framework allows practitioners to assess how closely road design and operation align with the Safe System objectives, and to identify elements that need to be modified to achieve closer alignment with Safe System objectives. The risk elements considered include road user exposure to risk (e.g. traffic volumes), likelihood of a crash, and the likely severity outcome in the event of a crash. The framework includes all four pillars of the system, including an assessment of issues relating to the road and travel speeds.

Safe System Assessments Some jurisdictions have developed guidelines which specify when a Safe System Assessment should be conducted and provide guidance on the assessment process. As a general rule, the larger or more complex a project is, the greater the need for such an assessment. It is also generally accepted that these assessments provide the greatest value when undertaken during the early stages of a project, when adjustments to the design and / or scope of the project are more readily accommodated.

2.2 Developing a Program to Address High Crash Risk Locations

Comprehensive programs to identify and treat high crash risk locations are required by all road agencies, whether at national, state or local government level. This also implies coordination between these different levels of government. Such programs should be undertaken in the context of Safe System objectives (see Section 2.3.2). When establishing such programs it is important to demonstrate the significance of the road safety problem (in terms of fatal and serious crash outcomes as well as the full impact on communities and economic well-being). It is also important to demonstrate that the problem can be addressed in a cost-effective manner. This includes the requirement to understand the benefits that targeted road infrastructure improvements can provide. With knowledge of these issues, a case can be developed to ensure appropriate investments are made in road infrastructure.

As discussed in Section 2, the response to crash risk will need to consider both proactive and reactive approaches. A mixture of both is typically used, although in situations where high severity crashes remain, but demonstrated crash locations (whether at points or along routes) are scarce, the reliance typically moves to more systemic safety improvements based on proactive risk-based approaches.

For any road agency, reducing crash risk requires a strategic approach, addressing different elements of a crash within their areas of responsibility. Local government, as well as being the local road agency, is responsible for a range of other activities into which road safety can be integrated. Similarly, many state road agencies are also responsible for activities like data collection, driver and vehicle registration and vehicle operation where good practices can enhance road safety. Further information on these broader issues, including the development of road safety strategies can be found in *Guide to Road Safety Part 7: Road Safety Strategy and Management* (Austroads 2021c).

As part of a treatment program, a clear process needs to be put in place to identify high risk locations, analyse the risk at these locations, select appropriate responses, prioritise these, and monitor and evaluate the outcomes from these efforts. This guide focuses on these aspects as they relate to existing high crash locations.

Along with the process for identifying and addressing risk, there are also institutional arrangements that need to be in place to assist in effective treatment of crash risk. This includes the availability of good quality road safety data (including crash data, which is of greatest relevance to this document). There is also a reliance on appropriately trained staff (whether inside road agencies, or outside). Although this document provides information on the appropriate processes to be undertaken when addressing risk, there is reliance at all stages on experts who will often be called upon to use their professional judgement. A well trained and experienced set of experts is required to ensure the success of the risk assessment and crash reduction process.

Several road agencies provide guidance for the development and administration of crash-based programs.

At national level in Australia, the Department of Infrastructure and Regional Development provides guidance through their website: (http://investment.infrastructure.gov.au/publications/administration/pdf/NoA_November_2014.pdf).

In New Zealand, the High Risk Rural Roads guide (http://www.New Zealand Transport Agency.govt.nz/resources/high-risk-rural-roads-guide/) and the High Risk Intersections guide (http://www.New Zealand Transport Agency.govt.nz/resources/high-risk-intersections-guide/) provide advice on program development. Other guides are available from the New Zealand Transport Agency website (e.g. Safer Journeys for Rural Schools, Safer Journeys for Motor Cycling on New Zealand Roads, Safer Journeys for People Who Cycle). These guides provide details of risk assessment, issues and treatments, program implementation and crash reduction results in the Safe System context.

Examples of state-based programs in Australia can be found below:

- New South Wales: http://www.rms.nsw.gov.au/business-industry/partners-suppliers/lgr/grant-programs/black-spots.html. Guidance from NSW is currently being revised and will be available from the Transport for NSW website when completed (http://www.transport.nsw.gov.au/)
- Victoria: https://www.vicroads.vic.gov.au/safety-and-road-rules/road-safety-programs/building-safer-roads
- Western Australia: https://www.mainroads.wa.gov.au/OurRoads/RoadSafety/BlackSpotProgram/Pages/approved_state.aspx
- South Australia: http://www.dpti.sa.gov.au/towardszerotogether/safer_roads/black_spot_program_2

2.3 Taking Action to Improve Road Safety

2.3.1 The countermeasure approach and the role of infrastructure

The cornerstone of an effective road safety program is that remedial treatments must target crash causation and/or severity factors. There are many possible countermeasures that could be applied to a particular safety problem including various engineering treatments (ranging in cost), speed management options, application of new technology or training and education. Packages of treatments are often the most effective way to address road safety risk.

Although the role of human error in road crashes is substantial, this knowledge can downplay the role that infrastructure has in achieving Safe System outcomes. Road infrastructure has a significant role to play in reducing the likelihood of a crash. However, when a crash occurs, road infrastructure has the most significant influence on the severity of a crash. For these reasons, improvements to infrastructure can contribute substantially to reductions in death and serious injury. However, this assumes that the treatments selected directly target the cause of the crash, or the severity of the outcome.

2.3.2 The Safe System approach

The Safe System approach recognises that humans are fallible and will continue to make mistakes on the roads. Additionally, humans can only withstand limited amounts of kinetic energy exchange when a crash occurs before death or serious injuries result. A 'System' is required to address the problems that encompass road users, vehicles, roads, speed and post-crash care solutions. These different 'pillars' of a Safe System are discussed in the *Guide to Road Safety Part 1: Introduction and the Safe System* (Austroads 2021a).

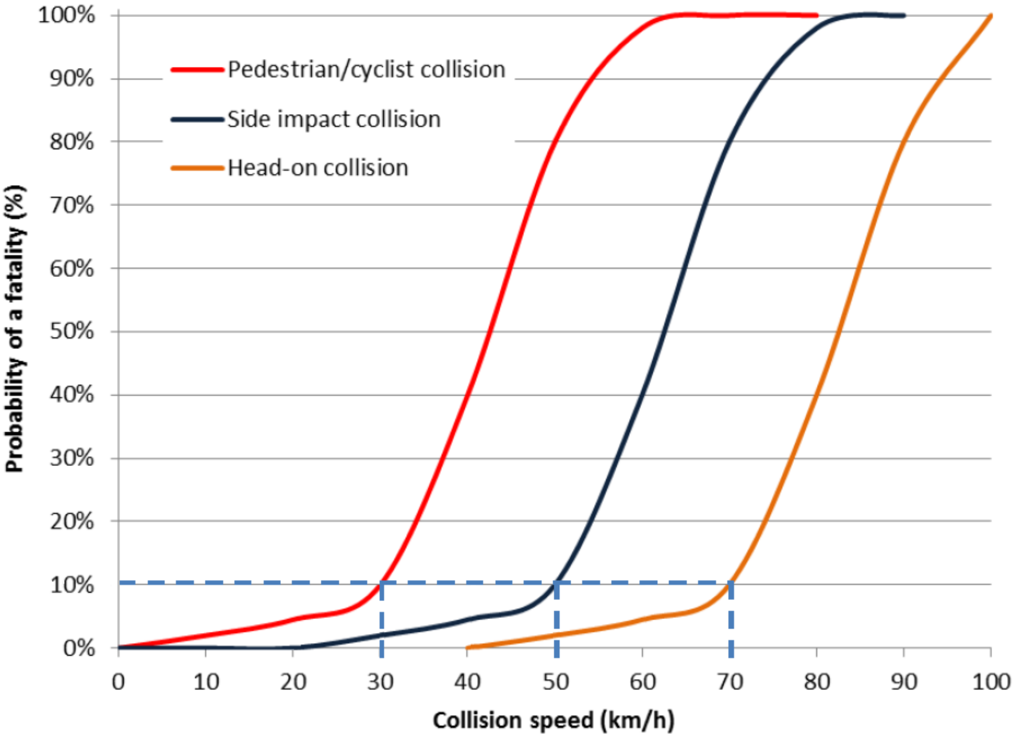
Appropriate infrastructure is required to take into account road user vulnerabilities and fallibilities in order to avoid death or serious injury should a crash occur. This System approach implies a shared responsibility for addressing fatal and serious crash outcomes. Road managers have a significant role in addressing these outcomes. It is not acceptable to blame the road user for a crash when there are infrastructure solutions that may be applied to help reduce this risk.

Haddon (1980) identified a systematic framework for road safety based on an epidemiological model. This comprises infrastructure, vehicles and users in pre-crash, in-crash and post-crash stages. An understanding of these phases permits possible countermeasures to be considered. Road safety engineering treatments can be applied to reduce the likelihood of a crash occurring in the first place (pre-crash) and secondly to reduce a crash's severity should it occur (crash). Thirdly, although to a lesser extent, road safety engineering can ensure that rescue services can reach a crash site promptly (post-crash).

Although it has been long understood that a priority is to address more severe crash outcomes, the Safe System brings this concept into further focus. The key objective of the Safe System approach is to address fatal and serious crash casualty outcomes. In some cases this has meant a re-shaping of how crash analysis is conducted, and how treatments are selected (including the types of treatments) to address risk.

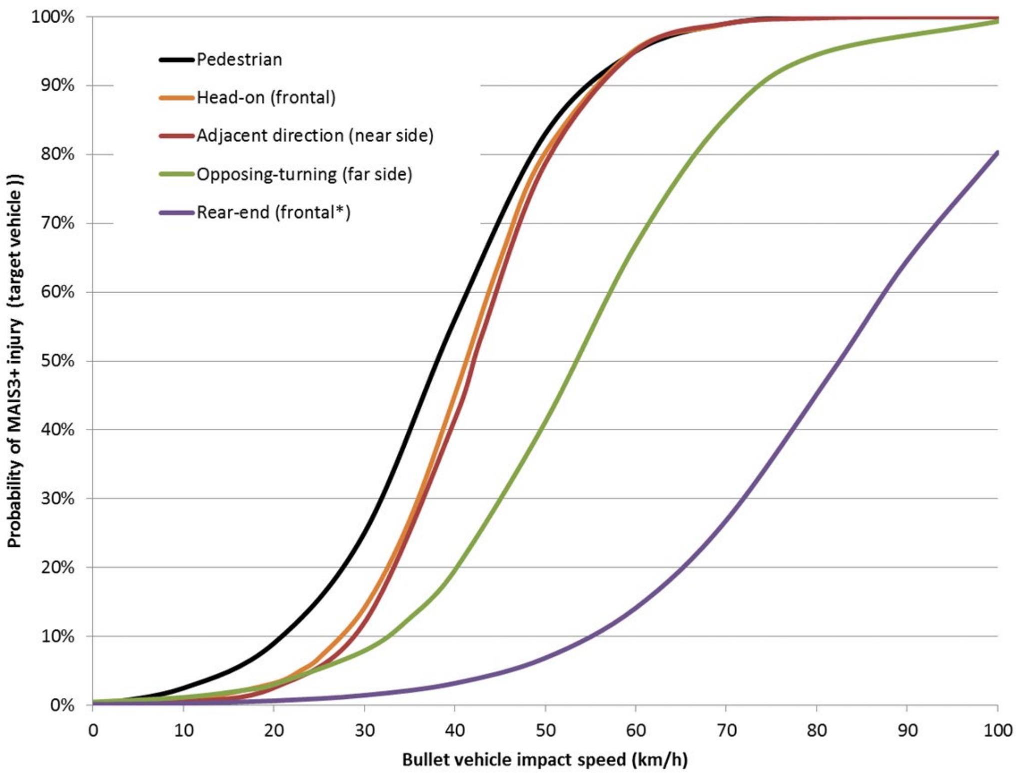
Safe speeds, which are integral to a Safe System, influence causation and play a major role in severity. *Guide to Road Safety Part 3: Safe Speed* (Austroads 2021b) provides detailed guidance on speed management. There is a strong relationship between safety outcomes for any given speed environment given the infrastructure that is also present, and the survival impact speeds for different crash types are reasonably well understood. This relationship is illustrated in Figure 2.1 for fatalities and Figure 2.2 for serious injuries. From Figure 2.1 it can be observed that at impact speeds above 30 km/h, the chance of survival following impact between vehicles and pedestrians reduces dramatically. The survival impact speed for side impact at intersections is 50 km/h, while that for head-on crashes is 70 km/h. Figure 2.2 shows that when considering serious injury in addition to fatality risk, the speed thresholds communicated by Figure 2.1 decrease. For example, the equivalent speeds to those shown previously become 20 km/h for pedestrians, 30 km/h for side impact (near side) and also 30 km/h for a head on collision. This strongly implies that if death and serious injury are to be eliminated, either infrastructure must be provided to prevent these crash types from happening (e.g. provision of median separation to prevent head-on crashes) or the speeds need to be reduced to these Safe System speeds (e.g. 70 km/h or lower where there is no median separation). This is the aspiration of the Safe System approach and should set a program framework for delivery of road safety infrastructure into the future.

Figure 2.1: Relationships between a motorised vehicle collision speed and probability of a fatality for different crash configurations



Source: Jurewicz et al. (2015) and based on Wramborg (2005)

Figure 2.2: Probability of serious injury versus bullet vehicle impact speed in different crash types



Source: Jurewicz et al. (2015)

2.3.3 Crash risk

As risk is the product of three elements: likelihood, exposure and severity, a road safety strategy must address all three elements. For a road agency these may include examples such as:

- Influencing the likelihood of a crash
  - applying sound traffic engineering and road safety engineering techniques in the development of new road designs and the treatment of known crash sites
  - modifying road user behaviour by appropriate design elements
  - using well targeted education and enforcement programs
  - applying appropriate speed management, including speed limits
  - independent auditing of proposed treatments
- Influencing the exposure to a crash
  - providing alternative, safer routes for vulnerable road users
  - promoting safer forms of transport in preference to less safe forms
- Influencing the severity of a crash
  - providing a more forgiving roadside environment (e.g. safety barriers)
  - providing appropriate speed management
  - providing good access for emergency services to reach crash sites.

It can be seen that the treatment of crash locations is just one element of a road safety strategy, but it is an important and potentially very cost-effective part. Further details on these issues can be found in *Guide to Road Safety Part 7: Road Safety Strategy and Management* (Austroads 2021c).

2.3.4 What is a crash location?

A crash location (sometimes called a blackspot or hazardous road location) may be:

- an individual site (e.g. an intersection or a bend in a road)
- a length of road (which could be e.g. urban or rural)
- an area of the road network (e.g. residential precinct, local traffic area or an entire suburb)
- locations across the road network which have a common hazardous feature (e.g. substandard guard fence end treatments) and/or crash type (e.g. pedestrians).

The prevalence of crashes at only some locations, and the clustering of crash types at a single location usually indicates that there are common causes for the crashes. It is the objective of crash location treatment to identify these common causes and to counter them by applying appropriate countermeasures.

As more individual sites are treated, the number of sites featuring crash clusters will continue to diminish. At a certain point, the number of fatal and serious injury (FSI) crashes occurring at a particular site cannot necessarily indicate a likelihood of a recurrence of similar crashes. At this point, the focus of road safety practitioners needs to shift to proactively treating high-risk sites and routes, including those that may not yet have a crash history but have potential for FSI crashes.

For instance, a large number of FSI crossover crashes occurring along a particular road could be easily addressed through the introduction of wire rope safety barriers along the median. There is a high likelihood that this treatment would reduce the occurrence and severity of this crash type.

2.3.5 Treating crash locations

The treatment of crash locations involves a step-by-step process, described in Section 2.4. Each of these steps needs to be followed. Further, resources need to be applied, firstly to provide the crash information on which all investigations are based, secondly to permit investigations and analysis to take place and thirdly to permit the identified problems to be treated. For example:

- A data collection and verification system and a crash positioning protocol are needed, so crash locations can be identified as accurately as possible.
- A comprehensive data base is needed, which includes details about a sufficient number of crashes and crash features, so that problem locations and common crash features can be identified.
- An appropriate criterion needs to be selected for defining ‘high’ crash locations. These criteria may vary as the number of ‘high’ crash locations are effectively treated. The criteria may also differ across programs funded by different levels of government (i.e. national, state and local).
- A thorough diagnosis of the crash problems at a location is needed, so that the correct conclusions may be drawn about contributing factors.
- Countermeasures need to be selected on the basis that they are known to be effective against the particular problems identified, so that the problems are resolved.
- Safe design principles and road safety audit need to be applied to countermeasure design, so that the countermeasure does not cause harm or result in new types of problems.
- An appropriate project ranking system is needed so that scarce resources can be applied effectively to a program of potential countermeasures.
- Monitoring and evaluation of the effectiveness of countermeasures at site, route or network level is needed to ensure that the targeted remedial treatments achieve their intended purpose, while also continuing to improve knowledge associated with the treatment of crash locations.

Implementation of Safe System involves first consideration of countermeasures which eliminate occurrence of fatal and serious injuries (primary solutions). In some situations, such options will not be feasible due to project constraints dictated by budget, site, conflicting road user needs, or the environment. If so, the next safest project-feasible solution needs to be identified (supporting solutions). This process requires a clear Safe System-based hierarchy of solutions. Section 9 and Section 10 provide treatment hierarchies for intersection crashes and lane departure crashes respectively.

2.3.6 Who should investigate crash locations and develop solutions?

Most of the steps in the crash location treatment process summarised in Section 2.4 and detailed in in Sections 4 to 8 can be undertaken by a practitioner with an analytical mind who has had training and experience in an engineering or scientific field. However, the following steps will require the inclusion of someone who also has road safety engineering skills and experience:

- inspecting the crash location (Section 5.3)
- drawing conclusions from the crash data and site inspection (Section 5.4)
- selecting countermeasures which address the factors leading to the types of crashes which are happening (Section 5.5).

It is also better at these stages of the process to use a team (ideally two to five people), rather than one person. The benefits of having a multi-member team include:

- the diverse backgrounds and different approaches of different people
- the cross-fertilisation of ideas which can result from discussions
- simply having extra sets of eyes/different perspectives of each member.

The types of skills and experience which should be considered for a crash location study team include:

- someone experienced in road safety engineering (essential)
- someone with local knowledge (e.g. a state road agency or local government engineer involved with traffic management)
- emergency services personnel (typically a serving traffic police officer) who has experience in traffic and safety and who is familiar with the location
- someone involved with the behavioural aspects of road safety.

2.3.7 What are road safety engineering skills?

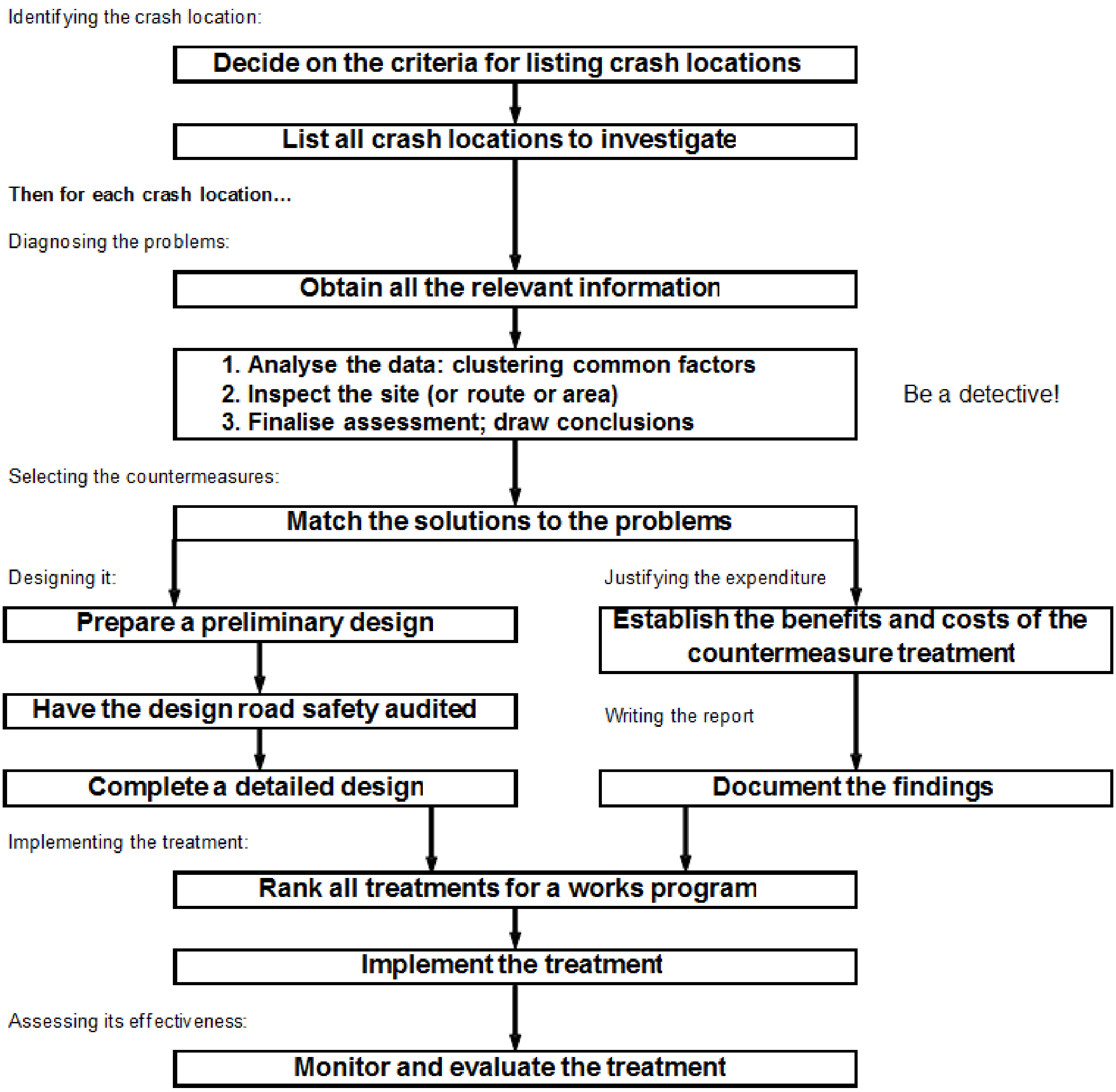
A road safety engineer may be described as a practitioner with:

- sound knowledge in traffic engineering and road design practice
- an appreciation of road user behaviour and the contribution it makes to road crashes
- competency in crash investigation (i.e. crash data analysis, and identification of crash causation and severity factors), and countermeasure development (i.e. identification of targeted cost-effective remedial treatments)
- competency in monitoring and evaluation methods.

2.4 Steps in the Crash Location Treatment Process

The treatment of crash locations should be a methodical, step-by-step process. The steps are illustrated in Figure 2.3, briefly outlined in this section and further explained in the following sections of this guide.

Figure 2.3: The steps in treating crash locations



2.4.1 The steps

1. Decide on the criteria for listing crash locations (Section 4)

   Define the physical limits of individual locations, so that sections with similar characteristics are considered together. Decide on the time period over which crash patterns are to be investigated. All sites need to be compared using an agreed selection criterion. The preferred criterion is 'cost of crashes by crash type' rather than a number of or rate of crashes. If necessary, select a crash threshold, above which locations will be considered for inclusion as crash locations.

2. List all crash locations to investigate (Section 4)

   Examine the information in the crash data base to identify locations which meet the definition of crash location. Establish the cost of crashes at each location, over the agreed time period. Make a list of all the locations which meet the minimum cost threshold selected. Ensure that locations are sensibly defined, so that no location worthy of investigation is missed through being subdivided in the data. Plan ahead for later monitoring.

   Having identified all the sites worthy of investigation, each one should be examined in a step-by-step fashion to identify the factors leading to crashes, develop solutions and organise having those solutions implemented, as set out below:

   Then, for each crash location:

3. Obtain all the relevant information (Section 5)

   Obtain the crash data for the location. Be aware of the limitations on the availability and accuracy of crash data. Obtain other information such as traffic volumes, recent changes in the road network or traffic generating land uses, and any documented concerns about safety at the location.

4. Diagnose the problems (Section 5.4)

   This is a three step process:

   a. analyse the crash data (including crash rates and densities) for any clustering by common crash types or factors such as common approach legs, common weather or daylight, common age of those involved, etc. Construct a factor matrix and draw a collision diagram. Is examination of the original crash report forms warranted?

   b. inspect the site from the perspective of the involved road users, as well as undertaking a close-up examination of the site's features and its users' behaviour.

   c. make any other investigations, then draw conclusions about the likely causes of crashes for which there are common factors. There may be other types of contributing factors (e.g. speeding),but focus on what it is about the road or traffic environment which is leading to crashes.

5. Select the countermeasures (Section 5.5)

   Match the solutions to the problems. The selection of countermeasures will consider the particular crash types which have been identified in the diagnosis phase (Section 4) and which are amenable to treatment with road or traffic engineering measures. Select the countermeasure(s) and take account of the crash modification factors for each countermeasure. Consideration should also be given to the prevention of other types of crashes which could result in death or serious injury. Preference should always be given to the use of "primary" Safe System treatments (i.e. those which virtually eliminate the risk of death or serious injury due to a particular crash type) ahead of "supporting" treatments (which typically address the likelihood of crashes only).

6. Prepare a preliminary design (Section 5.7.1)

   A preliminary design is required, so that its practicality can be confirmed and the cost of the remedial treatment can be estimated. The design should be subjected to a review process which may include a Safe System Assessment (if one is warranted, and has not been undertaken at an earlier stage) and/or a Road Safety Audit. Prior to implementing the project, the design needs to be finalised, taking account of any recommendations of the review process.

7. Establish the benefits and costs (Section 6)

   Undertake an economic appraisal. Establish the costs (i.e. the initial design and construction costs only) and the benefits (including reductions in crash costs by crash type). Decide whether to use net present value (NPV), benefit/cost ratio (BCR) or another appropriate metric. Conduct sensitivity testing.

8. Document the findings (Section 8)

   Draw together the documentation which has been undertaken through Steps 3 to 7 and set it out in a format which allows this project to be assessed against other potentially worthy crash countermeasure projects.

9. If there are several locations to treat - rank all treatments (Section 6.3)

   Compare all projects' NPV or BCR. An alternative 'goals achievement approach' can be used, whereby projects are ranked but no attempt is made to assess their economic benefits against their costs. These formalised forms of appraisal are simply an aid for decision making. They should not be the only criterion for selecting safety improvement projects and their numerical answers should not be a replacement for sound decision making.

10. Implement the treatment (Section 5.7.2)

    Once the countermeasure treatment has obtained funding it can be installed. It is important that the design which is being implemented accords with the results of the crash investigation. During the implementation phase, traffic safety will continue to be important. Once the works have been completed, the project should (where feasible) be the subject of a pre-opening road safety audit.

11. Monitor the treatment and evaluate its effectiveness (Section 7)

    Monitoring is the systematic collection of data about the performance of road safety treatments after their implementation. Evaluation is the statistical analysis of that data to assess the extent to which the treatment (or a wider treatment program) has met crash reduction objectives. These tasks are important to ascertain the positive and negative effects of a treatment and thus improve the accuracy and confidence of predictions of that treatment's effectiveness in subsequent applications. It may take a number of years to collect sufficient data.

These 11 steps are described in detail in Sections 4 to 8.

3. Road Crash Data

The process of accurately investigating, analysing and effectively treating crash locations relies on the use of comprehensive and accurate crash data and data related to the road and traffic characteristics at the crash locations.

Comprehensive and accurate data enables the:

- crash locations to be accurately determined
- events associated with crashes to be identified
- identification of crash contribution and severity factors, thus providing the basis for selecting targeted remedial treatment options
- identification of common factors across a number of crashes
- cost consequences of a single crash, all crashes at one location or several crashes with common factors to be identified
- crash sites to be ranked so that treatment can be applied to those sites that will derive the greatest safety benefits.

3.1 Data Sources and Codes

There is a minimum set of data about each crash which is necessary as a basis for the sound and satisfactory identification and investigation of a crash location. Although all states and territories in Australia have agreed to work towards a minimum common dataset there are a number of differences between jurisdictions. A reasonable knowledge of crash data definitions and limitations is required to accurately interpret this information in any given jurisdiction.

All jurisdictions have requirements for reporting casualty crashes to the police (i.e. fatal and injury crashes must be reported). At the other end of the severity scale, some jurisdictions require property damage (non-injury) crashes to be reported. There is a high level of reporting of the most severe injury crashes and a lower level and variable amount of reporting of lower cost crashes.

From a road safety perspective casualty data is the key indicator of the road safety problem. More recently, and in close alignment to Safe System principles and objectives, fatal and serious injury crashes and casualties are used as road safety key performance indicators. Lower severity outcomes as well as property damage data (where this is available) can provide valuable additional data that can support proposed countermeasure treatments.

The different crash severities are generally defined as follows:

- fatal crashes (one or more persons killed or died within 30 days)
- serious injury crashes (one or more persons admitted to hospital, although this is more typically based on whether a person was injured and taken by ambulance to hospital)
- minor injury crashes (one or more persons injured who is not admitted to hospital, although this is more typically based on a person not being taken by ambulance to hospital but requiring medical treatment)
- non-injury crashes above threshold values which may vary across jurisdiction, plus those where the property owner is not present.

3.2 Sources of Crash Data

Road crash information is used by a wide variety of people for a wide variety of purposes including:

- road safety practitioners, for developing remedial or pro-active road and traffic measures
- police, who may be investigating whether they will charge a person with a criminal offence in relation to a specific crash
- hospitals and health centres to monitor their health service requirements
- lawyers acting for clients in civil litigation, especially compensation for injuries and other losses
- insurers, seeking facts before settling an insurance claim
- those with responsibility for road safety education and publicity, to ensure that their efforts are well-targeted
- media
- police, in relation to enforcement activities, such as establishing the location for speed cameras or breath testing stations
- safety administrators, exercising a duty to report statistical information on road crashes
- researchers, who need access to an accurate, reliable data base in order to conduct rigorous research projects
- vehicle and component manufacturers and suppliers of highway materials, who wish to assess the safety of their product, perhaps from a viewpoint of litigation, marketing or product enhancement.

As the primary purposes for data collection within different organisations vary, the information collected, the way in which data bases are established, the opportunities for data aggregation and analysis, and interpretation of information will vary; the opportunities to supplement information on one data base with information from another will be severely limited. For example, the data base of a motor vehicle insurance company may not code crash location by a numerical geographic system, as this information is peripheral to concerns of insurance claim assessment and financial management. The total information on the data base is then not in a format which can be used by someone seeking information about the safety performance of a particular location.

3.2.1 Primary data sources for crash reduction programs

The primary source of road crash information across Australia and New Zealand is the police crash report form. In Australia, each state and territory has its own report form and it is usual for every crash attended by a police officer to result in a report form being generated. There are guidelines or directives about which crashes should be attended by the police. In general police will attend any crash involving a fatality or serious injury. However, often these crash outcomes are only known after the event, so police will sometimes attend relatively minor crashes and (less often) will not attend some serious crashes.

In most jurisdictions the facility exists for the generation of a crash report form for crashes not attended by the police, e.g. with a crash being reported at a police station. This form can be different in format and less detailed than the form filled out by an attending police officer.

The information on both these forms is usually entered into a police data base and a copy given to the road agency to be entered into the agency's data base along with additional road information (so long as it meets the coding criteria). In New Zealand, the Crash Analysis System (CAS) data base is managed by a central government organisation and made available on-line to any organisation or individual with a user licence. The primary sources of information are thus:

- the road agency/New Zealand data base (which is the most commonly used information and which is usually in an electronic form which permits data manipulation)

- the police data base
- the police report form (which can provide a greater amount of detail regarding the crash circumstances, for detailed analysis of individual sites; reference to police crash report form details is usually necessary if a collision diagram is to be prepared).

3.2.2 Other data sources

Traffic data, such as traffic volumes (including turning volumes), pedestrian flows and vehicle speeds may be helpful, depending upon the particular circumstances and problems at the site. In some cases these will be available, but in other cases they may need to be collected.

Hospitals record the causes of injuries as well as their nature, extent and treatment. Crash data sourced from police information may indicate whether someone was taken by ambulance or not, but typically does not give information as to whether that person was hospitalised, for how long, or whether the injuries sustained resulted in long-term impairment. With advances in technology, and greater collaboration between agencies, it is possible to link this information together, allowing for road safety treatments to be focused on those resulting in the most debilitating injuries.

In special circumstances, provided confidentiality of patient information is secure, hospital data may be made available for research purposes. This has been done with good effect in the development of countermeasures to reduce the severity of road crash injuries.

Insurance companies require claimants against policies to provide a description of the circumstances in which the loss, damage or injury occurred. This information is not usually released, although it has been released as consolidated data by some insurers. It provides a potential for establishing the true extent of lower cost crashes which are not reported to the police. Unfortunately it is generally not in a form which is compatible with the needs of crash location analysis and treatment.

A further source of information on crash occurrences is tow truck operators' records, although there is no system in place for collecting this information.

From time to time **in-depth crash studies** are undertaken into the nature and causes of crashes in a particular area. These studies are costly to undertake and involve specialist teams attending crash scenes and taking measurements and recording crash features. The results are usually published in special reports.

Local knowledge is an important source of information about safety problems on the road network. Subjective information about crash problems must be regarded cautiously, but it can be a pointer to problems or prompt further investigation. Information sources can include local residents, businesses, safety groups, emergency service personnel, local medical practitioners, maintenance contractors and local authority staff.

Interviews with road users, including people who have been involved in a crash at a site of interest, in a structured format have been used by some traffic authorities to gain information for the development of crash countermeasures.

Traffic conflict surveys may be used where the collection of crash data is not practical. These involve field observations or video recording of conflicts (near misses).

Coroners' reports can be a useful source of additional information concerning specific fatal crashes.

Site investigations are a necessary component of any countermeasure development program and will often yield insights into the crash history at a site.

Speed survey data also provides a source of information regarding speeding behaviour.

3.3 Technology Available for Data Collection

Computer based technology is being developed in two significant ways to improve the accuracy of data collection.

3.3.1 To improve the accuracy of location information

Global positioning systems (GPS) or satellite navigation systems are being used by most authorities for accurate determination of a crash location. The person attending the crash scene uses the system instead of, or as well as, documenting the location in traditional terms (ABC Road, xx metres N/S/E/W of XYZ Street). This method has great potential in rural areas where recording of the distance and direction to identifiable features can be subject to significant error.

All authorities now use a geographical information system (GIS) or digital mapping to record crash locations. This permits crash data to be incorporated within a relational data base, allowing crash sites to be overlaid on plans showing other geographical information such as highway features, traffic flows, intersection layouts and land uses.

New technology makes the initial collection and assessment of safety-related data easier and more useful. As an example, in Main Roads Western Australia, the crash investigation team has recently begun using video to assist in fatal and serious crash investigations. The video camera used records GPS information and has a viewer that overlays all route information on the video display. This assists in the completion of initial crash investigations. Furthermore, research is currently underway on incorporating inventory data e.g. road geometry data and crash data with the video information. This is to assist high risk crash route assessments for the identification of proposed crash mitigation measures. This research is in its early stages of development.

3.3.2 To improve the accuracy and completeness of crash data

Menu-driven crash data capture programs can be used with laptop computers or tablets by police attending a crash to ensure that all desired information is collected at the site. These programs can include in-built logic and consistency checks on the data as it is entered.

Crash report forms can be arranged so that the information can be scanned into the data base, to minimise costs and to reduce the opportunity for coding errors.

3.4 Limitations and Accuracy of Crash Data

It is crucial that practitioners using road crash data understand the limitations of the data and take steps to resolve any anomalies which may occur. The limitations include:

Under-reporting of crash data – although significant attempts are made to collect and record all relevant crash data, not all non-fatal crashes make their way to the relevant crash data base. Surveys conducted in New Zealand and in some Australian states have tried to compare data from crash data bases with information from hospital admissions and other sources. Information from New Zealand indicates only around 60% of serious crashes make it to the crash data base, with the percentage significantly less for minor injury crashes (Alsop & Langley 2001). Australian based research has also identified similar under-reporting of injury crashes (Cercarelli 1998). A review conducted for Austroads identified that reporting rates also varied by type of crash. For example, reporting rates were lower for cyclists, pedestrians and motorcyclists.

Systematic reporting bias – this bias can result from the regulations or policies covering the reporting of crashes. Reporting criteria vary between jurisdictions, resulting in crash experience not being comparable. Numerically, property damage (non-injury) crashes constitute the bulk of crashes: there may be as many as forty-one non-injury crashes for every casualty crash (James 1983). However, in some jurisdictions they are not reported, or are not recorded in the data base. This results in an incomplete and systematically biased crash picture.

Random reporting bias – Crashes involving children, cyclists, pedestrians and minor injury are substantially under-reported (James 1991). A similar situation applies to crashes involving illegal activity, such as under-age driving, driving while intoxicated, riding a motorcycle exceeding regulated capacity and carrying a pillion passenger when not permitted to do so by regulation.

Further, it is common for some human factors (e.g. alcohol and drugs) and roadway factors (e.g. the presence of a roadside culvert) not to be recorded. The absence of this information on the crash report form may mean the absence of the factor or the failure to record it. Erroneous conclusions can be made from the wrong interpretation of this absence of data.

Subjective bias – some crash forms require an assessment of possible contributing causes of the crash. This in itself adds a subjective element, as the range of possible responses to the question will be affected by the recorder's experiences and the purposes (other than crash recording) to which the information may be put. For example 'failure to give way' may be seen as a cause by someone regularly involved in traffic law enforcement, whereas the same situation may be seen as 'control device not visible' by someone regularly involved with road environment safety. One examination of the frequency of reported causes revealed distinct differences between police districts (Vincent 1996). Similarly, speed and fatigue are not typically based on direct observation.

Reporting errors – it is important to recognise the circumstances under which a police officer obtains information to complete a crash report. There will often be more pressing matters at a crash scene. The officer may not have local knowledge or adequate training in incident investigation, so some data items may be inadequately or wrongly recorded. Crashes do not always fit 'standard' formats and there may not be the motivation to fill in the form.

Coding errors – these can occur throughout the process from filling out the crash report form to the data entry at the computer terminal. It is estimated that errors of this type are present in 5% of crash files (Ogden 1996). They are unlikely to be revealed unless the data are used for detailed investigation at individual sites. Typical problems include wrong direction for the north point, wrong direction for one of two vehicle movements, selecting the wrong road user movement (DCA code), for example 'rear-end' instead of 'rear end into right turner', and numerical coding errors.

Location errors – the location may be imprecise or wrong in the original police report form and this will be carried through into the data base. If this continues through into coding, crashes at one location may appear in two separate parts of the crash data base. The location reference system may also be imprecise, so that a user of the data may not be able to accurately determine the location (e.g. all mid-block crashes may be recorded as being half way between the adjacent intersections).

Discontinuities over time – definitions or interpretations of field data may be changed over time by those responsible for coding and reporting, so that data from one time period cannot be compared with that of another. An abrupt change in recorded crash experience at a site should lead an analyst to enquire whether there has been any discontinuity of this kind.

Delays – agencies responsible for data processing may not be sufficiently resourced: it may be many months before information is available for analysis. Data may only be released annually. This means that countermeasure development may be responding to historical crash patterns which may be out of date.

Masked or hidden problems – it may be the case that a location is perceived as being so dangerous that people avoid using it. In this situation the safety problem results in a reduction of amenity (e.g. as pedestrians choose to cross the road somewhere regarded as safer) rather than resulting in crashes. The use of the other data sources outlined in Section 3.2 can help overcome this kind of data limitation.

3.4.1 Coding of crash types – DCAs, RUMs and VMCs

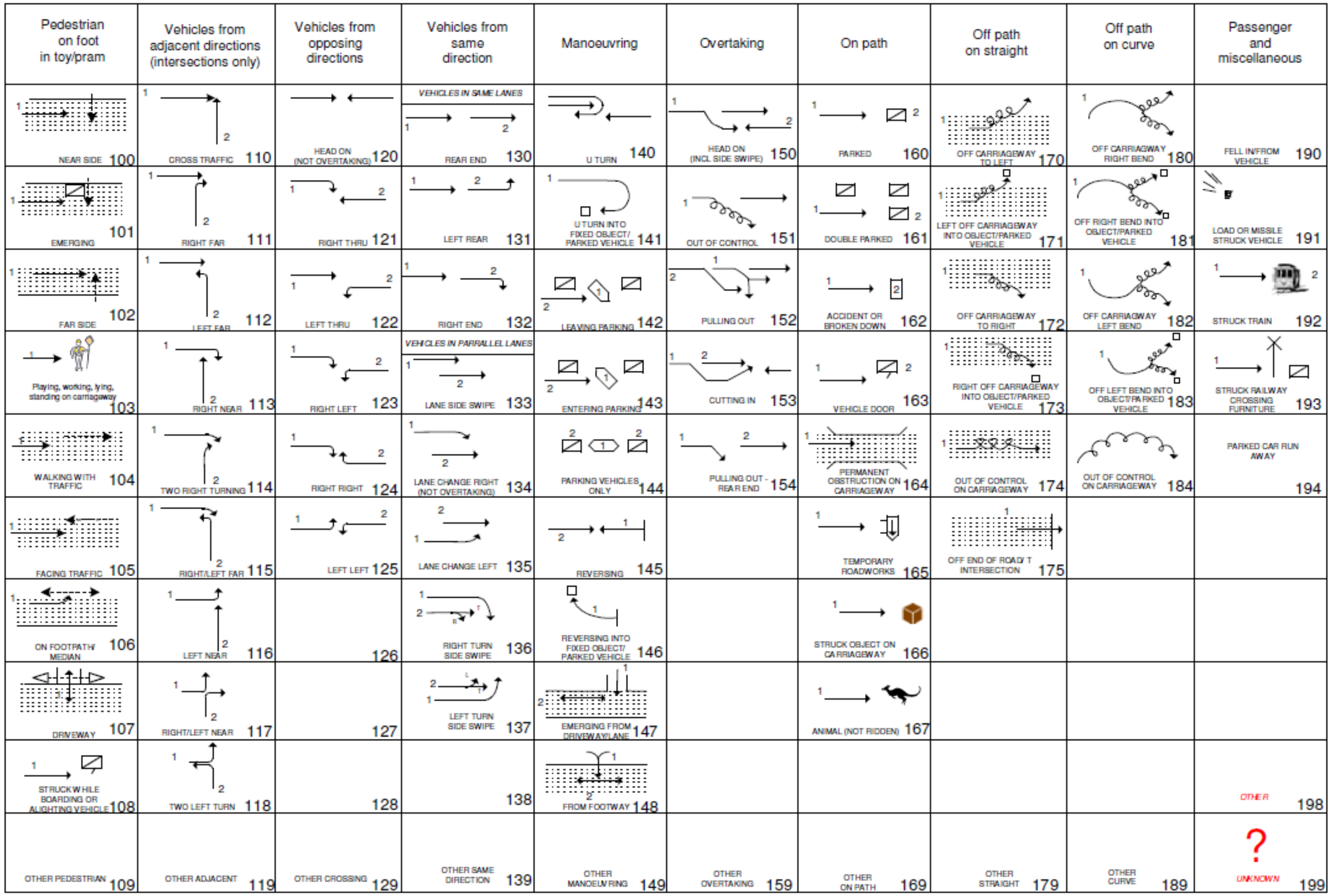
One of the basic tools for understanding what happened during a crash is the road user movement or crash type (originally referred to as the RUM code when introduced in Victoria in 1968). These now often go under the name of DCA Codes in Australia or VMCs (Vehicle Movement Code) in New Zealand.

Standard tables for Australian DCA codes are set out in Figure 3.1 and for New Zealand VMCs are shown in Figure 3.2, while the crash codes for each Australian jurisdiction are provided in Appendix A.

During the coding of information from the crash report form, each crash is given a DCA code indicating the movements the involved road users were making when the crash occurred based on the established codes used by that particular road jurisdiction. For example, a crash involving a right-turning vehicle colliding with an oncoming vehicle will be given a specific DCA code.

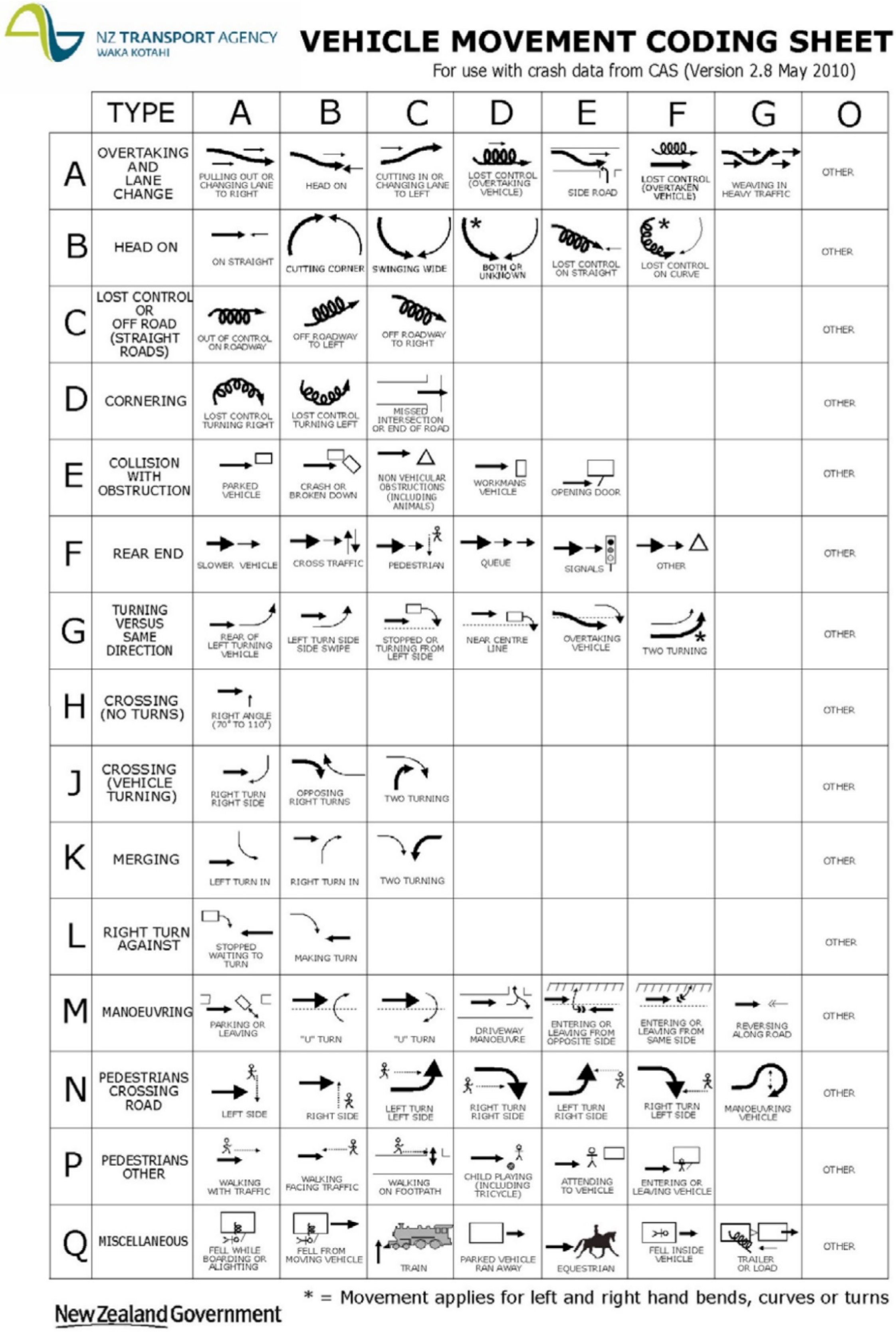
Figure 3.1 and Figure 3.2 show that the codes are grouped according to similar factors. For example, all the pedestrian crashes will have similar DCA codes. Through the use of DCA codes, an analyst is quickly able to identify any crash pattern at a particular location (which may suggest a common contributing factor and common treatment). This use of DCA codes is discussed in Section 5.1.

Figure 3.1: Standard accident-type codes for definitions for coding accidents (DCAs) in Australia



Source: Andreassen (1991)

Figure 3.2: Standard vehicular movement codes (VMCs) used in New Zealand



Source: New Zealand Transport Agency (2004)

4. Identifying Crash Locations

The crash location treatment process can be applied to individual sites, to routes and to areas (i.e. a network of roads) where crash clusters occur. As more crash locations are treated, identifying further sites for improvement can become more difficult, particularly with the ultimate objective of eliminating fatal and serious injury outcomes. In some areas the numbers of fatal and serious crashes are too low be used as a metric to assess risk or undertake a crash reduction study. There are various responses to this challenge, including lowering threshold levels (as discussed in Section 4.1.3), although this can only occur to a certain point. An alternative metric that has been adopted in some jurisdictions (e.g. New Zealand) is the use of DSI casualty equivalents (see Section 6.7). Other responses include greater use of route or area-based approaches and taking a broader risk assessment approach, including a mixture of reactive and proactive approaches. For information on more proactive solutions refer to *Guide to Road Safety Part 6: Managing Road Safety Audits (*Austroads 2019a) and *Part 7: Road Safety Strategy and Management* (Austroads 2021c)

4.1 Defining the Locations

Intersections are typically defined as the area bounded by the projections of the property boundaries, plus 10 m of the approach roads. Crashes occurring within this area are classified as intersection crashes and all others as mid-block crashes. However, some crash types (e.g. rear end or lane change crashes resulting from traffic control at an intersection) can occur much farther away than 10 m. These should be included in the investigation of the intersection.

In urban areas with frequent minor intersections on arterial roads, individual mid-block sections and minor intersections may need to be grouped together into a complete route length between major intersections. If this type of grouping is not undertaken, the fragmentation of crash information in the data base may hide a serious crash problem along a route.

When subdividing a route into sections, bear in mind that (Ogden 1996):

- Roadway and traffic characteristics should be fairly uniform within the section.
- The section length should be in keeping with the level of precision and degree of error in reporting crash locations.
- Statistical reliability should be maintained.

Regarding the last point, it is obvious that as the section length becomes very small the probability of either zero or one crash in the period increases. Conversely, as the section length becomes very large, the effects of isolated hazardous features will be submerged and lost. Zegeer (1982) suggests that data for road segments less than about 0.5 km long or carrying less than 500 vehicles per day are unreliable.

The crash location treatment process can also be applied in mass action programs to address:

- groups of crashes of a similar type (e.g. run-off-road), occurring across several sites
- a series of crashes that have common features, such as road features (e.g. curves, bridges), vehicle features (e.g. bicycles), road user features (e.g. pedestrians) or contributory features (e.g. driver fatigue)
- a series of `high profile' crashes such as those involving vehicles carrying dangerous goods, or crashes at railway crossings.

In this case the location will be numerous locations with common characteristics.

Crash location countermeasures can be applied on a site/route area or mass action basis. A brief discussion of these various actions is outlined in Sections 4.1.2 and 4.5.

4.1.1 Deciding on a time period

Crash data for a five year period is typically used, as this period usually provides statistical reliability. A three year period may be adequate, for example if the data base includes property damage crashes and crash frequencies are high at the sites being considered. A period longer than five years can be used (e.g. for remote or low volume roads), but it is more likely that changes to road features will have occurred which will affect crash causes. A data interrogation system which looks at both short term (one year) and long term (three or five years) data will allow problem locations to be identified sooner (refer to Section 4.1.4).

When deciding on the time period to be used:

- avoid environmental trends (e.g. traffic growth), other trends and changes to road layouts or roadside activity which could affect results
- use crash data for whole years to avoid the effects of cyclic or seasonal variations in crash occurrence
- be aware of any changes in data base definitions which might introduce discontinuities in the data.

4.1.2 Criteria for selecting locations to investigate for countermeasures

There will be many crash locations vying for countermeasures. There is a requirement to select those which are most worthy of treatment. Consistent with the Safe System approach, the focus should generally be on preventing future FSI crashes. In order to achieve this, roads that have a high number of fatal or serious injury crashes should be prioritised over roads that have a high number of minor injury or property damage only crashes.

Several criteria have been developed to identify locations worthy of investigation, but there is little consensus on which is the most appropriate. Selection criteria should be chosen in consideration of overall road safety program objectives, which may indicate the criteria that will be the most efficient.

Crash cost criterion

Generally, the recommended method is to compare locations using the cost of crashes by crash type (Andreassen 1992a; 1992b) as the criterion. This is done by assigning a crash cost to each crash type. For this purpose, several crash types are grouped together. Standard crash costs by crash type are different in each state and territory, depending on a number of factors including the reporting rates of non-injury crashes compared to casualty crashes. Consequently, these averaged crash costs by crash type already account for severity and there is no need to assign different costs to different crash severities within a particular crash type. This is a far more accurate way of establishing crash costs than by using separate average crash costs for all fatal crashes, all serious injury crashes, all minor injury crashes, etc. The use of crash cost by crash type also overcomes the problem of a single fatal crash (which is very rare) distorting the analysis because of its high cost.

The crash costs by crash type are assigned to each crash at every location where there has been a crash. This allows the locations to be ranked and those with the highest total crash costs to be identified. However, some crash locations will not experience a clustering of common crash types. These locations with single unrelated crash types are more difficult to treat, as there is no obvious crash pattern. Consequently, it is important to include for consideration more locations than will ultimately be treated, as some locations with significant total crash cost values may not be economically treatable due to a lack of common crash factors.

For uniformity of comparison, the total crash costs at all locations should be expressed as a cost per year over the appraisal period. Locations are then ranked according to decreasing crash costs. Crash cost by crash type is also the recommended costing method used in economic appraisal (Section 6).

This approach is consistent with the Safe System approach, and similar to the DSI equivalent approach developed and used in New Zealand (New Zealand Transport Agency 2013a; also see Section 6.7). Both have the same key benefits of smoothing out random variation (i.e. a fatal crash that might be a once in 100 year event would not dominate the crash listing), as well as more accurately predicting locations for future fatal and serious injury. As an example, a head-on crash in a high speed environment that only resulted in a minor injury would be recognised for its potential as a high severity outcome event.

Other criteria

Other, more minor, selection criteria are described below. By comparison with the recommended criterion they are all less effective, as they are less accurate in identifying the costs of crashes at a location and therefore less efficient in ranking sites to maximise the benefits of crash countermeasures:

- The number (i.e. frequency) of crashes (or crashes per kilometre of road) within the adopted time period. This takes no account of exposure or the different costs/severities of different crash types. This method may be appropriate in managing the allocation of resources in programs that treat a single crash type or where the overall program objective is to reduce crash numbers.
- The rate of crashes (per volume of traffic) within the adopted time period. This takes account of exposure. Rates are usually expressed in terms of crashes per 100 million vehicle kilometres travelled for road sections. The accuracy of a rate is dependent on the accuracy of traffic volume information.
- The number or rate of crashes both exceeding some defined threshold value (Section 4.1.3).
- The rate of crashes exceeding a critical value, derived from statistical analysis of rates at all sites. This method determines whether the crash rate is significantly higher than a predetermined rate for similar locations, based upon a Poisson distribution (Zegeer 1982).
- The difference between the observed and expected crash numbers, calculated from the site and traffic flow characteristics (McGuigan 1981; 1982). It is similar to the previous method, using frequencies (number of crashes) instead of rates.

Whichever method is used to determine whether a location is hazardous (and is thus worthy of consideration for treatment), there needs to be sufficient flexibility to ensure that:

- sites which have recently become a problem for obvious reasons do not have to experience another two or four years of crashes before they are considered (Section 4.1.4)
- sites with few crashes but requiring low cost treatments are not excluded.

4.1.3 Using a threshold method

If the crash data base does not allow the cost of crashes at each location to be directly compared, then a threshold method can be used to obtain an initial list of sites. Once these sites have been listed, crash costs by crash type can be applied so the sites may be ranked.

A threshold can also be used to provide an initial indication about whether a particular location has a crash problem.

The threshold could be in terms of the total number of crashes, but a threshold which identifies a pattern for a particular crash type may be more useful. Table 4.1 shows an example of threshold (or trigger) numbers used in one jurisdiction with high volume roads, some non-injury crashes reported and a limited crash treatment budget. In other jurisdictions, or under other budgetary conditions, the values in a table like this may be considerably lower.

Table 4.1: An example of threshold numbers used to identify sites for investigation

Type of location and criteria	Number of tow away and casualty crashes in five years						
	Pedestrian	**Intersection**	**Rear-end, overtaking, vehicle turning**	**Right-turn-against, oncoming**	**Off-road, lost control, head-on**	**Manoeuvring**	**Total**
Cross-intersection (not signalised or roundabout)		3	5	5			13
Non-signalised intersection (not roundabout or cross-intersection)		4	5	5			14
Signalised intersection		5	9	5			18
Roundabout		5	5				10
Rural intersection (give way or stop control		3	4	4		3	14
Urban mid-block location			4	4	3	4	15
Rural mid-block location			3	3	3		9
Mid-block location with a pedestrian crash problem	3						3

Notes:
- Urban = 80 km/h or lower; rural = over 80 km/h.
- 'Mid-block' means a length of road between intersections.
- For intersection locations, include crashes within 30 m (urban) or 100 m (rural).
- For mid-block locations, length of location is 100 m (urban) or 300 m (rural).
- If considering greater lengths than the above, be aware that the more distant crashes of the same crash type may be due to different contributing factors.

4.1.4 Chance variation

Crash data are subject to random fluctuations and it is therefore possible to subject them to statistical analysis in order to distinguish between significant factors and those occurring through chance variation.

In particular, it is important to assess whether an abnormally high number of crashes in a time period (e.g. one year) should be taken as evidence that the site has become hazardous or whether the fluctuation can be taken as mere chance variation. The practical example in Appendix C.2 provides an assessment method. It uses the concepts of the true underlying crash rate of crashes and critical changes in a mean value. The graphs in Appendix F (Nicholson 1987) are used for this purpose.

4.2 Intersections

An intersection treatment will involve considering the immediate intersection and its surrounding area. Sites are identified for treatment by having a large number of similar crash types, rather than just a large number of crash types generally. Crash codes, such as those shown in Figure 3.1 and Figure 3.2 can be used to identify particular crash types. Alternatively, crash groups can be identified (i.e. single vehicle crashes or two vehicle crashes, etc.). For example, a particular site may feature a cluster of right angle or run-off-road crashes.

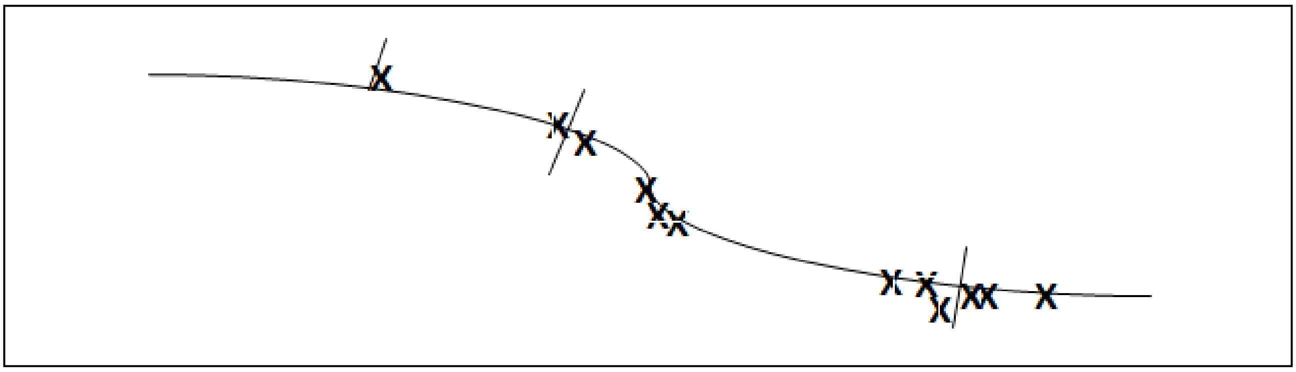
4.3 Routes

A treatment of a route or road section will involve systematically investigating crashes along a section of road where the road character is relatively homogeneous. This study must include investigations of each site and road section with repeated crash types, similar to a site investigation.

However, an attempt should also be made to see if there are common features in crashes (and treatments) along the entire route. For example, a scenic route may feature a high number of coach buses or motorcyclists and infrastructure may need to be upgraded to accommodate these vehicles. In addition, particular crash types (for example run-off-road crashes) may have occurred at specific locations, but there may be locations of equal or even higher risk elsewhere on the route. This is particularly the case on lower volume roads.

Figure 4.1 illustrates a route along which high numbers of crashes have occurred. Some of these have occurred in clusters (e.g. near intersections or at a curve), while others are more scattered.

Figure 4.1: Example crash sites along a route



4.4 Areas of the Road Network

Treating areas of the road network involves systematically investigating crashes throughout an entire area (e.g. a local traffic area or an entire suburb). The objective is to correlate crash problems over the area and investigate overall solutions, even though the study area may include individual problem sites and/or routes. Issues in area studies may include traffic management and network problems, such as short cuts through residential streets. The area of interest may fall across different geographic boundaries (e.g. across local government boundaries) and so responses may require more than one agency.

4.5 Mass Action

This involves applying a particular evidence-based remedial treatment (or package of treatments) to address a hazardous feature or crash type. Common features might include road features (e.g. inadequate shoulders on curves; unprotected bridge ends), vehicle features (e.g. bicycles), or road user features (e.g. pedestrians). Crash types might include specific crash types (e.g. run-off-road) or contributory factors (e.g. driver fatigue). Typical mass action treatments include delineation improvements and shoulder sealing on rural road curves, and the duplication of intersection control signs on wide approach roads in country towns by installing median islands.

Treatments should be assessed for use at locations where the feature is present, irrespective of whether crashes have yet occurred at all of them. All crashes attributable to the feature should first be identified. Then, locations with this feature should be identified and the viability of applying a proven treatment to all of these locations should be assessed.

5. Diagnosing the Crash Problem and Selecting Treatments

Crash data analysis and interpretation is the foundation on which the selection of effective countermeasures is based. Countermeasures need to be targeted and be able to address crash causation factors and factors that may increase crash severity.

The aim of the analysis therefore is to identify the factors which are contributing to crash occurrence and severity at the location under investigation. This requires more than identifying the result of the crash (e.g. a car left the road and hit a tree). It requires understanding the road environment factors which led to it and identifying the problems to be resolved (e.g. presence of a curve, inadequate superelevation, poor location or delineation, inadequate skid resistance). This requires knowledge of:

- road and roadside features that have proven themselves to contribute to crash occurrence and severity
- cost-effective proven remedial treatments.

With the advent of the Safe System approach, some jurisdictions are taking an approach to analysis that uses the Safe System pillars to structure the analysis task. As outlined in the *Guide to Road Safety Part 1: Introduction and the Safe System* (Austroads 2021a), these pillars include safe roads and roadsides, safe speed, safe people and safe vehicles.

Analysis of crash data

The first step involves obtaining electronically the detail of each of the recorded crashes that had occurred at the site under investigation. This then enables in-office analysis to be undertaken to identify predominant crash types (e.g. rear-end, head-on, etc.), and common crash characteristics (e.g. time-of-day, day/night/dusk, etc. of the occurrence of all of the recorded crashes). Discussion of this analysis task is provided in Section 5.1.

Obtain other relevant information

The second step is to consider other information that may be relevant to the site, such as community concerns and traffic demands (Section 5.2).

Inspect the site (or route or area)

The third phase is an on-site analysis involving observation of road features and road user behaviour. The road needs to be driven, walked, ridden, etc. at normal speeds and also observed at close quarters (Section 5.3).

Finalise the assessment and draw conclusions

Any additional studies, such as speed surveys, traffic counts, geometric checks, skid resistance tests, turning manoeuvres or conflict analyses are organised. Using all the information which has been collected and observed, conclusions are drawn about the contributing possible crash factors (Section 5.4).

5.1 Analysis of Crash Data and Interpretation

The primary sources of data for crash investigation are:

- the state or territory road agency crash data base (the most commonly used information and usually in an electronic form which permits data manipulation)
- the police crash data base
- the individual police crash report forms (which can provide a greater amount of detail regarding the crash circumstances; the use of police crash report form details are highly desirable if a collision diagram is to be prepared).

Analysis of the crash data involves presenting it in tables and diagrams so that any clustering of crash type or other common factors can be identified. Presentations will include:

- a crash factor matrix
- a collision diagram
- a frequency histogram of DCA code sub-groups (which may be optionally prepared in addition).

5.1.1 Examine crash types (DCA or other similar codes)

Crash types or DCA codes categorise crashes by the movements or activity of the involved road users. An example table of DCA codes used by an Australian road agency is shown in Figure 3.1 (Appendix A outlines the DCA codes for all Australian road agencies). New Zealand VMC codes are shown in Figure 3.2.

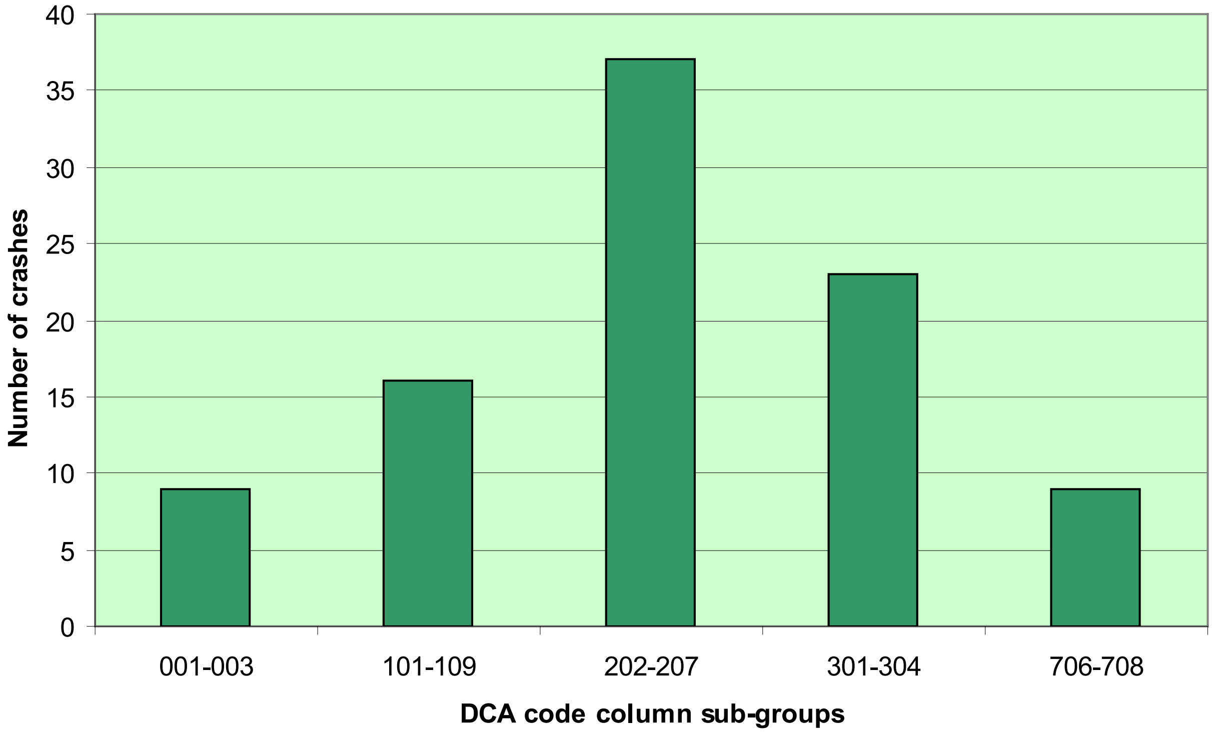
Dominant DCA types often provide the most reliable guide to the remedial action, since they are likely to be indicative of the future crash patterns at the site, if it is not treated. For most DCA types there will be one or more specific countermeasures which are applicable. Typical DCA types might include:

- collisions between vehicles entering from intersecting streets
- collisions involving vehicles turning from the opposite direction
- rear-end collisions
- collisions between vehicles and pedestrians
- collisions between vehicles travelling in the same direction
- vehicles running off the road
- collisions with fixed objects off the road
- collisions with parked vehicles.

Figure 3.1 shows that DCA codes are grouped by column, or sections of a column, into similar types (e.g. all the pedestrian crashes are grouped in the first column, but the thick horizontal lines divide this column into four separate sub-groups).

An example frequency histogram showing the distribution of sub-groups of DCAs occurring at the site is a useful, quick way of getting a first idea of possible clustering by crash types, as illustrated in Figure 5.1 (note the DCA codes outlined in Figure 5.1 are based on the example DCA diagram shown in Figure 3.1). Where any column in Figure 3.1 is divided by thick horizontal lines, each sub-group should be listed separately in the frequency histogram. However, a frequency histogram is not a substitute for a factor matrix or a collision diagram and it is rarely used in later analysis as it provides insufficient detail for tracking down crash causes. An alternative to the frequency histogram is the pie chart as shown in Figure C 7.

Figure 5.1: Example crash frequency histogram based on DCA code sub-groups



Note: DCA sub-group number based on the example DCA sheet shown in Figure 3.1.

5.1.2 Construct a crash factor matrix

DCA codes do not give a full picture of all factors. By examining the mass crash data and constructing a factor matrix (see the example in Table D 3) any patterns in these other factors can become apparent.

Construction of a factor matrix can allow quick and easy assessment of key crash characteristics that may be associated with many or all of the crashes at a site. Along with the DCA code, other relevant factors should also be included, for example:

- time of day and day of week (this may, for example, help identify if a crash was in the weekday commuter peak, or during darkness)
- road surface condition (may indicate if a crash occurred in wet conditions)
- involvement of alcohol and speed, or other behaviour factors
- the number of crashes involving pedestrians
- any vehicle factors (e.g. motorcycle involvement).

Where there are small numbers of crashes it may be useful to record each crash as a separate row in the factor matrix. Where there are a larger number of crashes, for each combination of DCA code and key direction (usually the direction of travel involving the error) which has experienced more than one crash, details can be recorded on one line of the Factor Matrix form. A blank form is provided in Appendix B. Note how the crashes in the case study example in Table D 3 are repeated for each factor across the matrix (e.g. on each line the crashes are all listed under Surface as well as Light Condition, etc.). Also, the northbound DCA 201 crashes are listed separately from the southbound DCA 201 crashes.

For sites, prepare a matrix as discussed above. For routes, a matrix can be prepared for any sub-section of the route where there is crash clustering, as well as for the entire route. For areas, prepare a matrix for any site or precinct where there is crash clustering, as well as for the entire area. For mass action, a matrix is not required as the focus is on one specific type of crash.

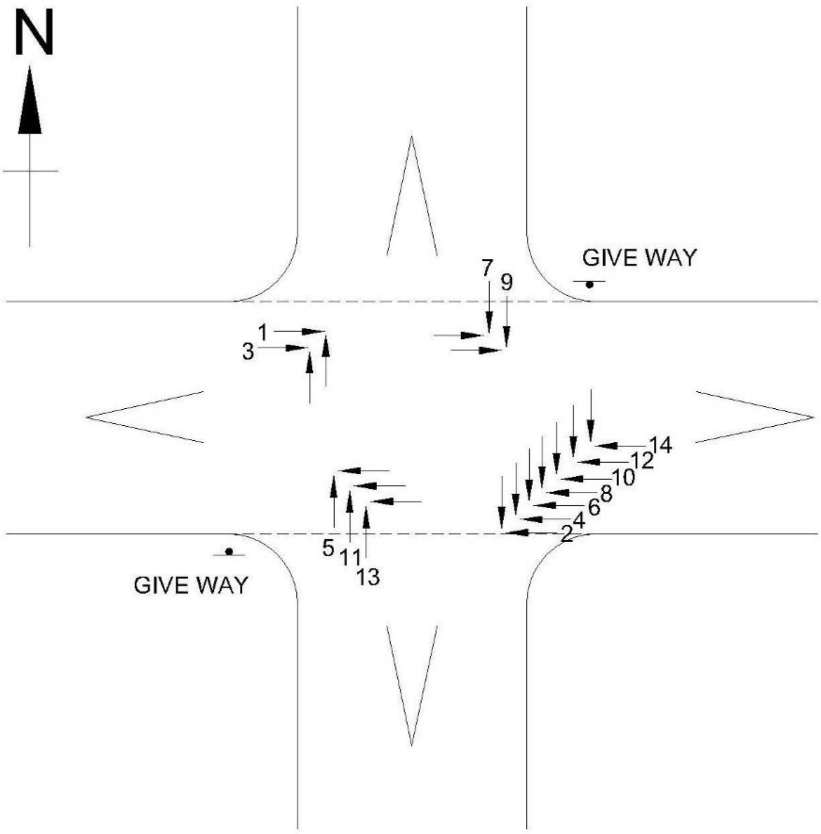
The construction of a factor matrix can also help with the drawing of a collision diagram.

Some jurisdictions are able to automatically generate a factor matrix using their crash data base system.

5.1.3 Draw a collision diagram

The fundamental tool used in crash diagnosis is the collision diagram, which is a schematic representation of all crashes occurring at a given location, route or area over a specified period (typically 3–5 years). An example is provided in Figure 5.2 (this also appears in Practical Example 6 in Appendix C.6).

Figure 5.2: Example collision diagram



Each crash (or each group of crashes with the same DCA code and involving the same approach direction) is represented by a small diagram similar to that shown for the crash movement type codes in Figure 3.1 and Figure 3.2, oriented in the true direction of road users involved in the collision. Each crash type code diagram in these figures typically contains one or two arrows, one for each vehicle and/or pedestrian involved, to indicate the type of crash and directions of travel. On the collision diagram the date, time, day/night, wet/dry surface, vehicle type, etc., can be labelled along one of the arrows or beside each crash type code diagram.

The collision diagram should contain street names, the locality name, a north point and GPS co-ordinates wherever available, and need not be to scale. It may also include road features such as intersection type and control, traffic lanes, islands, markings and significant roadside features. However, if the inclusion of all these features would make the collision diagram too cluttered, they should be provided as a separate site sketch plan, with the collision diagram showing only the basic site layout.

In summary:

- **Sites:** prepare a collision diagram as discussed above.
- **Routes:** prepare a collision diagram for any sub-section of the route where there is crash clustering, as well as for the entire route.
- **Areas:** prepare a collision diagram for any site or precinct where there is crash clustering, as well as for the entire area.
- **Mass actions:** select several sites having large numbers of crashes involving the particular factor for study during field investigations. Draw a collision diagram for each of these sites.

Some crash data base systems are able to automatically generate a collision diagram. However, these should always be checked against crash data to ensure they have been produced correctly.

5.1.4 Look for common factors

Review the crash data, the factor matrix and the collision diagram and identify common contributing factors. What factors have led to each crash? It is normal for several factors to combine in leading to a crash.

List the common crash factors. These can provide a prompt to the factors to consider during the on-site investigations.

If there is not a dominant crash type, development of a remedial treatment can be difficult.

In many cases, there will be a relatively small number of crash types at any given site. In such cases the text on the crash report forms describing the crash can provide a greater insight. Valuable information can be gathered from reading the commentary provided by the road users involved in the crash from these forms. In some cases this information is available directly through the crash data base system (e.g. through scanned images).

The location of the crash may not be clear, or it may conflict with other information. Examining the crash report form can help clarify this. It is often difficult to construct a complete collision diagram without reference to the original crash report forms for at least some of the crashes.

Where no clear pattern arises about crashes at a location, the crash report form can provide clues about an underlying crash problem. Before the site is discarded for treatment, consider looking at the information in the crash report forms.

5.1.5 Writing the preliminary report

The information and analysis to this point is required for the immediate purpose of informing all the crash investigation team members, prior to the field investigation. Later it will be required as part of the crash location treatment report (Section 8). At this point the preliminary report should be written in a format suitable for that purpose (see the introduction and data analysis sections of the summary report framework described in Sections 5.4 and 8). A practical example of a preliminary report can be found in Appendix C.3.

5.2 Other Relevant Information

As well as crash data, information should be obtained covering:

- traffic volumes
- significant changes to traffic patterns and land uses in the area
- surrounding land use
- concerns raised by interested people or organisations (often reported by the media).

Consideration of other data may help to highlight location specific concerns. For example, higher traffic volumes (especially motorcycles) occurring during weekends may indicate a high level of recreational travel, whilst the presence of a retirement complex would suggest a high level of elderly drivers in the area.

5.3 Site Investigation

The objectives of the site inspection are to:

- identify any factors which may have contributed to crash occurrence and crash severity
- identify cost-effective targeted remedial treatment options.

Environmental deficiencies that may have contributed to crashes can be many and varied but include:

- STOP/Give Way lines concealed by an uneven surface
- a line of poles which produces an illusion of continuous perspective through an intersection (often giving rise to overshoots)
- lack of carriageway definition
- horizontal curves concealed by a sharp crest in the carriageway
- masking of pedestrians by street furniture
- foliage obscuring regulatory signs.

To ensure that road deficiencies are identified it is essential that site inspections are carried out in an extremely systematic and purposeful manner. As indicated earlier, one option is to take a Safe System approach, using the pillars to structure the site inspection.

If the crash data show a cluster of a particular crash type, this means that several road users are misreading the situation as they approach, drive through, turn at, walk across, or otherwise negotiate the location. An assessment should be made of what is causing them to do this, or of what is misleading and what is difficult to deal with.

These issues cannot be identified only from crash data, crash report forms or photographs. It is essential to carry out a site inspection. When on-site, bear in mind the potential inadequacies in data and the reasons for them (Section 3.4). The crash location investigation team will need to:

- view the location as the road users in a crash may have seen it (time of day, level of lighting, weather, eye height and position)
- check the surrounding road environment
- observe travel speed behaviour
- collect information about road features and traffic behaviour.

5.3.1 Drive through the location

To see the location as the road users in the crashes may have seen it, use the following techniques:

- select the driver on the basis of the person least familiar with the location, and the front seat passenger the second least familiar
- drive the roads at a range of speeds, determined by a local risk assessment
- drive all approaches and repeat the manoeuvres featured in the crash data
- try to do this in similar conditions to the crash conditions (e.g. same time, peak/off-peak, light/dark, wet/dry, etc.)
- have the driver comment on the road and any problems or surprises
- have the front seat passenger concentrate on the surrounding environment.

It is also important to negotiate the location as would others involved in any crash (e.g. pedestrians or cyclists). This should be done as a specific task during the detailed inspection.

After the drive through, note any aspects of the road where expectations about the road and traffic facilities were at odds with what was encountered or the 'messages' the road layout gave out.

5.3.2 Inspect the location

To inspect the location:

- determine where the main crash patterns and directions are, on site
- observe traffic behaviour (including driver eye movements, vehicle paths, approach speeds, braking and pedestrian patterns, impairments to travel including parked vehicles)
- check from the point of view of a range of users, including vulnerable road user groups (e.g. from the eye height of drivers and young pedestrians, as appropriate)
- check and note relevant features (e.g. surface condition, lighting, crossfall, gradient, islands, signals, signs, markings and obstructions)
- take video and photographs, as a record to use back in the office as required.

A suggested checklist of issues is provided in Table 5.1. This should not be used to identify risks at the location (that is road safety auditing). Rather the checklist provides a prompt of possible issues the investigators can think about when trying to find a connection between the road and traffic environment and the crash types being investigated. An alternative approach would be to group these (and other) issues according to the Safe System pillars (see the *Guide to Road Safety Part 1: Introduction and the Safe System* (Austroads 2021a)).

A key aim of the site inspection is to identify any environment and traffic concerns which may have contributed to the recorded crash history. Conformity of the layout, signing, pavement markings, lighting, etc. with applicable standards or guidelines may be important, but it cannot be assumed that any non-conformity will necessarily have resulted in a safety problem, nor can it be assumed that a road designed according to standard will not have safety concerns. Road safety engineering judgement, based on experience, is vital in determining whether the absence of a standard treatment has contributed to a crash.

Video and photographs of the site, its problem areas and its approaches can be a valuable tool in crash investigation. Video-recording of the site can also help assess road user behaviour, and perhaps form the basis of a before-and-after study. This should serve as a supplement to a site visit, and should not be used instead of a site visit by any of the crash investigation team members.

5.3.3 Consider driver behaviour

In some cases, it may be helpful to have additional information on driver behaviour at the site. This behaviour (which may include late braking on entry to a sharp curve, evasive actions at an intersection, behaviour resulting from inadequate or misleading visual information) can be identified from observations, or recorded more formally through a conflict study. Such studies involve direct observation of the site, or the use of video recording, in order to examine near-crashes as a means of gaining insight into crash problems at a site:

- **Sites:** inspect as discussed above.
- **Routes:** place heavy emphasis on route continuity and driver expectation. In sub-sections of the route with crash clusters, examine and report separately.
- **Areas:** drive through in a logical sequence. Look for signs of inconsistent road environments. Look at all locations with crash clusters.
- **Mass actions:** the first emphasis is on identifying all sites having the hazardous feature under investigation. Investigate the higher frequency sites in greater detail.

Table 5.1: An illustrative checklist of possible contributing factors, for use during site inspections

Issues	Contributing Factors	
Road	• Width • Divided / undivided • Number of lanes • Crossfall • Gradient • Shoulder	• Verge • Median and openings • Footpath • Kerb, pram ramps • Drainage • Combination of factors
Road surface	• Type • Roughness	• Skid resistance ('friction') and texture / surface debris • Service access
Road geometry	• Curve • Gradient • Superelevation	• Crest • Sag at foot of hill
Intersection	• Type • Number of legs • Channelisation	• Turn lanes • Turning radius
Signs and markings	• Which signs • Legibility • Conspicuousness • Comprehensibility • Credibility • Lane, centre and edgelines	• Other markings • Pavement markers • Post-mounted delineators • Hazard markers • Chevron alignment markers
Traffic signals	• Primary/secondary/tertiary • Intensity • Location • Turn control	• Pedestrian display • Detector type • Part of linked system • Cycle times and green splits
Pedestrians and cyclists	• Number and types • Crossing facilities	• Pedestrian barriers • Pedestrian refuges
Lighting	• Type • Height	• Intensity • Obstruction
Parked vehicles	• On-street parking • Off-street parking and access • Visibility • Clearway hours • Parking controls	• Loading facilities • Bus stops • Taxi rank • Physical obstruction
Speed	• Safe speed • Speed limit	• Vehicle speeds • Late braking
Environment	• Land uses • School children • Heavy vehicles	• Ambient noise • Ingress/egress problems
Roadside	• Poles, posts, etc. • Horizontal railings • Rock, trees, other hazards • Safety barriers, fences	• Side slopes • Culverts • Bridge abutments, railings
Visibility	• On intersection approach • Of side road • Of traffic control devices • Of pedestrians	• Of parked vehicles • Of bus stops • Over crests • Subliminal delineation
Evidence of problem	• Broken glass • Debris	• Skid marks • Damaged road furniture

5.3.4 Identifying the cause of the crash

One type of crash may have different causes at different locations. Take, for example, right angle crashes at give way controlled intersections. Are drivers on the minor leg having crashes because:

- they cannot see the intersection, and drive through as if it was not there?
- they know there is an intersection, but they cannot see the give way position and they overshoot into the intersection?
- they know the intersection is there, they have stopped, but they make a mistake picking a gap in the traffic?

Each of these alternatives will be caused by different road or traffic factors. It is vital to understand which applies at the intersection in question, because each one will require a different countermeasure treatment to overcome it. For example, there is little point installing advance intersection warning signs as a solution, if the cause is poor judgement in gap selection.

A list of possible contributing factors for a selection of different types of crashes is provided in Table 5.2. Note that speed can contribute to the frequency and severity of all crash types.

5.4 Identification of Crash Causation and Crash Severity Factors

Before completing the analysis and preparing a summary report, consider what other data is required but not yet provided. For example, does the crash information or the site inspection indicate that skid resistance testing should be undertaken? Do sight distances need to be measured?

5.4.1 Draw conclusions

With all the information available from the analysis and the field inspection, conclusions can be made about the underlying factors contributing to the crashes. An assessment should be made of what it is about the road or traffic environment which is leading to crash occurrence and/or crash severity.

5.4.2 Write a crash summary report

A crash summary report can then be prepared. This summarises the information available about the site and incorporates the introduction and data analysis sections discussed in Section 5.1. This summary report can form the first part of the final crash location treatment report which will include consideration of countermeasures and an economic appraisal of the proposed treatment.

At this stage, the crash summary report would typically include the following sections of the report framework set out in Section 8:

- introduction
- data analysis. As well as the information set out in Section 8, a crash histogram by DCA code column sub-groups (or VMC rows in New Zealand) may optionally be included in the preliminary report (Section 5.1) or the crash summary report
- contributing crash factors
- appendices.

An alternative example of a shortened crash summary report is shown in Table 5.3. Note how the identification of common factors leads to the description of the site’s problems. Also, in this example, there are descriptions of possible remedial measures (which address these identified problems). The subject of countermeasures is dealt with in Section 5.5. Another alternative is to structure the report according to the Safe System pillars.

Table 5.2: Some possible contributing factors for different type of crashes

Crash Type	Contributing Factors
Right angle crashes	• Restricted sight distance • High approach speeds • 'See through' effect on a minor approach • Obscured control sign, control lines or signal lanterns • The presence of the intersection is not otherwise evident (at time of day) • Traffic volumes too high for Give Way or Stop controls (inadequate gaps)
Right turn collisions with oncoming traffic	• Restricted visibility • Queued oncoming right-turners block visibility • Insufficient number of gaps in oncoming traffic • Too many lanes of oncoming traffic to filter across • Complex intersection layout
Straight ahead rear end crashes	• Queued right-turn vehicles further ahead • Traffic signals around curve or over crest • Other unexpected cause of delay further ahead • Inadequate skid resistance or pavement drainage • Wrong offset timing of linked signals • 'See through' effect of consecutive traffic signals • Inadequate inter-green phase on signals • Presence of parked cars • Unstable flow on high speed road, including disturbance to traffic flow, such as from driveways and bus stops
Right or left turn rear end crashes	• Turning vehicles where they are not expected (e.g. just before or just after signals) • A left turn slip lane permitting high speed turns
Hit fixed object crashes	• Islands not visible • Complex layout • Reasons as for run-off-road crashes
Crashes involving a parked vehicle	• Unexpected parked vehicle in traffic lane • Edgeline not visible • Lanes too narrow
Side-swipe crashes	• Lanes too narrow (for traffic composition, speed, curvature of road, angle of lanes) • Lane lines, edgelines not visible • Presence of parked cars or other obstruction • Unexpected lane drop or merge area • Inadequate direction information
Head-on crashes	• Lanes too narrow (for traffic composition, speed or curvature of road) • Centreline not visible • Severity of curve cannot be judged • A hidden dip or crest • Insufficient overtaking opportunities • Road surface deficiencies
Run-off-road crashes	• Narrow lanes or narrow seal • Severity of curve cannot be judged • Edge of the road is not evident • Gravel shoulders do not allow recovery of control • Alignment of road is deceptive • Inadequate skid resistance or pavement drainage • Insufficient superelevation

Crash Type	Contributing Factors
Pedestrian crashes	• Too much traffic for adequate gaps • High speed, multi-lane and two way traffic • Complex or unexpected traffic movements • Traffic hidden by parked cars, other objects or excessive landscaping • A marked crossing which is not evident to drivers • Long signal cycles which encourage pedestrians to disobey signals • Inappropriate device or lack of devices for mix of pedestrians (e.g. disabled) • Inadequate lighting
Railway level crossing crashes	• Location of crossing is not evident • Impending presence of train is not evident • Form of control is not accurately identified (or is inconsistent) • Driver’s attention distracted by intersection or other feature • Obscured control devices

5.4.3 Applying the process to area studies and mass action programs

Area studies

The usual context for crash diagnosis on an area-wide basis is that a particular area (say a residential precinct up to 5 km^2 or a shopping/commercial district) has been identified as having a safety problem. In diagnosing that problem the task is to plot the location of all recorded crashes, together with a code indicating the road user movement or DCA. Since a focus of such studies may be vulnerable road users, an analysis and presentation similar to that described for site analysis is useful.

An explicit functional road classification scheme is important in this instance, since often in these types of study a solution involves adaptation of the road and street network to ensure that extraneous traffic is excluded or discouraged. This cannot be done until all the legitimate (and necessary) traffic routes have been determined.

Area studies will incorporate aspects of both site and route studies, to the extent that crashes cluster at these locations. However, one important objective of an area study is to consider all the crash problems of the area together, in a consistent manner. This may include road network problems which are contributing to the crash experience of the area (e.g. traffic using residential streets as a ‘rat run’). Solutions resulting from area-wide studies should be integrated into a total scheme to ensure that new safety problems are not created elsewhere, either in a nearby street or a nearby area. Implementation will often require community consultation.

Mass action programs

The approach to the diagnosis of crash patterns for mass action programs is a little different because the focus is not a particular site. Nevertheless, the basis of the investigation is again an interrogation of the mass crash data base. Crashes may be sorted by crash type (as described above) to identify the locations where a particular type of crash, amenable to a standard treatment, is occurring. Examples, with possible countermeasures, might include:

- crashes involving collisions with a bridge or structure (guard fencing and delineation)
- rural single vehicle run-off-road crashes (sealed shoulders)
- crashes with utility poles on bends (removal of poles, shielding them, making them frangible or improving skid resistance).

Alternatively crashes may be sorted by road user, to identify where crashes involving those users are occurring. Examples might include:

- crashes involving elderly or child pedestrians
- crashes involving cyclists or heavy vehicles.

Under mass action programs, a large number of sites are often treated, irrespective of whether crashes have occurred at all of them. Care therefore needs to be taken when conducting economic appraisals for mass action, as the crash modification factors (CMFs) applicable at such sites may differ to those from where clusters of similar crash types occur (they may be lower). Similarly, there may be economies of scale when installing treatments that make the cost per unit installed less.

To the extent that there is a significant occurrence of crashes of a particular type or crashes with a common contributing factor revealed by such a study, the analysis could form the basis of a mass action program. If there is no significant occurrence by crash type, it is unlikely that a mass action program of engineering countermeasures is appropriate.

Table 5.3: A report summary from a crash location investigation

SITE: Intersection of Bennett Highway with Smith and Green Streets, Red Springs	
Description of site	**Attached material**
This site is a signalised cross-intersection. It is the first signalised intersection for northbound vehicles on their approach to Red Springs and would be the first signals encountered since Glenvale. The intersection is located in a 60 km/h zone, however northbound vehicles enter this 60 km/h zone from a 70 km/h zone around 600 metres south of the intersection.	Relevant plans ☑ Site sketch ☐ Traffic counts ☐
Summary of common factors	**Attached material**
1. There have been 7 right-angle crashes, 4 involving northbound vehicles passing through a red signal and one involving a southbound vehicle (the other two right-angle crashes involving a southbound and northbound vehicle occurred when the signals were not operating). These crashes have been evenly distributed during the 5 year study period.	Factor matrix ☑
2. 21 of the 37 crashes were right-turn-against crashes. 13 of these involved vehicles turning off the Bennett Highway, 8 southbound and 5 northbound. None of these crashes occurred since the end of 2003. There were also 5 crashes involving westbound vehicles turning right and 3 involving eastbound vehicles turning right.	Collision diagram ☑
3. Four crashes, 2 rear end and 2 loss of control crashes resulted from northbound vehicles failing to stop approaching the traffic signals in response to a red traffic signal.	Crash listing ☑
4.	Police forms ☑

Description of measures previously implemented	**Safety effectiveness**	**Attached material**
1. At the end of 2003 the filter right turns from the Bennett Highway into Smith and Green Streets were discontinued with the turns being fully controlled by arrows.	Related right-turn-against crashes, from 13 2001-03 to 0 from 2004/05	Relevant plans ☑
2. The right turn for westbound vehicles on Smith Street to Bennett Highway (north) banned from end of 2003.	Related right-turn-against crashes, from 13 2001-03 to 1 from 2004/05	Relevant plans ☑

Description of problem identified	**Related common factors**			**Attached material**
1. Right turn filters were major problems, but 3 of 4 filters have been discontinued, and related crashes have been eliminated. One NRT sign in place for westbound vehicles on Smith and one crash in 2005 involved a vehicle making this banned right turn.	2			Photograph ☑ Sketch ☐
2. The northbound approach to the intersection is relatively fast down a hill, also the signals are the first encountered since Glenvale and prior visibility of the signals is obscured by a left hand curve. Lack of prior visibility of signal displays could have contributed to the 8 crashes involving northbound vehicles failing to stop for a red signal during the study period.	11	3		Photograph ☑ Sketch ☐

Description of possible remedial measures	**Address problems**			**Estimated cost**	**B/C**	**NPV**
1. A further NRT sign should be placed on the north-western signal pole (# 4) facing westbound vehicles on Smith Street.	A					
2. A signal display facing south should be placed on the pole on the south-eastern corner of the intersection (#7). This display will be seen by northbound vehicles before the existing displays due to the curved approach.	B					
3. A warning sign incorporating flashing lights triggered from the signals could be placed for northbound vehicles on the Bennett Highway to warn drivers of an impending red signal.	B					

5.5 Countermeasure Selection and Design

Having identified the elements of the road and traffic environment which contributed to the crashes and their severity, the next step involves consideration of countermeasures. For a solution to be effective, it must be applied to a particular problem which it is known to affect. It must be an effective countermeasure.

The aim of countermeasure development is to:

- select countermeasures which have been demonstrated to be effective in reducing the incidence and/or severity of target crash types
- check that adopted countermeasures do not have undesirable consequences, either in safety terms (e.g. lead to an increase in the number or severity of another crash type, or crash migration) or in traffic efficiency or environmental terms
- be cost-effective, i.e. maximise the benefits from the whole program of expenditure over a number of sites
- be efficient, i.e. produce benefits which outweigh the costs.

There are several criteria for countermeasure selection, including (Ogden 1996):

- **Technical feasibility:** can the countermeasure provide an answer to the safety problems which have been diagnosed and does it have a technical basis for success?
- **Economic efficiency:** is the countermeasure likely to be cost-effective and will it produce benefits that exceed its costs?
- **Affordability:** can it be accommodated within the program budget; if not, should it be deferred, or should a cheaper, perhaps interim solution be adopted?
- **Acceptability:** does the countermeasure clearly target the identified problem and will it be readily understandable by the community?
- **Practicability:** is there likely to be a problem of non-compliance, or can the measure work without unreasonable enforcement effort?
- **Political and institutional acceptability:** is the countermeasure likely to attract political support and will it be supported by the organisation responsible for its installation and ongoing management?
- **Legal conformity:** is the countermeasure a legal device, or will users be breaking any law by using it in the way intended?
- **Compatibility:** is the countermeasure compatible and consistent with other strategies, either in the same locality in similar situations elsewhere?

It can be seen that the decision to adopt a particular countermeasure may involve more than a simple matching of a solution to a problem.

5.5.1 What is a safe road environment?

A safe road environment forms an integral part of a Safe System. Such an environment is one which recognises the realities and limitations of human decision making. In other words, the road environment must not place demands upon the driver, or other road users, which are beyond their ability to manage, or which are outside normal road user expectations.

A safe road may therefore be described as one which is designed and managed so that it:

- provides a safe speed environment
- warns the driver of any substandard or unusual features
- informs the driver of conditions to be encountered

- guides the driver through unusual sections
- controls the driver's passage through conflict points or sections
- forgives a driver's errant or inappropriate behaviour (e.g. has a safe roadside).

It should:

- provide no surprises in road design or traffic control (the design matches expectations)
- provide a controlled release of relevant information (the design matches information-processing abilities)
- provide repeated information, where pertinent, to emphasise danger (again, to ensure the design matches expectations).

Designing a road according to these principles is not the same as designing a road which simply meets design standards. Lamenting the fact that decisions affecting the future safety of roads are so often strongly influenced by the habit of designing to standards, a safety review committee on one major road project commented 'this often means that minimum standards are just met. There is no reason to think that by meeting standards the appropriate level of safety is built into roads' (Professional Engineers Ontario 1997). A road designed to standards is not necessarily safe and a road which in some details fails to meet standards is not necessarily unsafe. There is no substitute for the application of sound road safety engineering experience and judgement, which is the basis of the principles outlined above.

Emerging approaches take a wider perspective on treatment options that include all pillars of the Safe System approach (see the *Guide to Road Safety Part 1: Introduction and the Safe System* (Austroads 2021a)). Investigations may highlight some issues involving Safe Vehicles and Safe Road Users which could be passed on to another party to follow up, thereby ensuring all parts of the system are addressed.

5.5.2 Safe System treatments

A challenge under a Safe System approach is to ensure greater usage of treatments that will provide Safe System outcomes (i.e. the elimination of death and serious injury). Due to cost considerations, safety improvements that have only moderate effects on fatal and serious crash outcomes are often used as these often produce a greater benefit-cost ratio (see Section 6). Although there is a place for such treatments in reducing crash risk, other treatments that produce greater benefits in terms of fatal and serious injury per dollar spent should be explored as first options where possible. Further discussion on this issue can be found in Turner et al. (2009). Example treatments providing Safe System outcomes are outlined in Table 5.4 and discussion on the concept of harm minimisation is provided in the *Guide to Road Safety Part 1: Introduction and the Safe System* (Austroads 2021a).

Table 5.4: Example Safe System treatments for various crash types

Crash type	Example Safe System treatments	Issues
Run-off-road	Centre and edge barrier systems – particularly wire-rope barriers which offer a greater degree of deflection, thereby absorbing energy and redirecting vehicles back into their lane	• Wire-rope barriers are less able to contain heavy vehicles • Most barrier systems pose risks for vulnerable road users • Barrier systems (including terminals and transitions) are still a hazard – some deaths and injuries still occur • Depending on type there may be Safe System implications for workers during maintenance activities
	Clear zones	• Crashworthy roadside furniture may be present within the clear zone, although this may still present a risk to motorcyclists • Significant crash reductions possible with moderate clear zone widths (> 4 m) but need to be very wide to minimise harm
Intersection (particularly where impact speeds are likely to be greater than around 50 km/h)	Grade separation	• Costly
	Roundabouts	• Need to be well designed with adequate deflection on approach • Concerns regarding vulnerable road users • Some issues with heavy vehicles (e.g. gap acceptance for road trains)
	Intersection platforms	• Suitable in lower speed environments, as they reduce speeds to 50 km/h or less. Relatively untested in Australian and New Zealand conditions, but used widely in parts of Europe
	Left turn out only with acceleration/deceleration lanes	• Motorists seeking to make right turns are inconvenienced
Head-on (particularly where impact speeds are likely to be greater than around 70 km/h)	Median barriers	• Depending on type there may be Safe System implications for workers during maintenance activities • Has to be appropriate type depending on vehicle usage and width considerations
Pedestrian (particularly where impact speeds are likely to be greater than around 30 km/h)	Grade separation	• There is often low utilisation of this treatment due to inconvenience to pedestrians
	Raised pedestrian crossings (wombat crossings) and other relevant traffic calming	• Suited to lower speed environments, or key locations on higher volume routes

Source: Adapted from Turner et al. (2009)

5.5.3 Speed management

Speed is known to have a significant impact on the likelihood and severity of crashes. A good evidence base now exists regarding the survivability of road users for different crash types based on impact speed. This knowledge needs to guide the approach that is taken to the management of speed. *Guide to Road Safety Part 3: Safe Speed* (Austroads 2021b) provides guidance on speed management and the application of speed limits as a speed management tool.

Where speed has been identified as a contributory factor to crash severity and/or causation, appropriate management of speed should be investigated as a countermeasure. At intersections, techniques include the installation of channelisation, roundabouts or threshold treatments. At mid-block locations, appropriately designed traffic calming can be used (see *Guide to Traffic Management Part 8: Local Street Management* (Austroads 2020d) for further details). Further information on speed management and road safety can be found in *Guide to Road Safety Part 3: Safe Speed* (Austroads 2021b) and also in *Guide to Traffic Management Part 5: Link Management* (Austroads 2020c) which describe the application of speed limits within a Safe System environment.

5.5.4 Enforcement

A Safe System approach requires that road users operate within certain limits to ensure that the system can protect them. As a minimum, this means that road users are expected to comply with road rules, and particularly those directly related to safety such as speed limits, traffic signals, use of mobile phones and driving under the influence of alcohol or drugs. Enforcement of these rules is an important part of ensuring that road users operate within the limits of the system.

Generally, studies show that enforcement is effective at improving the behaviour being targeted (e.g. speed cameras increase compliance with speed limits) but also at reducing associated serious injury crash frequency (e.g. red light cameras reduce right-angle crashes). Some enforcement activities are shown to be effective at improving a specific behaviour but do not show a corresponding reduction in crashes, and still others are only effective in some situations (Austroads 2020c).

5.5.5 Match the solutions to the problems

Often there will be a number of alternative countermeasures which could be applied, either individually or in combination. The final choice about which countermeasure(s) to select requires road safety engineering experience and judgement about the factors which have led to the crashes. Table 5.5 through to Table 5.8 list a range of options which can be considered. Further guidance on treatment options for intersection and non-intersection locations is provided in Sections 9 and 10 respectively.

Section 5.6 and Appendix E provide more information on the likely crash modification factors (CMF) for various countermeasures to common types of crashes. Road agencies may also have expanded lists of countermeasures and may require the use of other values when applying for blackspot funding.

Whichever CMFs are used, it is important to remember that these countermeasures will only be effective if they really are a countermeasure for the type of crashes (and the particular causes identified) at the location in question. This underlines the point that the process must firstly identify whether the safety problem at a location is amenable to treatment, then determine what (if anything) that treatment should be.

The countermeasure for one crash problem is likely to be different from the countermeasure for another problem. In some cases the countermeasures may possibly even be in conflict. For example, if there is a signalised intersection with a history of both pedestrian crashes and collisions between turning and oncoming vehicles, the latter can be tackled with fully controlled turn phasing of the signals, but this may make the pedestrian situation more complex, and perhaps even exacerbate it if the pedestrians do not obey WALK/DON'T WALK signals. In such cases road safety engineering knowledge and judgement is required to assess all possible positive and negative effects, including possible further countermeasures to address the negative effects.

5.5.6 Select the solutions

With some locations there may be a clearly defined crash pattern and an obvious countermeasure which can be confidently applied. In other cases the crash pattern is unclear and/or the solution is not evident. It may be that two solutions are relevant, one being a relatively expensive one which overcomes a large percentage of the crash problems and the other being a lower cost solution which reduces the crash problem to a smaller degree. Until the stage of analysing the benefits and costs it may be a good idea to keep both treatment options under consideration.

The practical examples provided in Appendix C.1 show the basic process for investigating a high crash location and selection of treatments.

Table 5.5: Countermeasures for crashes at intersections and major driveways

Adjacent crashes	
• Check sight distance available and where practical, clear obstructions (including parked vehicles) to provide the appropriate standard of sight distance. Where standards cannot be achieved, consider options for intersection controls or speed controls (avoid reliance on Stop signs where visibility remains poor at the stop line). • Check the minor road approaches to see if a driver's view is drawn to a distant feature, past the intersection. If so, highlight the intersection: consider a median island, larger or duplicated control signs, a roundabout if appropriate. • Check day and night visibility of traffic control devices and consider renewing, duplicating, delineating or enlarging the device. • Consider the installation of appropriate warning signs and devices. • At an unsigned T-junction, install a Give Way sign. • At signalised intersections, check adequacy of yellow phase and all-red clearance time. Also, consider red light safety cameras, larger diameter traffic signals, overhead mast arms and supplementary advance flashing yellow warning lights.	• Where a high frequency of night crashes is involved, consider adding or amending street lighting. • Consider installation of channelisation such as median islands to support control devices on side road approaches, wide median treatments (where appropriate) and staggered intersection treatments in rural areas. • Consider installation of a roundabout where the function of the two roads makes this appropriate. • At an existing roundabout consider realigning approaches to reduce speeds. • Consider installation of traffic signals where appropriate. • Install mast arms at existing signals. • At angled T-junctions, add a hazard board opposite the junction. • Check the speed limit is appropriate.
Right-turn collisions with oncoming traffic	
• If the intersection is signalised, consider provision of fully controlled right-turn phases or reduce the cycle length to increase the number of end-of-phase filter turn opportunities. • If a right-turn phase exists, consider provision of a right-turn red arrow to prohibit the filter movement. • Check the sight distance from the centre of the road or median opening to opposing traffic and improve it if necessary. • At signalised intersections, check adequacy of the yellow phase and all-red clearance time. Also, consider red light safety cameras, larger diameter traffic signals, overhead mast arms and supplementary advance flashing yellow warning lights.	• If on a divided road with a wide median, consider alignment/shape of right-turn lanes to avoid sight line obstruction by oncoming right-turn vehicles. • If at a crossroad intersection on an undivided road, consider head-to-head central right-turn lanes with painted island protection, to improve visibility past oncoming right-turn vehicles. • If through traffic can 'see through' to a second set of signals, alter phasing or realign distant lanterns and add louvers. • Consider Type B treatments at high speed rural intersections. • Check the speed limit is appropriate.

Adjacent crashes	
Straight ahead rear-end crashes	
• Check if these collisions are due to queuing by uninvolved right-turn vehicles. If this is the case, consider banning the turn or provision of a protected auxiliary turn lane. This may include a right turn just after a signalised intersection. • Where a high frequency of night-time crashes is involved, consider street lighting. • Where there is a red light camera at a signalised intersection, remove or replace with a red light speed camera. • Where there is a speed limit reduction located near to the intersection, relocate further downstream.	• If there is a high involvement of wet weather crashes, check skid resistance and pavement drainage. • At signalised intersections, check stopping sight distance to the 'tail of queue' and adequacy of the yellow phase or all-red clearance time. If there is poor visibility to signal aspects consider provision of an overhead mast arm signal. • Where closely spaced linked signals occur, check offset timing. • Where signalised intersections or crossings are close but can operate separately, check for a 'see through' effect of a distant green and near red signal. • Check that the speed limit is appropriate.
Right or left-turn rear-end crashes	
As well as considering treatments for straight ahead rear-end crashes: • Provide protected right/left turn auxiliary lanes or extend or supplement existing ones. • Consider prohibition of right-turns if this can be adequately catered for at other locations without adverse safety or environmental effects. If at a left-turn slip lane, modify the intersection angle of the lane with the intersecting road to 70 degrees minimum, or consider signalising it, or provide an added lane in the road being entered.	

Table 5.6: Countermeasures for non-intersection collisions

Side-swipe crashes	
• Check the visibility of lane lines in daylight and at night. • In a rural area provide or check adequacy of centre and edgelines and, where relevant, lane line delineation. Supplement with retroreflective pavement markers (RRPMs). • Consider provision of wider lanes. • If at an isolated curve, consider adequacy of alignment design and superelevation. Aim to remove need for drivers to reduce speed at curves.	• On the approach to an intersection, consider improving direction signing including overhead lane use signs where relevant. Also consider adequacy or provision of auxiliary lanes for turning traffic. • If at a lane drop, check that warning signs and pavement markings are to standard. • Check that the speed limit is appropriate.
Head-on crashes	
• In a rural area check adequacy of centreline marking and consider supplementing this with RRPMs. If on a curve, check delineation of the curve as well. • If at locations where visibility is restricted, consider barrier lining. • If at a location of local widening (e.g. at an intersection), check that it does not look like an overtaking lane. Consider altering right turn lane markings. • Where justified, consider separation of opposing flows by means of a painted median with or without rumble strips or by means of a raised median where economically justifiable.	• Consider increasing the number of overtaking opportunities by duplication or overtaking lanes. • If occurring on a divided roadway, consider improving delineation, widening of the median, provision of a median barrier or, if due to wrong way manoeuvres at intersections, check design, signs and lighting at intersections. • Consider removing or relocating that may encourage drivers to drive further to the centre of the road. This includes poles, trees, and barriers in close proximity to the roadside. • Check that the speed limit is appropriate.
Rear-end crashes	
• On busy roads, check forward visibility. • On freeways, take action to provide stable flow, including added lanes on uphill grades, balancing numbers of lanes, adequate merge and diverge capacity, shifting traffic from the left lane prior to heavy on-flow, variable speed limits or ramp metering.	• Provide auxiliary lanes for access to driveways and bus stops. • Check that the speed limit is appropriate.
Run-off-road type crashes	
• Consider improved delineation, including post-mounted delineators, RRPMs, edgelines, tactile edgelines and chevron alignment markers. • Consider a delineation package to treat all curves on rural high speed roads. The amount of delineation would match the risk level of the curve (difficulty). The higher risk, the more intense the delineation. • If at an isolated curve, consider adequacy of alignment design and superelevation. Aim to remove need for drivers to reduce speed at curves. • Widen the lanes or seal the shoulders. • If at critical curves, consider warning signs and advisory curve speed signing.	• Widen the edgeline on curves. • If in urban areas with a high night-time crash involvement, consider street lighting. • If there is a high incidence of wet weather crashes, check surface texture, skid resistance and pavement drainage. • Check that the speed limit is appropriate. • If a conflict point, such as an intersection, is placed towards the base of a long, steep gradient, consider removing or signalising conflict.

Hit fixed object crashes	
• As well as providing the run-off-road crash treatments listed above: • Remove or relocate objects to less vulnerable positions. • Consider relocation or use of frangible lighting poles or sign posts.	• If an object cannot be relocated or made frangible, consider provision of guardrail, crash barriers or a crash cushion. • If an object is an island, illuminate or delineate it; provide linemarking beside and past it.
Note: removing a tree or object does not prevent the vehicle from being out-off-control, but this measure will be expected to reduce the crash severity outcome of this type of crash.	
Crashes involving a parked car	
• Prohibit parking. • Indent parking, clear of the traffic lane. • If angle parking is involved consider conversion to parallel parking. • Consider increasing the clearance between the parking and through traffic lanes.	• Delineate the edge of the traffic lane past the parking area. • If there is high night-time crash involvement, prohibit parking or consider adequacy of or the provision of street lighting. • Consider whether it is appropriate to implement treatments listed for run-off-road and hit fixed object crashes.

Table 5.7: Countermeasures for pedestrian/vehicle crashes

Countermeasures for pedestrian/vehicle crashes	
• Consider provision of pedestrian operated signals (including pelican type). • If at a zebra crossing on a busy road, consider replacing it with a refuge, a median or pedestrian operated signals. • Install a pedestrian (zebra) crossing where this can be done safely (e.g. on left-turn slip lanes). • Consider barriers to inhibit jay walking. • Consider parking prohibition and/or provide footpath extensions (into a parking lane) to improve pedestrian sight lines and reduce pedestrian crossing distance. • Consider the installation of pedestrian refuge islands so pedestrians need find gaps in only one traffic direction at a time. • Where a high frequency of night crashes is involved, consider adding or amending street lighting.	• If there is a high pedestrian demand at an unsafe location, consider installing a pedestrian overpass. • Check that the speed limit is appropriate. • Consider local street traffic management measures such as road humps, raised pedestrian crossings, slow points, etc. to reduce vehicle speeds. • If at a signalised intersection consider adequacy of existing walk and don't walk intervals, consider provision of exclusive pedestrian phase, early start for walk display or ensure walk displays show on both sides of the intersection when button is pressed on one side. • If at mid-block pedestrian-operated signals, consider reducing delay to walk signal (e.g. double phasing within the cycle). If visibility is restricted: clear the sight lines or relocate crossing to where visibility is adequate. • Consider a lower speed limit. This measure may require traffic speed management treatments.

Table 5.8: Countermeasures for railway level crossing crashes

Countermeasures for railway level crossing crashes	
• Check adequacy of advance warning signs and markings. Consider advance signals or vehicle-activated warning signs. • Check the sight distance available and improve if practicable. Consider road realignment where economically justified. • If there is a high night-time crash involvement, consider provision of street lighting. • Where no warning bells and lights exist, consider their provision where economically justified. • Consider lowering the speed limit on high speed roads and heavy vehicle routes. • Check adequate stacking distance is available between adjacent control points (intersections) and rail, if not consider alternative routes for long vehicles. • Consider grade separation. • Consider overhead mast arm flashlights. • If the railway crossing is equipped with bells and lights, consider adequacy of their visibility and audibility. • Where justified, consider the provision of double-side boom barriers. • Make consistent with other nearby crossings.	• Where signals or booms are visible but ignored, consider red light cameras. • If flashlight controlled level crossing is adjacent to traffic signals, link to traffic signals to provide an early clearance phase. • Remove roundabouts installed close to level crossings as they can lead to queuing on level crossings. • If vehicles queue on a crossing add a queue detector downstream of the crossing linked to traffic signals upstream of the crossing to stop vehicles from entering the crossing when queues are present. • If vehicles queue on the crossing add yellow box hatching and ‘keep crossing clear’ signs. • If crossing has two tracks and trains can arrive from either direction at the same time, install boom barriers. • Provide rumble strips to highlight the approach to the crossing. • Provide visual traffic calming measures to encourage slower approach speeds towards the crossing. • Upgrade passive railway level crossing to active railway level crossing. • Provide median barriers.

5.6 Crash Modification Factors

Detailed information exists on the expected benefits that are likely to come from different engineering treatments. The benefits are termed Crash Modification Factors (CMFs, expressed as a fraction, indicating the expected remaining crashes) or Crash Reduction Factors (CRFs, expressed as a percentage reduction). Ideally, the reduction in death and serious casualties would be used, but unfortunately information that breaks crash reduction down by severity is rare. Instead, the reduction in casualty crashes is often used as a proxy.

CMFs provide an indication of the expected remaining casualty crash rate following the implementation of a typical countermeasure. This will help the practitioner choose the treatments that are likely to bring about the greatest safety benefits depending on the crash types targeted.

The CMF serves as a simple multiplication factor applied to the existing crash rate. Therefore, a CMF of less than one indicates a reduction in the crash rate, whilst a CMF greater than one indicates an increase.

Reliable information on crash reduction has been produced by Austroads (2012c) for use in Australian and New Zealand conditions. Appendix E shows CMFs for various treatment options. Extensive information on CMFs is also available from overseas (e.g. Elvik et al. 2009; CMF Clearinghouse from the US, see www.cmfclearinghouse.org). Overseas sources of information on CMFs should be used with caution, as the environment where such treatments were used may be different to local conditions. Evaluations of treatments also have variable quality, so care should be taken when selecting these.

Crash countermeasure selection is not as simple as identifying the treatment with the lowest CMF. The practitioner should identify the most applicable treatment for the crash type and road environment considered, and then consider the relevant CMF.

Crash Reduction Factors (CRFs) are often also referred to. These provide information on the expected percentage reduction (or increase) in casualty crashes (i.e. a CMF of 0.8 would be the same as a CRF of 20%).

Care should be taken when applying CMFs to ensure that the treatment type being considered will appropriately address the crashes of concern, and not result in any adverse impacts. Appendix C.4 presents practical examples of what to consider when applying CMFs.

The development of CMFs is an ongoing process (Beer & Beer 2017), with these values further refined as new information comes to light. Most jurisdictions provide their own list of CMFs. Austroads also conducts and publishes research in this field (see Austroads 2010d and Austroads 2012c).

5.6.1 Multiple treatments

It is often the case that more than one treatment will be applied at the same location. As an example, at a rural bend where road users are running-off-road, and where site investigation justifies this, improvements could be made to the road surface as well as to delineation (e.g. new signs and road markings). An analysis of treated crash locations in New Zealand identified that around 80% of sites used a package of countermeasures to address crash risk (e.g. Turner & Tziotis 2006).

In such situations, CMFs cannot simply be added together. If this were to happen, inclusion of more treatments would eventually lead to a situation where the expected crash reduction would exceed 100%. Instead, a diminishing return is usually expected with each additional treatment type. A number of techniques exist to calculate the cumulative benefit of more than one treatment. The most common approach used is application of Equation 1:

$$\mathrm{CMF_t} = \mathrm{CMF_1} \times \mathrm{CMF_2} \times \mathrm{CMF_3} \times \ldots \qquad 1$$

where

CMF_t = total crash modification

CMF_x = individual crash modification for treatment x

As an example, if three treatments are being considered in one location, with respective CMFs of 0.6, 0.75 and 0.8, the results would be as follows.

CMF_t = 0.6 x 0.75 x 0.8

= 0.36, or 36% of crashes will remain (i.e. 64% of crashes will be eliminated).

Whilst each treatment acts to reduce crashes, the impact of each successive crash on reducing the numbers of crashes is diminished.

In some cases there will be diminishing returns similar to those identified in the formula above. In other cases, the addition of treatments may produce negligible additional benefit, or treatments may act together to provide benefits greater than the sum of the individual treatments. Professional judgement is required when making estimates of the combined benefits of more than one treatment.

5.6.2 Step 1: Select the most appropriate countermeasure/s

Using Table 5.5 to Table 5.8 and road safety engineering experience and judgement, select either:

- one solution
- a combination of solutions
- two alternative solutions (e.g. lower and higher cost solutions with different crash reduction effects), for the repeated crash types at the location.

5.6.3 Step 2: Apply CMFs

Use Appendix E (or alternative, robust sources of effectiveness values) to determine the effect of the proposed treatment. The cost information in Appendix E will be used in Section 6 to estimate the economic benefit of the proposal.

Do not, as a first step, go to Appendix E to find a solution which produces a good benefit/cost ratio to justify a project. Step 1 must always be applied first, to match any solution to the factors contributing to the crash types.

For example, CMFs are available to estimate the crash reduction as a result of applying audio-tactile edgelines as a countermeasure to combat run-off-road crashes.

Figure 5.3: Audio-tactile edgelines as a remedial treatment for run-off-road crashes

Source: Safe System Solutions Pty Ltd

Documentation:

After these steps, document the selection of the countermeasure/s, in a format suitable as part of the final crash location investigation and treatment report (Section 8). It will include:

- a list of the proposed treatments which are designed to counter the identified crash causes (with mention made about which treatment is aimed at which problem)
- a plan of the preliminary design of the countermeasures (Section 5.7).

The document may put forward two or more options to be considered, i.e. each with unique costs and effects on crash reduction.

5.7 Implementing the Treatment

5.7.1 Designing a safe remedial treatment

Preparing a preliminary design: show the solution is practicable

The selected countermeasures need to be developed into a preliminary design in order to:

- show the general practicability of the countermeasures at this location
- check the compatibility of the proposals with the surrounding roads and intersections
- establish whether there is adequate space, or whether land acquisition is required
- check the vertical geometry for basic issues such as sight distance
- allow further consideration of options
- permit an initial cost estimate, so that an economic appraisal can be made (see Section 6).

Have the design road safety audited

Once this is done, the preliminary design should be road safety audited. An audit is a formal examination of a design by a qualified team with experience in road safety engineering (see *Guide to Road Safety Part 6: Managing Road Safety Audits* (Austroads 2019a)). An audit is an input into the design process. Its aim is to help the designer produce a safe design, by identifying any foreseeable safety problems that the design may contain.

Where feasible a road safety audit should be conducted at the following stages:

- the feasibility stage
- the preliminary design stage
- the detailed design stage
- prior to opening of the project.

The earlier a design is audited, the easier and more cost-effective it is to consider and incorporate changes, resulting in less wasted design time and effort.

Designs for crash remedial treatments should not be considered to be immune from potentially unsafe design flaws. Indeed, because the aim of a treatment is to reduce the number or severity of crashes, it would be unfortunate if new and unforeseen crash problems were to result from some aspect of the new design. The chances of this happening can be minimised by having the design road safety audited.

Completing a detailed design

Detailed design can occur at any stage after the preliminary design. This may mean that it occurs well after the crash location treatment report (Section 8) is finalised.

The detailed design will incorporate all the information required to permit the treatment to be implemented safely. This will include details such as signs, markings, landscaping and lighting, as well as those recommendations from the preliminary design audit which the project manager has decided to adopt.

Depending on the scale of the project and the safety design issues identified in the preliminary design audit, the detailed design may also benefit from a road safety audit (see the practical example in Appendix C.5.

Design of devices

Devices are installed on roads for a range of reasons, for example:

- traffic management treatments to reduce speed
- kerbs, gutters and culverts to collect and disperse rainwater runoff
- guide posts to hold reflectors for night-time delineation
- signs to provide traffic control, warning or guidance
- posts to hold signs or delineators
- crash barriers to shield roadside hazards
- traffic signal poles to hold up traffic signal lanterns and detectors
- utility poles to provide services (generally a non-road function, or lighting)
- medians and barriers to separate opposing flows.

Each of these devices has the potential to inflict damage and injuries in the event of a vehicle or vehicle occupant leaving the roadway. Recognition of the injury causing effects of device design has led to the concept of a clear zone, the development of frangible posts and barrier end treatments and the extensive use of low profile, mountable kerbs. But many devices are of the same fundamental design as they were before the safety of errant vehicles and vehicle occupants took on the importance it has today.

Practitioners are faced with a limited choice for the physical devices that they can use in traffic management: some devices which have undergone safety development have complex failure mechanisms and modification requires a detailed understanding of them (e.g. w-beam guard fence). However a broad understanding of the principles of safe design for traffic devices will allow practitioners to assess the suitability of existing devices and new products which may be marketed without specific consideration of impact safety.

Using standards does not guarantee a safe road design, but it is an important starting point. The intersection shown in Figure 5.4 is potentially confusing by having Give Way controls on three of the four legs, instead of just two opposing legs. The holding lines do not have an approach centreline, making them harder to detect. These matters are covered by the national standard on traffic control devices (Australian Standards AS 1742.2:2009).

Figure 5.4: Example of an intersection where layout and priority are confusing

5.7.2 Implementing the treatment

Once the countermeasure has obtained funding it can be procured and implemented. It is vitally important that the design which is being implemented accords with the results of the crash investigation: that it has not been modified or trimmed to the point where it will not have a meaningful effect on the crash problem. If it is being implemented in conjunction with other works at the site or nearby, it is important that these other works do not introduce any new safety problem. If there is any reason for concern, road safety engineering advice (e.g. in the form of a detailed design stage road safety audit) should be sought.

Prior to committing remedial works to commence practitioners should check that the assumptions upon which the report's conclusions and recommendations are based have not changed in the intervening period.

During the implementation phase, traffic safety will continue to be important. Works zones can be potential places for crashes, due to the changes in road layout and the temporary absence of permanent kerbing, delineation, markings or signs. Works zone traffic controls need to be planned before works commence and carried out in a manner which provides safely for the travelling public and works personnel. National and state guidelines on roadwork traffic management should be complied with. For larger, more complex projects, a road safety audit of the construction stage should be considered. This involves auditing the traffic management plans and undertaking site inspections during the construction.

Once the works have been completed, the project can be the subject of a pre-opening road safety audit, to ensure it is implemented as planned and with no unexpected road safety hazards introduced.

6. Economic Appraisal

The key objectives of economic appraisal are to ensure that treatments are cost-effective, and that they optimise road safety benefits producing the greatest reduction in fatal and serious injury based on available budgets. The term appraisal is used here to refer to the analysis of measures before they have been undertaken. By contrast, the word evaluation is used to refer to the analysis of measures after implementation. The word evaluation is sometimes used generically to refer to either process, but the terminology used here is consistent with current practice.

This section of the guide provides an overview of the economic appraisal approach. Appraisal approaches include cost-effectiveness analysis (CEA) and benefit cost analysis (BCA) (also referred to as cost benefit analysis). Benefit cost analysis uses monetary values to compare total benefits with total costs of any given countermeasure indicating whether a project is worthwhile and to determine the applicability of an investment based on the total benefits and costs of the investment. It is also used to compare a project with any alternative projects, isolating and measuring the benefits and costs of each project.

The steps for conducting BCAs are outlined below and discussed in Section 6.1.2 to Section 6.3.

- Project definition: identify the crash problem, define the target and outline treatment options.
- Define base case and project options.
- Determine parameters (e.g. treatment life, discount rate, time frame etc.).
- Identify and quantify all impacts (benefits and costs, in terms of treatment effectiveness i.e. the target number of crash reductions; implementation, maintenance and operation costs, social cost of crashes etc.).
- Convert all benefits and costs to present values (discounting).
- Calculate the benefit cost ratio and net present value.
- Sensitivity analysis.
- Report and present results.

For more detailed information, refer to the *Guide to project evaluation part 2: Project evaluation methodology* (Austroads 2012a); *Economic evaluation manual Volume 2* (New Zealand Transport Agency 2013b) and the *National guidelines volume 3: Appraisal of initiatives—a comprehensive guide to appraisal of transport initiatives* (Australian Transport Council 2006). Practical examples are provided in Appendix C.7.

6.1 Cost of Crashes and Remedial Treatment Options

6.1.1 Treatment options

The first step in the analysis is to identify the scale and nature of the road safety problem. This entails obtaining the number of observed crashes and injury types (e.g. fatal, serious, minor) over a specific period of time. The data forms the basis from which reductions in crash occurrence and severity, and thus benefits are estimated (see Section 5.1).

Countermeasure options generally differ in levels of expenditure and maintenance costs. Treatment options selected will depend on the direct impact on the identified crash problem. As discussed in Section 5.5, and Section 5.6, this involves selecting targeted remedial treatments that have been demonstrated to reduce the likelihood and/or severity of these crashes.

An assessment of the safety problems at a site may lead to recommendations for very low cost engineering treatments, such as a few signs, or some added line marking, or chevron alignment markers around a curve. The example in Appendix C.6 is an illustration of where a crash investigation team expected six signs and some minor line marking to have a significant effect on the crash type investigated – at least until a higher cost, permanent treatment could be funded.

If a very low cost treatment is judged to be an effective course of action, there is little point undertaking a full economic appraisal of it. It may well cost more in time and effort to justify the expenditure than to implement the treatment. It should simply be implemented as soon as possible, e.g. using a budget allocation for minor safety works or for maintenance. But keep in mind:

- Any very low cost treatment must actually reduce the identified crash type(s).
- There is a limit to how effective very low cost treatments can be; to treat most crash locations a significant expenditure of money will be required.
- Avoid the temptation to solve every problem by putting up a sign although it is also important to check existing signs are appropriate and well maintained.

6.1.2 Cost of crashes

A key component of benefit cost analysis is the cost of crashes. The benefits from safety countermeasures over time are estimated by placing an economic value on crashes and applying this to the expected reduction in crashes (by injury or crash severity). This economic value, referred to as the social cost of crashes, is the value of property damage caused by vehicle crashes, medical and ambulance costs, insurance and administration costs, loss of output costs, police costs and human costs associated with the pain and suffering caused by death and injury. In Australia, the cost of crashes are calculated using both the human capital and the willingness-to-pay approaches while in New Zealand, the willingness-to-pay approach is used. The cost components are outlined in Table 6.1.

Table 6.1: Crash cost components for Australia and New Zealand

Crash cost components for Australia	Crash cost components for New Zealand
• Human costs - ambulance costs, hospital in-patient costs, other medical costs, long-term care • Labour in the workplace, labour in the household, quality of life • Insurance claims, criminal prosecution, correctional services, workplace disruptions, funeral, coroner • Vehicle costs- repairs, unavailability of vehicles, towing • General costs- travel delays; insurance administration, police, property, fire	• Loss of life and life quality (permanent disability) • Loss of output (temporary disability) • Medical costs – hospital/medical costs, emergency/pre-hospital costs, follow-on costs • Legal and court costs • Vehicle damage costs

Source: Ministry of Transport (2013) and Transport and Infrastructure Council (2015)

There have been many projects and considerable debate about the best way to determine crash costs but it is now generally accepted that only two methods should be considered: the willingness-to-pay (WTP) and the human-capital (HC) approaches. The WTP approach values society's willingness to pay for avoiding death, injury, and damage outcomes from road crashes. The HC approach is described as 'resting on accounting principles, the benefit of avoiding a premature death is given by the present value of the income flow the economy could lose in that case' (Rizzi and Ortuzar 2005). For a detailed description of these approaches, see Bureau of Infrastructure, Transport and Regional Economics (2006), Austroads (2012a), and the World Road Association (PIARC 2012).

Costs must be determined for crashes of varying levels of severity, that is, fatal, serious injury or minor injury. These severity levels have been defined in Section 3.1. The costs also vary by environment (urban and rural road environments) as outlined in Table 6.2 and Table 6.3 showing the human capital and willingness-to-pay estimates respectively.

Table 6.2: Human capital average crash cost estimates for Australia at June 2013 prices (A$)

Jurisdiction	Rural			Urban		
	Fatal crash ($)	Serious injury crash ($)	Other injury crash[1] ($)	Fatal crash ($)	Serious injury crash ($)	Other injury crash[1] ($)
New South Wales[2]	2 875 402	588 546		2 538 351	546 230	
Victoria	2 843 808	628 913	26 217	2 521 383	562 234	24 550
Queensland	2 728 617	642 034	25 822	2 456 691	595 802	23 760
South Australia	2 826 042	610 963	26 079	2 385 285	553 306	23 479
Western Australia	2 868 661	638 357	28 969	2 447 722	583 884	26 899
Tasmania	2 568 291	579 621	28 381	2 351 822	533 536	24 695
Northern Territory	2 803 647	664 274	24 241	2 945 055	620 767	23 343
Australian Capital Territory				2 857 595	536 679	

1. *Minor crashes.*
2. *Serious crash costs computed using the ratio of serious and other injury crashes for all of Australia.*

Source: Transport and Infrastructure Council (2015).

The willingness-to-pay values for Australian jurisdictions were obtained using the willingness-to-pay estimates from Hensher et al. (2009) and crash data for 2010. The values were updated to June 2013 prices. The values for New Zealand in Table 6.3 were obtained from the Ministry of Transport (2013) while the values for New South Wales were obtained from Transport for New South Wales estimates (Transport for New South Wales 2013). All estimates are at June 2013 prices.

Table 6.3: Willingness to pay average crash cost estimates for Aus and NZ June 2013 prices (A$)

Jurisdiction	Rural			Urban		
	Fatal crash ($)	Serious injury crash ($)	Other injury crash(1) ($)	Fatal crash ($)	Serious injury crash ($)	Other injury crash[1] ($)
New South Wales[2]	7 848 085	216 675		6 476 155	136 505	
Victoria	8 319 000	289 603	31 746	8 217 515	407 929	24 225
Queensland	8 059 079	294 906	31 268	7 741 325	436 471	23 446
South Australia	8 725 852	297 939	31 579	7 625 610	424 018	23 168
Western Australia	8 537 384	294 498	35 079	7 796 362	423 650	26 544
Tasmania	8 087 424	267 427	34 368	7 525 710	386 848	25 831
Northern Territory	8 043 372	302 627	29 353	8 439 524	449 694	23 034
Australian Capital Territory				8 982 222	389 364	
New Zealand	4 640 000	871 000	91 000	4 260 000	783 000	82 000

1. *Minor crashes.*
2. *Serious crash costs computed using the ratio of serious and other injury crashes for all of Australia, cost estimates based on recent willingness-to-pay values for NSW released by Transport for New South Wales.*

Source: Transport and Infrastructure Council (2015), Ministry of Transport (2013).

For the purpose of prioritising actions aimed at reducing crash frequency, a single average cost for all injury crashes is generally considered sufficient, particularly in view of the difficulty in predicting the specific severities of crashes that might be prevented.

The value of the crash reduction benefits is calculated using the standardised costs of particular crash types (DCA codes). Table 6.4 illustrates this information for one Australian state (Queensland). The dollar values in the table will be different in each state and territory as they are affected by the proportion of recorded crashes (by crash type) which are non-injury. This varies from jurisdiction to jurisdiction. Otherwise check with the road agency for up-to-date values applicable to the location being assessed. A method for calculating these values is given in Section 7 of Andreassen (1992a; 1992b).

Table 6.4: Example crash costs by crash type (A$)

DCA code group	DCA codes	Description	Low speed < 80 km/h $	High speed 80 km/h + $
Two vehicle crashes				
1	100–109	Intersection, from adjacent approaches	93 440	213 559
2	201, 501	Head-on	213 320	372 921
3	202–206	Opposing vehicles, turning	92 482	183 888
4	301–303	Rear-end	46 421	89 850
5	305–307, 504	Lane change	72 502	223 250
6	308, 309	Parallel lanes, turning	64 845	182 572
7	207, 304	U-turn	88 654	187 836
8	401, 406–408	Entering roadway	65 683	122 034
9	503, 505, 506	Overtaking, same direction	87 816	139 621
10	402, 404, 601, 602, 604, 608	Hit parked vehicle	65 802	147 756
11	903	Hit train	259 262	522 591
Single vehicle crashes				
12	001–009	Pedestrian	196 929	347 437
13	605	Permanent obstruction on carriageway	89 611	151 705
14	609, 905	Hit animal	48 215	53 838
15	502, 701, 702, 706, 707	Off carriageway, on straight	72 502	147 756
16	703, 704, 904	Off carriageway, on straight, hit object	139 023	251 365
17	705	Out of control, on straight	100 977	194 297
18	801, 802	Off carriageway, on curve	122 871	216 909
19	803, 804	Off carriageway, on curve, hit object	164 626	281 156
20	805, 806, 807	Out of control, on curve	104 925	143 449
Exceptions				
21	000, 200, 300, 400, 500, 600, 700, 800, 900, 901, 906, 907, 403, 405, 606, 607, 610	Crashes which are unlikely to be attributable to any road environment factor, and which are therefore unlikely to be addressed by any road-based remedial treatment. Crashes in this DCA code group will not be used in crash rates or BCR calculations or reports.		

Notes:

- Crash costs for Queensland – estimated per crash by crash type.
- Costs are in 2014 dollars.
- Costs are based on those contained in Crash costs – 2001: costs by accident-type (Andreassen 2001), factored up by CPI and rounded to the nearest $100.

6.2 Calculating the Costs and Benefits

6.2.1 Key parameters

The key parameters for estimating countermeasure benefits and costs include the countermeasure's treatment life, costs, benefits and the discount rate.

Treatment life

Project or treatment life refers to the time period over which a treatment will deliver safety benefits before major rehabilitation or replacement is required. The treatment life varies with type and scope of project, climate causing infrastructure to deteriorate, traffic volume either causing infrastructure to deteriorate or growth causing congestion requiring changes to infrastructure, local standards and resource availability affecting ability to replace infrastructure when due and level and regularity of maintenance (Austroads 2010c).

For projects involving multiple treatments e.g. network or national blackspot programs, the service life applied is that of the longest-lived component. According to Austroads (2010c), accurate information on a countermeasure's life helps determine the allocation of funds so as to achieve the most cost-effective returns in terms of injury and crash reductions. Table 6.5 outlines example treatment lives for the different countermeasures.

Table 6.5: Treatment life examples

Treatment type	Recommended maximum treatment life (years)
Grade separation	50
Realign curve	35
Stagger or realign intersection	35
Roundabout	30
Median barrier	30
Shoulder sealing or widening	25
Add or widen lane (including overtaking lane)	25
Provide acceptable superelevation	25
Railway level crossing barriers	20
Median island (or other island)	20
Guardrail (roadside)	20
Street lighting	20
Remove roadside hazard (trees, pylons, etc.)	20
New traffic signals (hardware and/or software)	15
Improve sight distance by removing impediment on main road	10
Edge marker posts (guideposts)	10
Skid resistant surface	10
Signs (advisory, warning, parking, speed limit, etc.)	10
Linemarking (thermoplastic)	5
Raised reflectorised pavement markers	5
Linemarking (paint)	3

Source: Adapted from Austroads (2010c)

Costs

Total countermeasure costs include: implementation (installation, material and labour costs), routine and periodic maintenance, and any operating costs (e.g. electricity supply).

There are different definitions of treatment costs with some texts defining costs as initial or upfront costs only and others treating costs as both initial and operating/maintenance costs. It is common practice to include changes in maintenance expenditure on the costs side of the equation, as these are a cost (or saving) to the road agency. This section will treat ongoing/operating costs as negative entries in the benefits balance sheet. Whichever definition is chosen, it is important that it be applied consistently, because criteria based upon dividing one number (e.g. costs) into another (e.g. benefits) will produce different values depending upon the definition of costs and benefits. Funding programs or government agencies (e.g. treasury) often specify what must be included in costs.

Initial cost (e.g. engineering and capital)

Initial costs refer to the costs incurred up-front, as the project is designed and built (implementation costs) e.g. installation, material and labour costs for each countermeasure. The costs differ by road environment type, traffic volumes, local environment, local labour costs and availability of materials (Australian Transport Council 2006, Austroads 2012a).

Annual maintenance and operating costs

These costs refer to routine and periodic maintenance costs and running costs. The level and regularity of maintenance and associated running costs depend on the countermeasure or in the case of multiple treatments, countermeasures.

Benefits

The benefits of a safety countermeasure principally comprise savings in road crash costs which are estimated to result from its implementation. They are due either to a reduction in the number or the severity of crashes. Other significant cost reductions or increases resulting from the treatment should also be included. Unlike the cost, which is usually incurred in one (or possibly two) years when the project is designed and built, the benefits are gained over the life of the project.

Benefits are expressed in terms of monetary savings from crash reductions or prevention of casualties (fatalities and injuries) over a given number of years. For example, in the case of crash location treatments, the estimate of resulting crash changes reflects the changes in target crashes (i.e. crash types the treatment is aiming to prevent).

The crash changes can be presented as crash rates (e.g. per 100 million vehicle-kilometres of travel) or as changes in the number of casualty crashes. The use of crash rates as an estimate of crash changes depends on whether they reflect the number of crashes and crash severity and how they are measured (Bureau of Infrastructure, Transport and Regional Economics 2012). In some cases, the crash rate may not fully reflect the changes in crash severity. The effectiveness and magnitude of crash changes vary, for example by road environments, i.e. built-up (urban) and non-built-up (rural); and the existing crash severity and type.

Treatment effectiveness is measured by crash modification factors (CMFs) as outlined in Section 5.6. Different methods are used to obtain the numbers of crashes avoided and to estimate the treatment effectiveness. The estimate of treatment effectiveness depends on different factors including data availability related to the past performance of the treatment, estimation method (i.e. whether confounding factors are taken into account), local conditions and changes in traffic volumes over time. In the case of multiple treatments, evaluation studies traditionally identify and measure the effectiveness of the primary or main treatment.

6.2.2 Discounting

In any economic appraisal, it is important to identify a given base year from which all future costs and benefits can be assessed. This is because the value of a dollar received in the future is less than the value of a dollar now (also referred to as the time value of money). Crucial to this process is the appraisal period, base year and discount rate.

Appraisal period

The selection of an appraisal period has a critical impact on the value of benefits and costs. The potential economic/treatment life of the project should only be used as the appraisal period after careful consideration because traffic patterns, traffic management objectives, technology, etc. may all change over the whole economic life of the works.

For example, the period used for appraisal for road marking projects will usually be no greater than five years, while those for signing and road surface improvements will generally not exceed 10-years. For construction of new works, the appraisal period will generally be up to around 20-years, although in some circumstances (e.g. grade separation or curve realignment), the appraisal period may be far greater. Specialists in individual jurisdictions should be consulted regarding appraisal periods.

Base year

The base year is the year to which all monetary values for the impacts (benefits and costs) of a treatment are discounted. According to Austroads, the base year for small projects is usually the first year of implementation but varies from the year preceding construction to the year preceding operation or the last year of construction.

Discount rate

The discount rate is used to convert future benefits and costs to present values. The appropriate discount rate for this form of economic appraisal is often a matter of some disagreement. Often, it is prescribed by another arm of government (a treasury or department of finance) in order to maintain consistency across different agencies. In Australia, values of 4 to 7% are in common use while in New Zealand the discount rate is 8%. These are real values, i.e. the nominal value minus the rate of inflation.

The choice of discount rate can have significant effects on the desirability and selection of projects, especially where benefits and costs accrue later in the treatment's life. A higher discount rate reduces the value of benefits and costs occurring later in the treatment's life, favouring projects where benefits occur early in the project as illustrated in Table 6.6.

Table 6.6: Illustrating discount factors for different discount rates

Year[1]	Discount rate			Year[1]	Discount rate		
	4%	7%	8%		4%	7%	8%
0	1	1	1	16	0.534	0.339	0.292
1	0.962	0.935	0.926	17	0.513	0.317	0.27
2	0.925	0.873	0.857	18	0.494	0.296	0.25
3	0.889	0.816	0.794	19	0.475	0.277	0.232
4	0.855	0.763	0.735	20	0.456	0.258	0.215
5	0.822	0.713	0.681	21	0.439	0.242	0.199
6	0.79	0.666	0.63	22	0.422	0.226	0.184
7	0.76	0.623	0.583	23	0.406	0.211	0.17

Year(1)	Discount rate			Year(1)	Discount rate		
	4%	7%	8%		4%	7%	8%
8	0.731	0.582	0.54	24	0.39	0.197	0.158
9	0.703	0.544	0.5	25	0.375	0.184	0.146
10	0.676	0.508	0.463	26	0.361	0.172	0.135
11	0.65	0.475	0.429	27	0.347	0.161	0.125
12	0.625	0.444	0.397	28	0.333	0.15	0.116
13	0.601	0.415	0.368	29	0.321	0.141	0.107
14	0.577	0.388	0.34	30	0.308	0.131	0.099
15	0.555	0.362	0.315	31	0.296	0.123	0.092

1. *Refers to the number of years from base year.*

To calculate the present value, first compute the discount factor as in Equation 2:

$$\text{discount factor} = \frac{1}{(1+\mathrm{r})^{\mathrm{t}}} \qquad (2)$$

where

r = discount rate

t = number of years from base year

The present value is therefore computed as the benefit or cost multiplied by the discount factor. The values are used to calculate an index which is used to assess the worth of the treatment, and later to rank it against other candidate projects for a works program.

6.2.3 Calculating costs and benefits

Selection criteria in benefit cost analysis include the first year rate of return (FYRR), the internal rate of return (IRR), benefit cost ratio (BCR) and incremental benefit cost ratio (IBCR) as well as net present value (NPV). However, the two main indicators in assessing a project or treatment are the BCR and the NPV. They indicate whether the benefits of the proposed treatment outweigh the costs and if the preferred treatment has the greatest net social benefit.

Benefit cost ratio

Benefit cost ratio (BCR) is defined as the present value of benefits (net operating and maintenance costs) divided by the present value of implementation costs. It is used to rank projects where there is a budget constraint and serves as an indicator of a project's economic efficiency (Equation 3):

$$\mathrm{BCR} = \frac{\mathrm{PV(B-OC)}}{\mathrm{PV(IC)}} \qquad (3)$$

where

PV = present value

B = all benefits

OC = treatment operation and maintenance costs

IC = treatment implementation costs

Source: Australian Transport Council (2006).

A BCR greater than 1.0 indicates that the alternative is worthwhile, and the greater the BCR, the higher the benefits are. However, this says nothing in itself about whether a project should be undertaken. Although the approach can determine whether a project is worthwhile, ranking according to BCR will not necessarily maximise reduction in fatal and serous crash outcomes. BCR tends to provide more favourable outcomes to low cost treatments, which may be less effective in terms of fatal and serious casualty reduction. For example, installation of warning signs, although providing a high BCR tend only to marginally reduce fatal and serious crash outcomes marginally. For this reason, it is recommended that BCR not be used on its own when prioritising options, but rather NPV also be used. Also see Section 6.3 regarding the ranking of alternative projects.

Net present value

Net present value (NPV) is the difference between the discounted (present value) monetary value of all the benefits and costs of a particular project or measure. A treatment with a positive NPV can be regarded as economically worthwhile, i.e. the community is better off to undertake it than not. A positive NPV therefore indicates an improvement in economic efficiency compared with the base case. The NPV is expressed as (Equation 4):

$$\mathrm{NPV} = \sum_{\mathrm{t}=0}^{\mathrm{n}} \frac{\mathrm{B_t} - \mathrm{OC_t} - \mathrm{IC_t}}{(1+\mathrm{r})^{\mathrm{t}}} \tag{4}$$

where

t	=	time in years
n	=	number of years during which benefits and costs occur
B_t	=	benefits in year t
OC_t	=	operating and maintenance costs in year t
IC_t	=	implementation costs in year t

The major methodological advantage of the NPV method compared with the BCR method is that it provides a consistent, simple comparison of alternatives and is unaffected by interpretations or errors in deciding what is a cost or a benefit. Moreover, the NPV method is applicable where there is a budget constraint (Section 6.3).

Conduct sensitivity tests

An economic appraisal should always be subjected to a sensitivity test. This is a test to determine how sensitive the results are to changes in the assumptions made about the values of variables.

In particular, a range of expected crash reduction percentages should be assessed, since one can never be certain about the actual outcome (see Section 5.6). Using a low and a high estimate of possible and realistic outcomes is always good practice. If the outcome is favourable, even when a pessimistic forecast of crash reduction is used, one can be confident that the project is worthwhile. Conversely, if the outcome is unfavourable even with optimistic assumptions, one can be confident that the project is unlikely to be worthwhile.

It is in the middle ground (favourable under optimistic assumptions and unfavourable under pessimistic assumptions) where effort should be put into refining the estimates of assumed values to get a better forecast of benefits and costs. Austroads (2012a) provides further information on sensitivity testing.

6.3 Ranking the Treatment of Crash Locations

Once each countermeasure has been subjected to an economic appraisal, all the candidate projects need to be ranked to decide which one to implement. Usually this means comparing all projects' NPVs or BCRs. The key objective is to provide the greatest benefit (reduction in fatal and serious crash outcomes) for the available budget. The economic appraisal is an aid to decision making. If all decisions are based on benefit/cost ratios alone, a situation can arise where, for example:

- a project is delayed until the number (cost) of crashes is sufficient to justify the project, even though at the time it is delayed it can be reasonably predicted that the rate of crashes will continue unabated
- the cost of a treatment is artificially restricted and it does not include sufficient improvements to address the crash problems.

Consequently, the ranking procedures described in this section should not preclude decision makers from applying sound judgement to approve projects which need to be advanced or which need adequate funding to achieve project objectives.

The choice of selection/ranking criteria depends primarily on available data as well as the scope of the treatment. The NPV provides information on the total welfare gain over a project's treatment life while the BCR highlights the relationship between the present value benefits and implementation costs of a project (PIARC 2012).

The NPV method is applicable where there is a budget constraint and the aim is to select the most worthwhile set of projects. In this case, the solution is to 'combine those projects whose total initial costs are less than or equal to the budget constraint but whose combined total net value is the largest' (Wohl & Hendrickson 1984, p.173).

The benefit/cost ratio itself must not be used to rank alternatives. Rather, ranking involves a comparison of all alternatives with a BCR > 1. Generally, the NPV is the preferred criterion as it provides an estimate of the absolute size of the treatment's net social benefit. Table 6.7 provides guidance on when to use the different criteria.

Table 6.7: Decision criteria for economic evaluation

Criterion			
Budget	**Decision context**	**Net present value (NPV)**	**Benefit-cost ratio (BCR)**
Unconstrained budget	Accept-reject decision	Accept if NPV is non-negative ✓	Accept if BCR exceeds/equals unity ✓
	Option selection	Select project with highest non-negative NPV ✓	No rule exists ×
Constrained budget	Accept-reject decision	Select project such that NPV of project set is maximised subject to budget constraint ✓	Rank by BCR until budget is exhausted or BCR cut-off reached ✓
	Option selection	Highest NPV subject to budget constraint ✓	No rule exists ×

An alternative approach is to apply the goals achievement approach, whereby projects are ranked but no attempt is made to assess their economic benefits against their costs. This is discussed in Section 6.7.

For a comprehensive step-by-step approach on economic appraisals as well as a summarised discussion of the selection criteria, see Austroads (2005b), Australian Transport Council (2006), Bureau of Infrastructure, Transport and Regional Economics (2012), and the World Road Association (PIARC 2012).

6.3.1 A useful checklist

With economic appraisal of proposals increasingly required for road safety engineering projects, here is a useful checklist, particularly in conjunction with sensitivity testing (based on Andreassen 1992a, p.11):

- identify the project costs in terms of capital, maintenance and operating costs
- select an appraisal period
- chose a discount rate
- define the effects on various crash types
- differentiate between the effects of this treatment on (i) crash frequency (numbers) and (ii) casualty outcomes (severities)
- use robust data to estimate the effects of this treatment on the frequency of crash types
- identify the crash type or types in which this treatment is likely to have its greatest effect on the casualty outcome
- identify other crash types in which this treatment may have some effect on the casualty outcome.

6.4 Presenting the Results

Having conducted the economic appraisal, present the results in a form which allows the decision maker to review the values for net present worth of benefits and costs and the values of the selected relevant variables. Tabular or graphical presentations, highlighting the economic benefits, the crash savings and the expected performance against crash reduction targets can be helpful in explaining the results of the appraisal. Presentation of results is discussed further in Section 8 and Austroads (2011b).

6.5 Applying to Routes, Areas and Mass Actions

6.5.1 Routes and areas

Where a route or area-wide action is being considered, the route or area should be divided into individual components (usually by individual devices) and the benefits and costs calculated separately. The costs and benefits can then be aggregated over the entire scheme to arrive at the net present value or benefit/cost ratio. In some instances separate NPVs or BCRs can be calculated for individual components of the scheme where it is considered that these components could be installed as stand-alone treatments. Take care, though, that this does not result in a route or area having a series of inconsistent layouts or treatments after only the high BCR sites are treated.

6.5.2 Mass actions

For a mass action scheme the NPV or BCR should be calculated for the scheme as a whole. Mass actions are implemented on the basis that individual sites may not have a crash problem, but collectively the type of road feature is known to have a worrying incidence of crashes. It is thus not correct to calculate the BCRs separately for each site or for those sites having the greatest numbers of crashes.

6.6 Post-completion Evaluation

Post-completion evaluations are carried out after the project has been implemented. They assess the project's performance against the stated objectives and identify future improvements. They also provide feedback on the efficiency of implementation, the effectiveness of the measure, feedback on the project evaluation process, lessons learnt and indicate whether the investment was worthwhile.

The timing of post-completion evaluations should allow for the project effects to settle, meaning they should not be in the early stages of project implementation. The main component of post completion evaluations involve comparing the observed before and after crash rates and comparing these to the forecast crash modification factors to determine if the forecast effectiveness was realised. See Bureau of Infrastructure, Transport and Regional Economics (2012) and Austroads (2012b).

6.7 Alternatives to Benefit Cost Approach

6.7.1 The goals achievement approach to project appraisal

The 'goals achievement' approach is an alternative to the economic appraisal method discussed above. It aims to show the extent to which alternative proposals achieve a range of pre-set goals. The goals may be both quantifiable (e.g. economic) and non-quantifiable (e.g. social and environmental). The purpose of this evaluation is to present the decision maker with information about the consequences of alternative courses of action.

The approach involves the development of a table which shows the extent to which each alternative achieves the prescribed goals or objectives. Typically, the presentation is in the form of a table where measures which are to be used to assess the various goals are provided as rows. These measures (called criteria, or measures of effectiveness) may include safety related factors, economic factors, accessibility issues, environmental factors or other issues of interest. The values for each of these measures are presented as columns of values for alternative project options. Alternatively, a matrix approach can be used with the purpose of determining the extent to which each alternative will meet objectives. A simple assessment scale can be used to determine whether the alternative contributes towards goal achievement (+), whether it detracts from it (–) or has no effect (0). Further details of this approach can be found in Ogden (1996).

6.7.2 Cost-effectiveness

Cost effectiveness analysis (CEA) involves comparing the cost of a proposed countermeasure with the effect it produces (see Equation 5). Within CEA, projects are ranked and screened according to their cost and effectiveness in improving road safety or achieving policy objectives. Effects are generally expressed in non-monetised units, e.g. the change in the number of fatal and serious injuries. CEA is mainly applied when comparing alternative projects, programs and policies with a similar outcome. The cost-effectiveness is expressed as the cost-effectiveness ratio (CER).

$$\text{Cost effectiveness ratio} = \frac{\text{number of crashes prevented}}{\text{cost of measure}} \quad 5$$

The cost-effectiveness approach to decision making is concerned with determining the extent to which each of a number of alternatives contributes to the attainment of prescribed objectives. It is most applicable where there is a fixed budget and the aim is to achieve maximum results from that expenditure and where there is a specified objective and the aim is to determine the cheapest way of achieving it.

This approach and all other goals assessment techniques differ from other economic appraisal techniques in that they say nothing about how worthwhile the objective is: there is no measure of worth or value about the objectives or the results of the analysis. Therefore, the cost-effectiveness approach has relevance to road safety project appraisal only to the extent that it assists in screening and ranking alternatives which are essentially similar in nature and which can be assessed with respect to a single objective, such as reduction in the number of fatal and serious casualties.

For example, if an agency has a simply expressed goal of reducing the number of fatal and serious casualties in total, then the economic benefits or other impacts of remedial schemes are essentially irrelevant to that goal. A cost-effectiveness approach which simply lists the expected crash reduction from each of various competing schemes would therefore be appropriate to that goal, as it would indicate to the decision maker the set of treatments which are expected to have the maximum potential to reduce crash frequency.

An approach used in several jurisdictions (including New Zealand and New South Wales) is the cost per fatal and serious injury (FSI) saved (or cost per death and serious injury, or DSI, as it is termed in New Zealand).

Death and Serious injury (DSI) casualty equivalents represent the average number of people that are killed or seriously injured for every reported injury crash. DSI factors have been calculated for intersections and midblock locations for a range of different crash types. The DSI factors take into account the relationships between speed environment, road form and crash type and is founded on knowledge that the changes in these factors affects the severity of crash outcomes.

The DSI casualty equivalents are applied to each reported injury crash to estimate the number of people that can be expected to be killed or seriously injured if current crash trends continue. The DSI casualty equivalents method acknowledges that actual fatal and serious crash data alone is not a good indicator of the underlying risk of a high-severity crash at many locations. The DSI casualty equivalents method allows parts of the road network with moderate crash numbers to be identified as high-risk if the type of crashes occurring are suggestive of a high likelihood that the next occurrence will be of high severity.

This approach is very consistent with the key Safe System focus of maximising the reduction in these severe crash types. As an example, the New Zealand High Risk Intersections Guide (New Zealand Transport Agency 2013a) provides a quick guide to conducting such an evaluation. This suggests the following steps:

- identify treatment options
- calculate treatment costs for each of these options
- each DSI saved for intersection projects is approximately NZ$1m
- convert the annual savings to present value of the whole-of-life of a project with long-term benefits by multiplying by 16
- use this value to calculate DSI saved per $100m
- projects with the highest DSI saved per $100m spent would produce the best Safe System outcomes.

Victoria’s Safe System Road Infrastructure Program (SSRIP) includes additional metrics similar to the New Zealand approach in prioritising projects. These include Cost per Serious Casualty Saved per Year and the Number of Serious Casualties Saved per $100m invested.

7. Monitoring and Evaluation

Monitoring is the systematic collection of data about the performance of road safety treatments after their implementation. Evaluation is the statistical analysis of that data to assess the extent to which the treatment (or a wider treatment program) has met crash reduction objectives.

Post-implementation monitoring is essential to ascertain the positive and negative effects of a treatment and thus improve the accuracy and confidence of predictions of that treatment's effectiveness in subsequent applications. There is a duty to ensure that the public does not experience additional hazards as a result of treatments and this duty carries with it an implied need to monitor what happens when a scheme is introduced.

The purposes of monitoring a treatment are to:

- assess what changes have occurred in crash occurrence and whether safety objectives have been met
- assess the treatment's impact on the distribution of traffic and the speeds of motor vehicles
- call attention to any unintended effects on traffic movements or crash occurrence
- assess the effects of the treatment on the local environment
- learn of the public's response to the treatment: its acceptability in general and any concerns about safety in particular.[1]

There are three elements to monitoring and evaluation (County Surveyors' Society 1991):

- Pay careful attention to a site immediately after treatment in case things go badly wrong.
- Assess the effects over a longer time period, say three years, to attempt to determine the influence of the treatment on crashes or other performance measures. This requires careful statistical analysis, correcting for external factors (Section 7.1.1) and bearing in mind that crash frequencies may be so low that any observed changes in crashes may not be statistically significant.
- Focus, over this longer time period, upon the crash types which the treatment was intended to correct and assess whether these have declined.

Monitoring and evaluation are only meaningful if there has been a clear statement of the objectives of the treatment, a prediction of its effects and a logical link between the treatment and its effects. Monitoring reinforces the rigour that should apply to all crash investigation and prevention work. It is important to plan for monitoring and evaluation before a treatment is implemented, to ensure that adequate data is collected and objectives are set (Section 7.2.1).

Performance indicators may relate not only to crashes, but also to other changes which may follow the treatment. Ward and Allsop (1982) suggest that road safety schemes potentially affect the following parameters and so some or all of them may need to be monitored:

- the number and type of crashes
- the severity of crashes
- the distribution of crashes over the road network
- traffic flows and travel times
- turning movements and delays at intersections
- access times and distances within residential areas

1 Based on Institution of Highways and Transportation 1990, p.58

- routes taken by motorists, cyclists and pedestrians
- operations of buses and heavy vehicles.

A comprehensive monitoring exercise should ideally include all of these effects, since without a knowledge of what has happened to (say) traffic volumes, information about what has happened to crashes may be misleading or meaningless. Consideration should also be given to changing road environments (e.g. new commercial activity) and crash migration, particularly where there have been changes in traffic flows.

Because crashes are comparatively rare events, it may take a very long time for a statistically reliable sample to accrue. This can be partially overcome by the use of proxy measures such as traffic conflicts or indirect measures such as media monitoring, insurance company claims records, emergency service records (e.g. ambulance, hospital admissions) or tow truck records if they are available for before and after periods.

Finally, it should be acknowledged that the resources devoted to monitoring in most agencies are very limited. There is an understandable inclination to direct resources into the development and implementation of schemes which have been prioritised and shown to have a potential for crash reduction, rather than into monitoring exercises.

As a consequence it needs to be acknowledged that, without widespread evaluation, understanding of the safety effectiveness of road safety engineering treatments (and other road safety measures for that matter) will remain limited. This point is made by Hauer (1988), who says that 'the level of safety built into roads is largely unpremeditated. Standards and practices have evolved without a foundation of knowledge. At times the safety consequences of engineering decisions are not known, at others some knowledge exists but is not used.'

Detailed guidance on the evaluation of road safety treatments is available in Austroads (2012b), and the contents of this section should be read in association with that document.

7.1 Monitoring and Evaluation Methods

The essence of monitoring is to measure what is actually happening in the real world and then, in an evaluation phase, to attempt to compare that with what is expected would have happened if the treatment had not been introduced. There are several experimental design challenges in doing this and these are discussed in Appendix G. It is necessary to take these factors explicitly into account in the evaluation of road safety treatments or programs. This can be done by:

- before and after studies
- comparisons using control sites.

These techniques are described in Appendix G, with further details in Austroads (2012b).

7.1.1 Statistical analysis

Statistical analysis is required to evaluate the effectiveness of crash location treatments. These guidelines commenced by defining a crash location (or hazardous road location) as a location where a limited range of crash types occurs repeatedly, suggesting that there are common causes, rather than the crashes being the result of mere chance. In evaluating the effectiveness of an individual crash location treatment or a treatment program, the aim is to establish whether or not a drop in the number of crashes should be attributed to the treatment or to chance alone.

Statistical analysis is a complex though important subject. It is beyond the scope of this guide. Possibly the best available reference is Council et al. (1980). Others are the Organisation for Economic Cooperation and Development (OECD 1981) and Miller (1983). The topic is also discussed in Ogden (1996) which includes worked examples. Bear in mind that the extent and accuracy of data which are generally available to the practitioner are such that sophisticated analyses are not possible.

The three main applications of statistical testing in the road safety engineering area are:

- comparison of crash frequencies, for which a chi-squared test is suitable, or a paired t-test if the distribution of crashes can be assumed to follow a normal distribution
- comparison of crash rates, for which a paired t-test is suitable
- comparison of proportions, for which a z-test is suitable.

In all statistical analysis of crash reductions, the 95% confidence level should be applied (i.e. an effect should not be claimed as statistically significant unless it is achieved at this confidence level).

If a more comprehensive analysis is to be undertaken and the data exist to support it, there is a wide range of statistical techniques which can be brought to bear. These are summarised in Table 7.1.

Readers should also see the practical example in Appendix C.2 regarding the true underlying crash rate.

Table 7.1: A guide to statistical tests

Evaluation design	Criterion	Test(s) or procedures
Before and after	Frequencies	X^2 (chi-squared) for Poisson paired t-tests (if normally assumed)
	Rates	Paired t-test
	Proportions	z-test for proportions
	Variances	F-test
	Distribution shifts	RIDIT Kolmogorov-Smirnov
Before and after with randomised controls, comparison groups, or with correction for regression-to-the-mean	Frequencies	X^2 (chi-squared) for Poisson frequency
		Paired t-test for before/after within group
		t-test for group vs group
		Analysis of covariance
		Median test (categorical data)
		Mann-Whitney (categorical data)
	Proportions	z-test for proportions
	Rates	Paired t-test for before/after within group t-test for group vs group
		Analysis of covariance
	Variances	F-test
	Distribution shifts	F-test Kolmogorov-Smirnov

Source: Adapted from Council et al. (1980)

7.2 Issues for Consideration

7.2.1 Planning before treatment for monitoring afterwards

Monitoring and evaluation are tasks which typically occur after a remedial treatment is implemented. As they involve a comparison of circumstances before and after treatment, it is essential that monitoring is considered at an early stage. What data should be collected now (before) and over what period about the performance of the particular road location so that meaningful and valid comparisons may be made with data collected after treatment has occurred? The period of review is important to ensure that the data considered is representative.

Performance indicators which will need to be monitored and measured may relate not only to crashes, but also to other changes which may follow the treatment (refer to the parameters identified by Ward and Allsop 1982, in Section 7).

A comprehensive monitoring exercise should ideally include all of these effects, since without a knowledge of what has happened to (say) traffic volumes, information about what has happened to crashes may be misleading or meaningless.

7.2.2 Threats to the validity of evaluation

There are some factors outside the time period or location being assessed which may affect the calculations of treatment effectiveness at the location. To ensure that the findings of an evaluation are valid, these effects need to be accounted for. Not accounting for each of these factors will have the effect of increasing the calculated value of gains from a crash location treatment program, with the consequence that invalid conclusions may be drawn. Basic information is provided below, while more detailed discussion is provided in Austroads (2012b).

Changes in traffic flows

Crash rates can be affected by changes in traffic flows, with increases generally occurring with greater flows, and reducing with diminished flows. These changes may result directly from the treatment, or for reasons unrelated to the treatment. These increases or decreases may not happen in a linear manner.

General trends in the number of crashes

Consideration should be given to general trends in crashes. For example, there may be a general trend of reduced numbers of crashes in the region due to general factors such as safer cars, legislative changes, general road improvements or rising fuel prices. These general changes can be accounted for by inclusion of similar ‘control’ sites.

Regression-to-the-mean

Over a period of years, if there are no changes in the physical or traffic characteristics at a site, crashes at that site per unit of time (e.g. annually) will tend to fluctuate (due to the random nature of crash occurrence) about a mean value. Because sites are commonly selected for treatment on the basis of their ranking in numbers of crashes compared with all other sites, there is a high possibility that sites will be chosen when their crash count is higher than the long term average. In this case, even without treatment, the crash rate at these sites is likely to reduce (i.e. it will regress to the mean) in the following year.

This aspect of crash experience is a matter of concern in the post-implementation evaluation of a safety treatment because, to the extent that the phenomenon is present, the impact of the treatment will be exaggerated. This matter is discussed further in Appendix G, together with methods to account for it by estimating the true underlying crash rate.

Other possible methodological issues

There is a reasonable degree of acceptance that the above factors should be accounted for when undertaking evaluations of crash location treatments. In addition there are other possible factors, about which there is no conclusive evidence and for which there is no general acceptance. The effect of accounting for each of these factors (were they to be shown to be real) would be to diminish the value of gains from crash location treatment programs. The two factors are crash migration and risk compensation and they are included here to provide an understanding of the terms.

Crash migration

The hypothesis in relation to crash migration is that crashes may increase at sites surrounding the treated site due to changes in trip patterns or changes in drivers' assessment of risk. There is some evidence that the phenomenon exists, but none regarding the degree to which it has an effect. An example of this is seen in Practical example 8 (Appendix C.8).

Boyle and Wright (1984) found in a sample of sites in London that crashes at the treated sites fell by 22% but crashes in the surrounding streets increased by 10%. Their work did not account for regression-to-the-mean and Maher (1987) has suggested that crash migration is generated mainly by a combination of regression-to-the-mean downward of the high crash numbers at the treated sites and regression-to-the-mean upward of the low crash numbers at the surrounding sites. Indeed, Maher (1987) showed that using adjacent or nearby sites as control sites leads to bias in the evaluation results.

This raises the issue of driver expectation and the need to provide drivers with consistent treatment of similar situations: when treating a location it is important to consider what drivers might expect at other similar locations further along the road. If the physical arrangement at those other locations is incapable of matching their expectations, then some form of treatment at those locations should be considered.

Not all the effects hypothesised as being due to crash migration can be explained in terms of regression-to-the-mean, but at this stage any review of crash risk migration would require significant investment. In a review by Austroads on this issue (Austroads 2010b), it was suggested that there are a number of treatments where crash migration may occur, particularly as a result of changes in traffic volume. It makes intuitive sense that the installation of a treatment that changes traffic flow may have an influence on safety, although this effect could be negative, neutral or positive. As an example, if traffic calming is installed on a local road, some through traffic will be deterred from using this route. If traffic is re-directed to a higher quality road, the net effect on safety might be an improvement. However, if traffic now uses an alternative route that is less safe than the route originally taken, then the net effect on safety may be negative.

Examples of treatments where crash migration may have an effect and how this occurs is outlined in Table 7.2.

Table 7.2: Summary of treatments which may result in crash risk migration (CRM)

Treatment	Extent of influence	Potential mechanisms
Turn controls or bans	The next intersection that is not similarly modified	Increased delays on intersecting roads, increased queuing on intersecting roads
Major changes to a route such as parking changes	Approximately 1 km	Altered parking patterns and associated risks on nearby streets
Bridge/route closure	Potential for CRM effects to occur at more than one location beyond the primary treatment site	Increases in traffic on alternative routes
Localised speed limit changes	Approximately 2 km	Drivers seeking other routes to avoid lower speed limits
Intersection changes e.g. signalisation, turn phase timing change, turning lanes	CRM to the next intersection that is not similarly modified	Increases in delays on intersecting roads, increased queuing on intersecting roads
Traffic calming	Up to approximately 2 km	Diversion of traffic, deliberately or accidentally, into other nearby streets
Lane additions	Up to approximately 5 km downstream	Transfer of bottlenecks
Addition of overtaking lanes	Approximately 3 km	May reduce crashes elsewhere if drivers are aware of the new overtaking provision, may increase crashes at merge point
Pedestrian treatments at intersections and at mid-block locations	Approximately 1 km	Fencing may encourage pedestrians to cross at other locations
Railway crossing control	Up to approximately 2 km	Increase in delays, with drivers seeking other nearby uncontrolled crossings
Mid-block turning provision	Dependent upon proximity to alternative intersections where traffic can turn	Changes in traffic at alternative intersections

Source: Austroads (2010b)

Risk compensation

Risk compensation theory postulates that at any given time there will be a level of risk that an individual will tolerate or seek. If a safety measure reduces the potential for harm in one way, a person will compensate for that by increasing risk in another way, such as:

- a motorist provided with an enhanced braking system might use the benefit to drive faster or brake later, resulting in crashes of higher severity
- a motorist wearing a seat belt might feel safer and drive in a manner which places pedestrians more in danger.

In the area of road safety, risk compensation theory postulates that safety benefits tend to be consumed as performance benefits, risk is redistributed to other locations (crash migration) and risk is redistributed to more vulnerable groups of road users.

Risk can be described as either objective risk (as measured for example in crash studies) or as perceived or subjective risk (which is what affects behaviour). It is only where a treatment results in a reduction in both objective and subjective risk that risk compensation would, logically, become a factor, since in other cases there is either no change in the subjective risk, or an increase in it (a treatment would not be implemented which lowered subjective risk without also lowering objective risk). However, provided that the reduction in objective risk is at least as great as the reduction in subjective risk, the treatment will still produce a positive outcome (Rumar 1982). Wong and Nicholson (1992) for example, found that while vehicle speeds increased after an improvement in road alignment, the levels of side friction demanded by drivers declined significantly, indicating that the level of safety had indeed been increased by the realignment. They stated that the ultimate test of the effect of the realignment is whether the actual margin of safety has improved, and the results of this study show clearly that it has. What risk compensation, if any, has occurred has been insufficient to completely undermine the intended goal of the realignments, namely a reduction in the likelihood of crashes at the curves.

This carries with it the implication that any road design change which reduces the subjective risk should also reduce objective risk to at least the same extent, otherwise the road user will have a tendency to respond inappropriately. In particular, care should be taken in situations where sight distance is increased, since this will possibly lead to an increase in approach speeds. If the geometry and/or traffic control at the site does not support these higher speeds, it is possible that the situation could become more, not less, hazardous. To put it in the words used above, the subjective risk has been reduced to a greater extent than the objective risk.

8. Preparing a Crash Report

The documentation prepared in Sections 5.1, 5.4, 5.5 and 5.7 needs to be drawn together into a report which sets out the crash patterns, their causes and proposed solutions. If the documentation has not yet commenced, the following is a report structure which covers the topics to include.

- **Cover**
  - a title such as 'crash location investigation and treatment' or, if it embraces a wider investigation, 'crash location investigation and road safety audit' or other appropriate combination
  - a brief description of where the location is (e.g. street name, local authority area, highway kilometre post, GPS and map references)
  - the organisation for whom the investigation is being undertaken and a list of the investigation team members and affiliations
  - the name of the organisation in charge of the study
  - the date of the report (month and year).
- **Introduction**
  - the organisation for whom the investigation is being undertaken and a list of the investigation team members and affiliations
  - a detailed description of where the location is (e.g. street name, local authority area, highway kilometre post, GPS and map references)
  - an aerial view of the crash location (e.g. from Google Earth or NearMap), showing the location and direction of photos
  - reference to any previous crash reports and their outcomes
  - a description of the location (e.g. road geometry, environment, speed limit, volumes), including roadworks (if any) within the period of crashes being analysed.
- **Data Analysis**
  - a crash listing (showing the basic details of each crash):
    - location, distance
    - time
    - day of week
    - date (day, month, year)
    - crash type (DCA code)
    - direction of approach of Vehicle 1
    - severity
    - road surface (wet/dry)
    - light condition (light/dark/dusk or dawn)
    - traffic control.
  - a summary, for all crashes, of characteristics not in the factor matrix, e.g.:
    - total number of reported crashes and severities
    - year of the crash

        - period of week (i.e. weekday or weekend).
    - the estimated cost of crashes for each separate DCA code grouping in a table like Table 6.4
    - a factor matrix showing the number of crashes by the following factors:
        - crash type (DCA code)
        - direction of approach of Vehicle 1
        - vehicle types involved
        - road surface (wet/dry)
        - light condition (light/dark/dusk or dawn)
        - any other common factors identified (alcohol, fatigue, roadside objects, driver age etc.)
    - a collision diagram, together with a copy of the DCA code table being used
    - a summary of common factors in the crashes, deduced from the above
    - measures previously implemented and their effectiveness.
- **Contributing Crash Factors – Deduced from the Data Analysis and Site Inspection**
    - conclusions about the road environment factors which have contributed to the particular crash groups for which there are common factors. These are the crash causes which are addressed in the next section. These factors could be structured based on the Safe System pillars to focus investigation and analysis
    - any identified vehicle or human behaviour factors.
- **Crash Countermeasures**
    - a list of the proposed treatments which are designed to counter the identified crash causes (with mention made about which treatment is aimed at which problem). These treatments could be structured based on the Safe System pillars
    - other safety problems warranting treatment: a section about minor items identified on-site which can be improved by very low cost measures
    - a plan of the preliminary design of the countermeasures
    - this section may put forward two options with different costs and different effects on crash reduction.
- **Economic Appraisal**
    - the cost of the crashes (by crash type)
    - the effect on crash types expected (e.g. using CMFs) and the consequent benefits in crash reduction. This should be clearly tabulated, so that evaluation can take place at a later date
    - other benefits
    - the cost of design and construction of the proposed treatment
    - the net present value and benefit/cost ratio.
- **Appendices**
    - photographs of the site, relevant to the crash factors.

9. Harm Minimisation at Intersections

What do we know?

- Intersection collisions are one of the major sources of injury on the road network.
- Most harm is associated with unprotected right turns and red light running.
- Intersection planning, design and operation relies on drivers and riders recognising that an intersection is present and making the right decisions in all circumstances – this is unrealistic.
- There are a multitude of circumstances and reasons why driver and rider errors may occur – a harm minimisation approach is the most practical way to compensate for this.
- Design tends to favour intersecting approach legs at 90 degrees; this also ensures that vehicles collide in their most vulnerable configurations: side impacts and offset frontal impacts.
- There are strong relationships associating change in velocity in an impact between vehicles (Delta V) with injury severity; Delta V is a function of travelling speed and mass of vehicle. The orientation of the colliding vehicles is also an important determinant of injury.
- Well designed roundabout designs achieve high levels of safety performance as they manage approach speeds, do not have 90 degree impact angles and simplify decision making.
- Primary collisions between vehicles are sometimes followed by secondary collisions with roadside objects – there is no consideration of secondary collisions in intersection design.
- Current design practices do not take into account key error types relating to dynamic visual obstruction and “looked but failed to see”.
- It is likely that the majority of intersections that have severe injury crashes would pass engineering assessments for traffic control, geometry and sight distance according to current standards.
- Intersection designs that manage speeds on approach or within the intersection footprint are associated with good safety performance (e.g. via vertical or horizontal deflection devices).
- Traffic efficiency at intersections need not be compromised with improved safety for many design types.
- Safe Intersection Design Principles have been established that can guide a harm minimisation approaches.

What does this mean?

- Minimise conflict points where possible.
- Many current intersection designs cannot deliver Safe System outcomes.
- Design elements that guarantee safe interaction speeds at intersections need to become more widespread.
- Innovative designs are required that reduce collision angles.
- Roundabouts should be a preferred treatment option in many circumstances.
- Designs must also address the high prevalence of non-compliant behaviour at intersections or at the very least mitigate the consequences of such behaviour.
- Signalised roundabouts provide a favourable combination of traffic control, speed management and collision geometry.
- Intersections with 90 degree intersecting approaches (including signalised, stop, give way and offset T junctions) should no longer be regarded as a primary treatment where speeds are in high speed environments (>50 km/h); alternatives should be used where possible, and safety enhancements provided where these are the only alternative.

Figure 9.1 shows a crash scene at a typical metropolitan signalised intersection. It demonstrates that vehicles are struck in different orientations (e.g. side versus front), that secondary impacts with surrounding objects are possible (e.g. signal posts) and that bystanders can also be involved in the crash (e.g. pedestrians or stationary vehicles at the stop line).

Figure 9.1: The result of a collision at a signalised intersection

Source: CASR

In general, crash locations in urban areas are dominated by exposure (i.e. those with the highest traffic volumes) and are most commonly associated with a signalised intersection or the junction between a local road and an arterial road. Many of the safety issues are associated with unprotected right turns and red light running.

Although traffic signals may have lower crash rates, there is an irony associated with the large numbers of crashes occurring at signalised intersections. These locations are where traffic managers exert the most control on road users. Road users are instructed when to stop, when to go and what manoeuvres can be performed. While they may have relatively low crash rates on an exposure basis, they have a high injury risk when collisions occur. Many metropolitan intersections have been amongst the worst performing locations in the road network for decades. Road authorities have had limited success in addressing the core safety problems associated with unprotected turns and red light running.

For non-signalised junctions, stop or give way controls have been a feature of traffic control for decades in both urban and rural areas. There is also a legacy in some jurisdictions that the T-junction rule is deemed sufficient for traffic control in lieu of stop or give way signs in certain situations.

The approach to intersection design and operation is predicated on road users firstly realising that an intersection is present and then making the right decisions when using the facility. There are a myriad of reasons and circumstances as to why road users make errors that lead to collisions at intersections. Intersection collisions need to be considered from a system failure perspective rather than as road user performance failure. Table 9.1 and Table 9.2 highlight some of the differences in features that exist between conventional and Safe System intersections.

Table 9.1: Signalised Intersections comparing conventional and Safe System features

	Conventional	Safe System
Signal Control	Ranges from unprotected to protected turns often governed by efficiency objectives	Default position is provision of protected turns
Speed Management	Rely on compliance with general speed limit; occasional use of safety cameras	Design features that guarantee survivable impact speeds
Redundancy	Primary, secondary and sometimes tertiary signal locations; mast arms, advanced warning signs	Geometric design features that influence drivers who might otherwise inadvertently travel through a red light
Points of Conflict	Maximise throughput by increasing the number of lanes – this creates more points of conflict	Limit points of conflict
Expectations of Road Users	Road users make the right decisions in all circumstances; the decision making environment tends to be complex	Road users will make errors; the decision making environment is simplified
Collision Orientations	90 degree vehicle to vehicle impacts; right turn against offset frontal collisions	Collisions at acute angles
Dynamic Visual Obstruction	Rarely considered	Considered in design process;
Inattentional blindness (Looked but did not see)	Rarely considered	Compensated for with design that limits crash severity
Secondary Impacts	Rarely considered	Considered in design process
Crash severity	Rarely considered	Considered in design process
Pedestrians	Usually pedestrian/vehicle conflict can exist in a phase; occasional use of all pedestrian crossing phases	30 km/h speeds where pedestrian/vehicle conflict exists in a phase; segregation or all pedestrian phases for higher speeds
Cyclists	Usually cyclist/vehicle conflict can exist in a phase; occasional use of exclusive cyclist phases	Design features that support the vision of cyclists from vehicles and ensure slow vehicle speeds; segregation where speeds are high

Table 9.2: Unsignalised intersections comparing conventional and Safe System features

	Conventional	Safe System
Control Philosophy	One road has priority for which travelling speeds remain constant	All approaches may have an expectation to stop or that speed may need to be reduced (eg roundabout)
Traffic Control	Ranges from no control to Stop and Give Way	A control must be present unless speeds managed well
Speed Management	Rely on compliance with general speed limit	Design features that guarantee survivable impact speeds
Redundancy	Advanced warning signs, median islands, transverse rumble strips, pavement marking	Geometric design features that influence drivers who might otherwise inadvertently travel through the intersection when required to give way; if one fails another will compensate
Points of Conflict	Permit turning and through manoeuvres across multiple lanes of traffic	Limit points of conflict
Expectations of Road Users	Road users make the right decisions in all circumstances; the decision making environment tends to be complex	Road users will make errors; the decision making environment is simplified
Collision Orientations	90 degree vehicle to vehicle impacts; right turn against offset frontal collisions	Vehicle impact orientations that maximise occupant protection
Dynamic Visual Obstruction	Rarely considered	Considered in design process;
Inattentional blindness (Looked but did not see)	Rarely considered	Compensated for with design that limits crash severity
Secondary Impacts	Rarely considered	Considered in design process
Crash severity	Rarely considered	Considered in design process
Pedestrians	Warning signs, pavement marking	30 km/h speeds where pedestrian/vehicle conflict exists; segregation for higher speeds
Cyclists	Warning signs, pavement marking	Design features that support the vision of cyclists from vehicles and ensure 30 km/h vehicle speeds; segregation where speeds are high

The great majority of intersections that have crashes would pass engineering assessments for combinations of traffic control, geometry and sight distance according to current standards. However, existing intersection design standards and practices do not compensate for some significant error types associated with the visual scanning task.

The phenomenon of inattentional blindness and change blindness may explain why road users sometimes do not notice other vehicles or road users when selecting gaps in traffic. Objects as large as heavy vehicles may not be detected in the complex scanning processes required at intersections and motorcycle and bicycle riders are certainly aware that motorists do not always see them. Inattentional blindness is the failure to notice an unexpected yet fully visible object when attention was focussed on another task. Change blindness is the failure to notice an obvious change in a scene. There has been a growing body of research evidence that is associating the complex nature of perceptual awareness with "*looked but failed to see*" type crashes (for example White (2006); Galpin, Underwood & Crundall (2009) and Martens (2011)). Although things such as contrast and conspicuousness may influence the ability to detect objects researchers generally conclude that human visual scanning is so complex, detection failures should be expected and are unlikely to be eliminated.

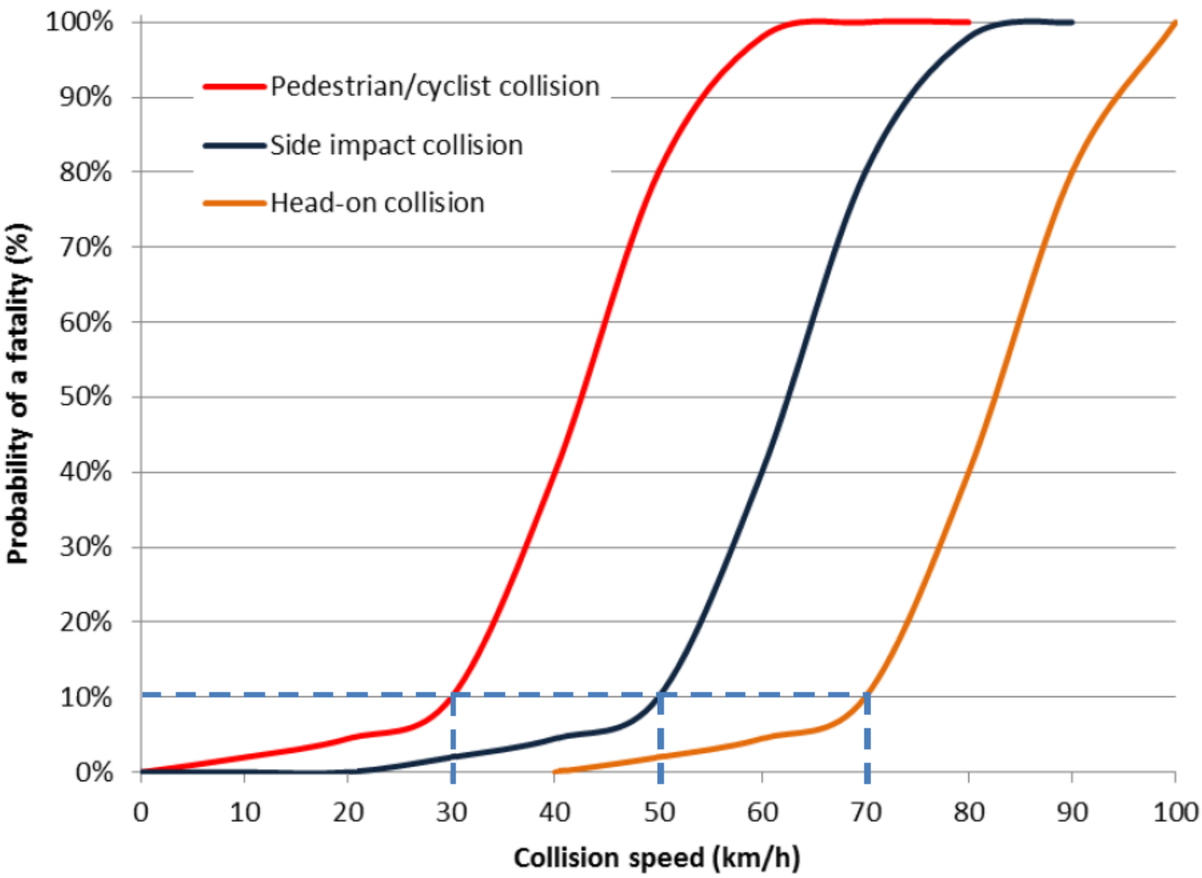
Dynamic visual obstruction represents the visual obstruction caused by moving vehicles on the road and was identified as the main likely contributor to many in-depth crashes investigated at intersections. A common scenario involves a vehicle in the left turn lane blocking visibility to vehicles in the adjacent through lane for vehicles waiting at the side road.

On the basis of these visual performance traits alone, a harm reduction approach is required. Given the many circumstances in which errors may occur at intersections, efforts must be made to provide road designs (supported by network planning approaches) that mitigate crash severity when errors do occur.

9.1 Determinants of Injury at Intersections

The Wramborg curves (Wramborg 2005) have been adopted internationally to illustrate “survivable” thresholds against impact speeds as shown in Figure 9.2. A 10% threshold for fatal outcomes was used as the basis for establishing a Safe System performance threshold. There is nothing to say that a threshold less than 10% would be inappropriate, however given the initial illustrative purpose of the curves, the 10% appears to have been universally adopted.

Figure 9.2: Relationships between collision speed and probability of a fatality for different crash configurations



Source: Jurewicz et al. (2015) and based on Wramborg (2005)

Often referred to as the Safe System Speeds, the following aspirational operating speeds are as follows (OECD / ECMT, 2006):

- **30 km/h** - Where there is the possibility of a collision between a vulnerable road user and a passenger vehicle
- **50 km/h** - Where there is the possibility of a right angle collision between passenger vehicles
- **70 km/h** - Where there is the possibility of a head on collision between passenger vehicles
- **≥100 km/h** – where there is not possible side or frontal impact between vehicles or impacts with vulnerable road user impacts.

An extension often added to the above scenarios is a 30 km/h threshold for a passenger vehicle in a side impact with a tree or pole. Note that at present there is only limited evidence on cyclist and motorcyclist injury thresholds and an assumption is often made that their injury potential is the same as the pedestrian curve.

The curves only represent passenger car interactions and do not account for young and elderly people and heavy vehicles. The curves are also limited in that they only provide the probability of fatality and not serious injury and there is little published evidence demonstrating the origins of the curves. Despite this, the Wramborg curves have become the aspirational criteria for Safe System speeds and have achieved practical application in The Netherlands and Sweden.

The Wramborg curves indicate that at the 10% threshold for fatal injury outcome, vehicles colliding at right angles should be limited to impact speeds of 50 km/h. For many years this was the main guidance available on intersection design.

While the consideration of conflict angles was recognised in the 1970s when roundabouts became more widely applied in Australia, recent theory has revisited the role of speed and impact angles in the context of kinetic energy management (Figure 9.3). Further information can be found in *Guide to Road Safety Part 3: Safe Speed* (Austroads 2021b). Corben et al. (2010) conducted some work to consider the role of collision angle and speed in intersection injury outcomes. A series of principles for safe intersection design were defined with safety improvements accruing from:

1. Fewer vehicles;
2. Fewer intersections;
3. Fewer conflict points per intersection;
4. Impact speeds and impact angles constrained to biomechanically tolerable levels. i.e.,
    a. For 90° collisions -impact (and, therefore, travel) speeds need to be less than 50 km/h;
    b. Where angle of impact can be somewhat reduced through layout design -impact speeds can be greater than 50 km/h but not greater than 70 km/h;
5. For conflicts between vehicles and unprotected road users (i.e. pedestrians, cyclists and motorcyclists), impact speeds should not exceed 30 km/h regardless of geometric layout, if pedestrian and cyclist risks of death are to remain below the nominated level of 10%;
6. Where the above speed and angle combinations cannot be met, crash risk must be reduced to a negligible level.

An intersection safety model was developed that associated kinetic energy with injury outcomes. The Kinetic Energy Management Model for intersections (KEMM-X) reinforced the importance of impact speed and collision angle in determining severity of injury and provided additional insights that were useful for intersection design as shown in Table 9.3.

Table 9.3: Acceptable conflict angles for corresponding maximum impact speeds

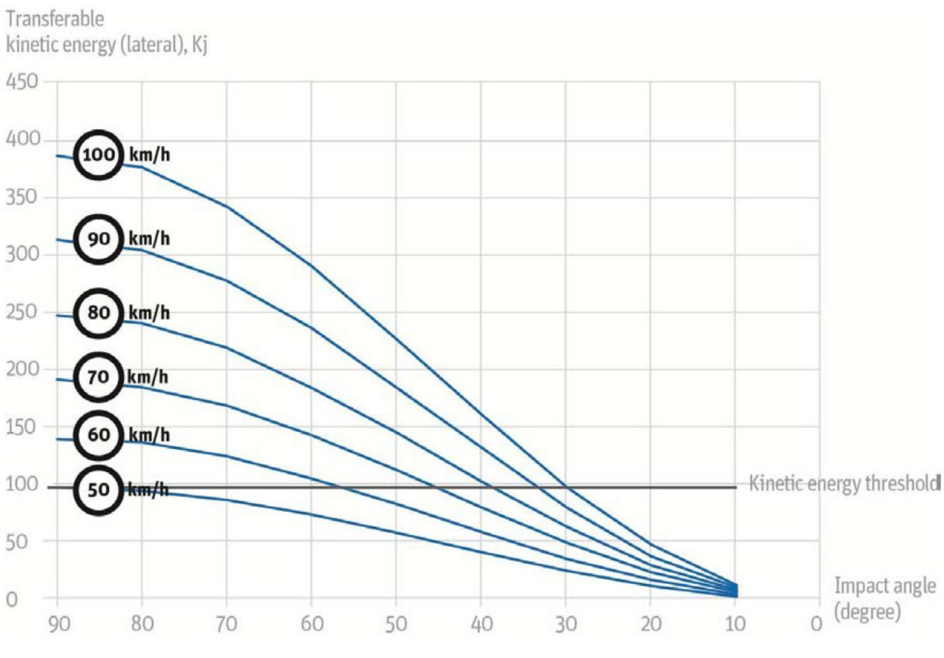
Maximum impact speed	Maximum acceptable conflict angle
40 km/h and below	All OK
50 km/h	90°
60 km/h	52°/128° (from KEMM-X)
70 km/h	0°/180°
80 km/h and above	None feasible

Note: 0° and 180° correspond to head-on and rear-end collisions, respectively.

The work of Jurewicz et al. (2015) extended the KEMM-X model created by Corben et al. (2010) to incorporate each point of conflict in an intersection and multiple intersection crash configurations. The model was updated with more recent studies of the relationship between Delta-V and injury outcome and a design tool is currently under development that can quantify the relationship between basic intersection design elements with the potential for death and serious injury.

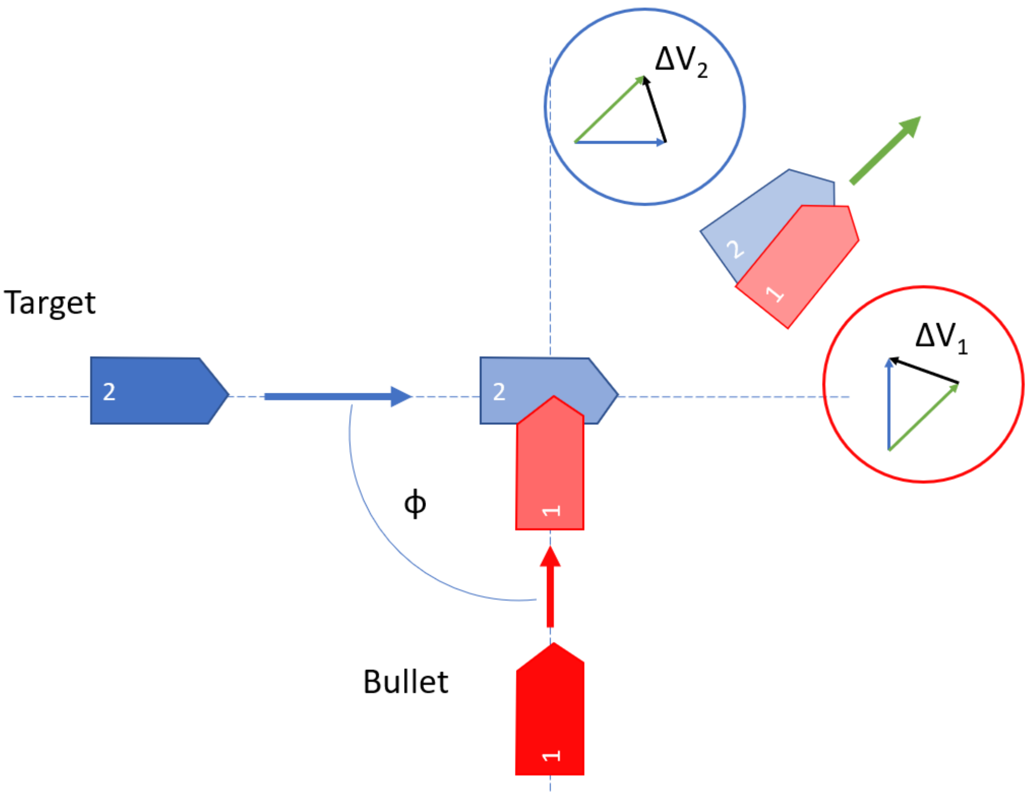
Jurewicz et al. (2015) show the relationship between the impact speed of a "bullet" vehicle (i.e., the vehicle that impacts another vehicle, person or object) and the probability of MIAS3+ injury obtained by a "target" vehicle occupant (Figure 9.4). This model was based on earlier work by Bahouth et al. (2014) and Davis (2001). Critical impact speeds (a 10% probability of a MIAS3+ injury) are given as 20 km/h for pedestrian/vehicle crashes, 30 km/h for head-on crashes, 30 km/h for right-angle (near-side target vehicle impact) crashes, 30 km/h for right turn (far-side target vehicle impact) crashes and 55 km/h for rear-end crashes. The model therefore presents a different picture of Safe System speeds when compared to previous interpretations of the Wramborg model. Most notable of these is the substantially lower critical impact speed for head-on crashes. The model presented by Jurewicz et al. (2015) is accompanied by a guide to the sensitivity of change to MIAS3+ injury probability with a change in impact angle. Right-angle and right turn crashes are noted as having high (~30%) and moderate (15-20%) sensitivity to changes in impact angle.

Figure 9.3: Relationship between speed, impact angle and the kinetic energy threshold related to the human biomechanical tolerance to harm



Source: International Transport Forum (2016)

Figure 9.4: Diagram of bullet and target vehicles in a right-angle crash



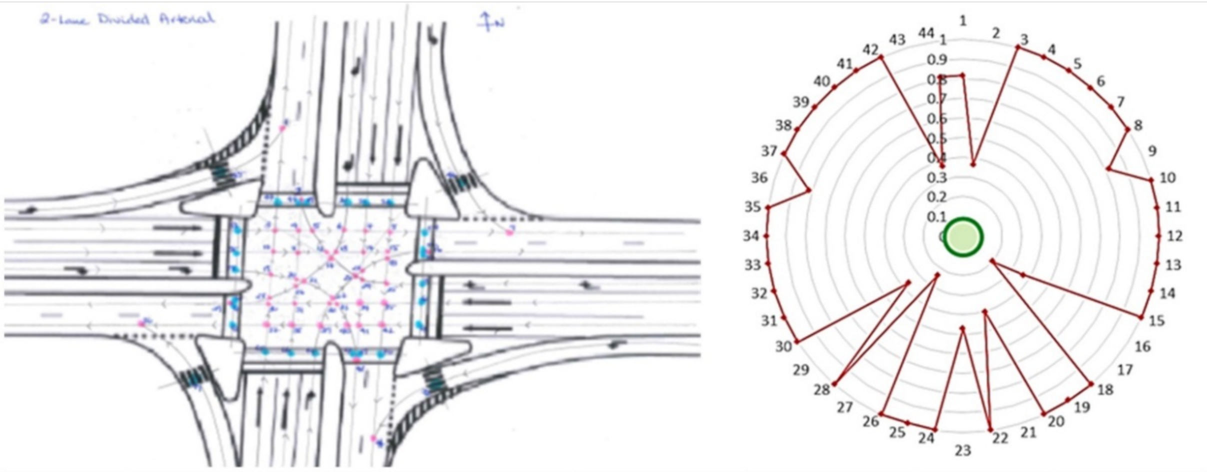
Source: Jurewicz et al. (2015)

Developmental work with X-KEMM-X has provided some useful information for aligning the design of intersections to Safe System objectives, leading to the creation of several rules for minimising the risk of severe crash outcomes:

- Minimise the number of conflict points – especially right-angle, near-head-on and pedestrian
- Minimise crash likelihood at each conflict point through simplification of road user decision making, such as with a high level of movement control
- Minimise angles of all impacts through geometric design, such as with horizontal deflection
- Minimise all impact speeds, such as with geometric deflection and approach speed limits.

Note that as presented in this report, X-KEMM-X only accounts for crash severity and not likelihood. The outcomes of an evaluation for an 80 km/h signalised junction are shown in Figure 9.5. The dots in the diagram on the left represent points of conflict in the intersection for vehicles and pedestrians. The polar graph plots the probability of death or serious injury outcomes for each vehicle to vehicle conflict point with 100% on the outermost circle and the 10% threshold towards the centre (shaded area). It is evident that the majority of potential crash configurations influenced by the speed limit and intersection geometry are associated with very high probability of death and injury outcomes. A plot of all pedestrian conflict points would sit on the outer circle (not shown).

Figure 9.5: X-KEMM-X evaluation of an 80 km/h signalised cross road intersection

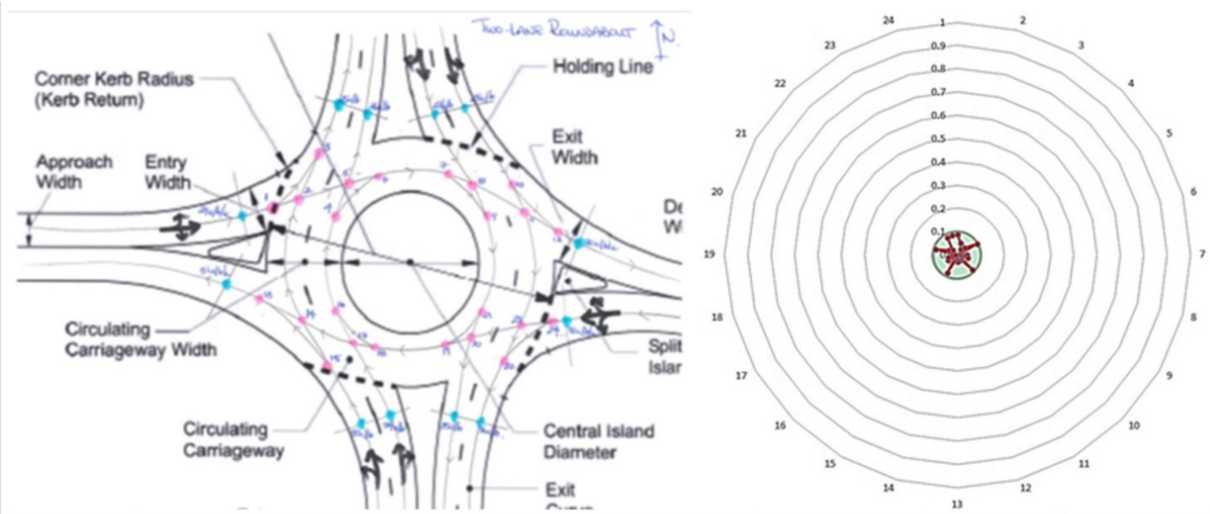


Total vehicle conflict points	Crash types			Vehicle conflict points with Pr(FSI) > 0.1	Pedestrian conflict points with Pr(FSI) > 0.1	Average vehicle Pr(FSI)	Maximum vehicle Pr(FSI)
	Opposing vehicles	Adjacent vehicles	Pedestrian				
44	8	36	28	44	24	0.86	1.00

Source: Austroads (2017)

The utility of this tool is realised when a comparison is made with a roundabout design as shown in the figure below (Figure 9.6). It can be seen that the probability of death and serious injury is reduced to the 10% level or below (noting car to car impacts) for all conflict points in the intersection. This provides a clear indication of how controlling speed and impact angles can reduce injury when crashes occur.

Figure 9.6: X-KEMM-X evaluation of an 80 km/h roundabout intersection



Total vehicle conflict points	Crash types			Vehicle conflict points with Pr(FSI) > 0.1	Pedestrian conflict points with Pr(FSI) > 0.1	Average vehicle Pr(FSI)	Maximum vehicle Pr(FSI)
	Opposing vehicles	Adjacent vehicles	Pedestrian				
24	0	16	12	0	12	0.05	0.096

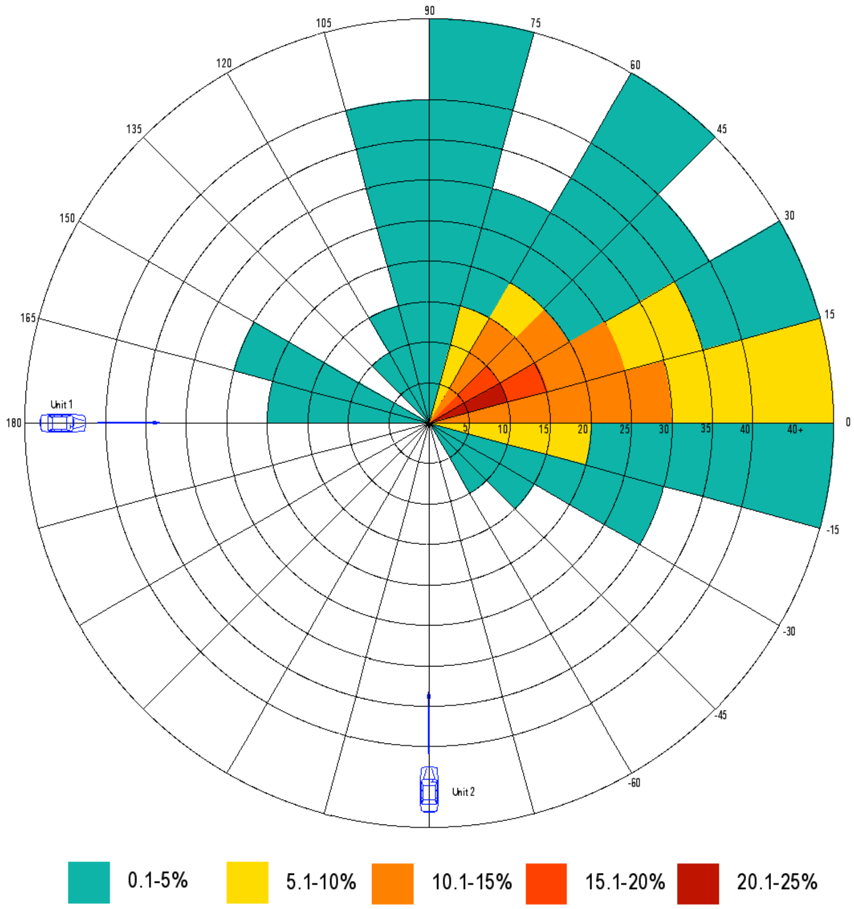
Source: Austroads (2017)

9.1.1 Post impact vehicle trajectories

Another facet of intersection design that is currently not actively considered is consequent impacts that follow an initial impact between two vehicles. The post impact trajectory of vehicles can be important because the occupant safety features are utilised in the primary collision where crumple zones are consumed and seat belt pre-tensioners and air bags are deployed. Occupant protection is therefore compromised in any consequent collisions with other vehicles or objects. In the case of vehicle frontal design for pedestrian collision, protection mechanisms are likewise compromised should a pedestrian be struck following the primary collision. Another implication is that following a primary collision between two vehicles, vehicles may rollover or change configuration such that parts of the vehicle are stuck that offer almost no occupant protection capability. This is the case, for example, where a struck vehicle might rollover and collide roof first with a utility pole. Collisions with bystanders or other queued vehicles at the intersection may also be involved in secondary collisions.

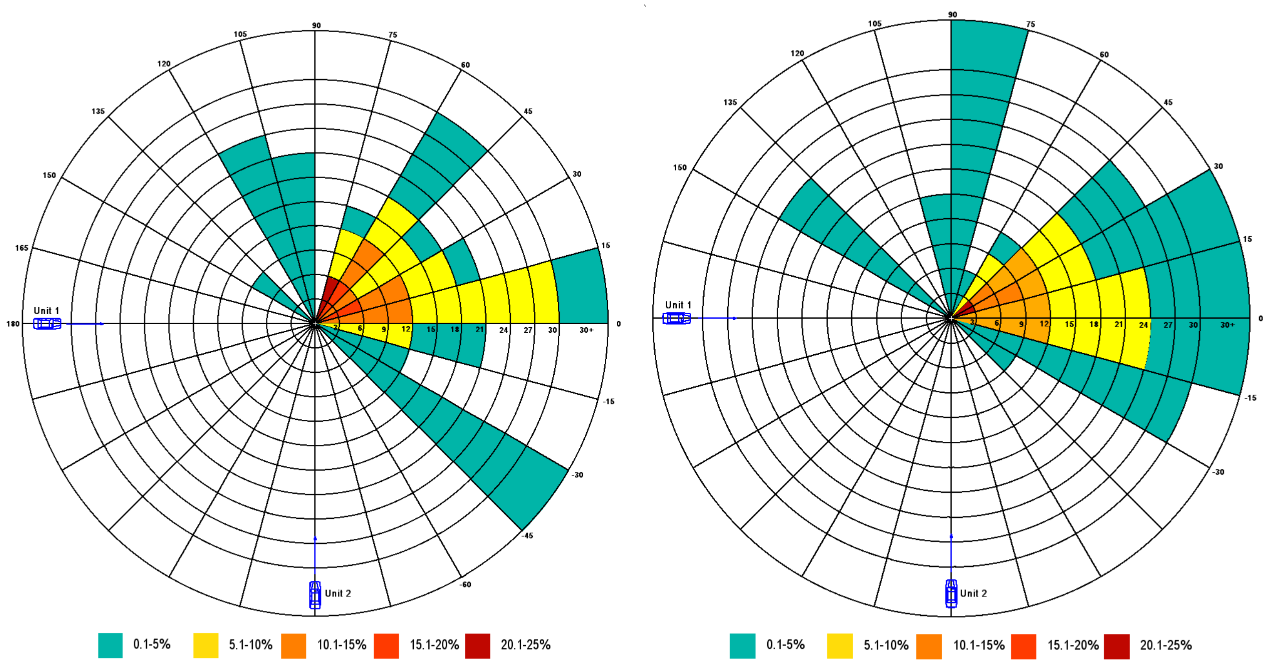
Doecke, Mackenzie and Woolley (2013) and Doecke and Woolley (2011) conducted an investigation into the trajectory of vehicles following a primary collision at intersections. Each sector % represents the proportion of vehicles from the sample of crashes (n=72) to traverse that sector following a primary collision. Crashes from the CASR indepth database were used to build up a profile of trajectories to a common datum for rural junctions, urban signalised intersections and unsignalised intersections. A series of charts were produced (Figure 9.7 and Figure 9.8) that can be overlaid onto intersection drawings to inform designers of the most likely post impact trajectories that vehicles may take following a collision. Consideration can then be given to how vehicle occupants can be protected from hazards and roadside furniture and stationary road users protected from potential secondary collisions.

Figure 9.7: Crash trajectories at rural intersections



Source: Doecke and Woolley (2011), Doecke, Mackenzie and Woolley (2013)

Figure 9.8: Crash trajectories at urban signalised (left) and un-signalised (right) intersections



Source: Doecke and Woolley (2011), Doecke, Mackenzie and Woolley (2013)

It is difficult to determine from mass crash data the extent to which secondary collisions with other vehicles or objects are the major contributing cause of the serious injury or fatality. In-depth crash data provide some insight but sample sizes are small. The research work highlights the evolving knowledge that exists on intersection design and the need to move from the predominant focus on crash likelihood associated with past approaches and give more consideration to the crash event itself and ways in which survivability can be increased.

9.2 Innovation Towards Harm Minimisation at Intersections

Austroads (2016b) suggests a hierarchy of treatments that should be considered for intersections (Table 9.4).

Table 9.4: Safe System Assessment Framework hierarchy* of intersection treatments

Hierarchy	Treatment	Influence (E = exposure L = likelihood S = severity)
Safe System options ('primary' or 'transformational' treatments)	• Close intersection • Grade separation • Low speed environment/speed limit • Roundabout • Raised platform	L, S E L, S L, S L, S
Supporting treatments (compatible with future implementation of Safe System options)	• Left-in/left-out, with protected acceleration and deceleration lanes where required • Ban selected movements • Reduce speed environment/speed limit.	L, S E L, S

Hierarchy	Treatment	Influence (E = exposure L = likelihood S = severity)
Supporting treatments (does not affect future implementation of Safe System options)	• Redirect traffic to higher quality intersection • Turning lanes • Vehicle activated signs • Improved intersection conspicuousness • Advanced direction signage and warning • Improved sight distance • Traffic signals with fully controlled right turns • Skid resistance improvement • Improved street lighting.	E L L L L L L L L
Other considerations	• Speed cameras combined with red light cameras • Route planning to avoid unprotected right turns	L, S E

Note: The objective of the treatment hierarchy is to apply the primary treatments in a systematic, targeted way. Where it is not possible to apply these, or in the short term, other solutions should be used, working down through the options.

Source: Austroads (2016b)

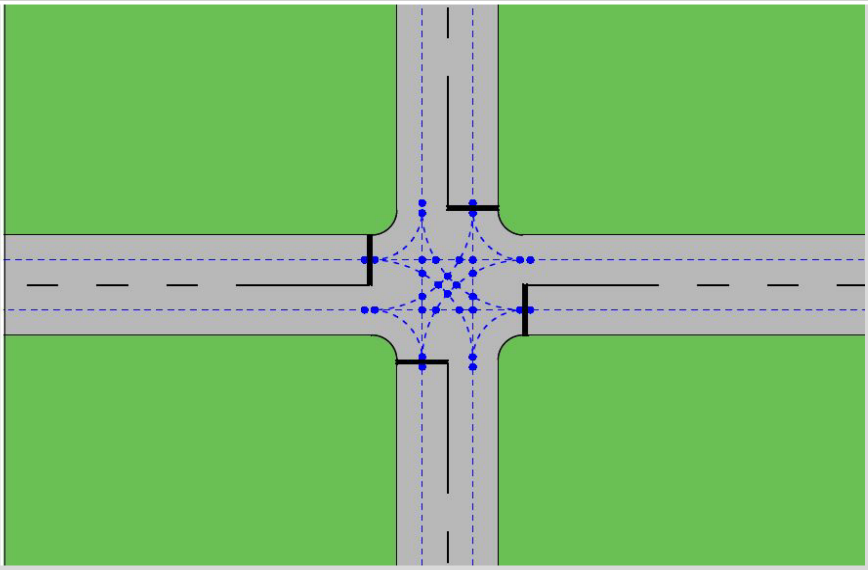
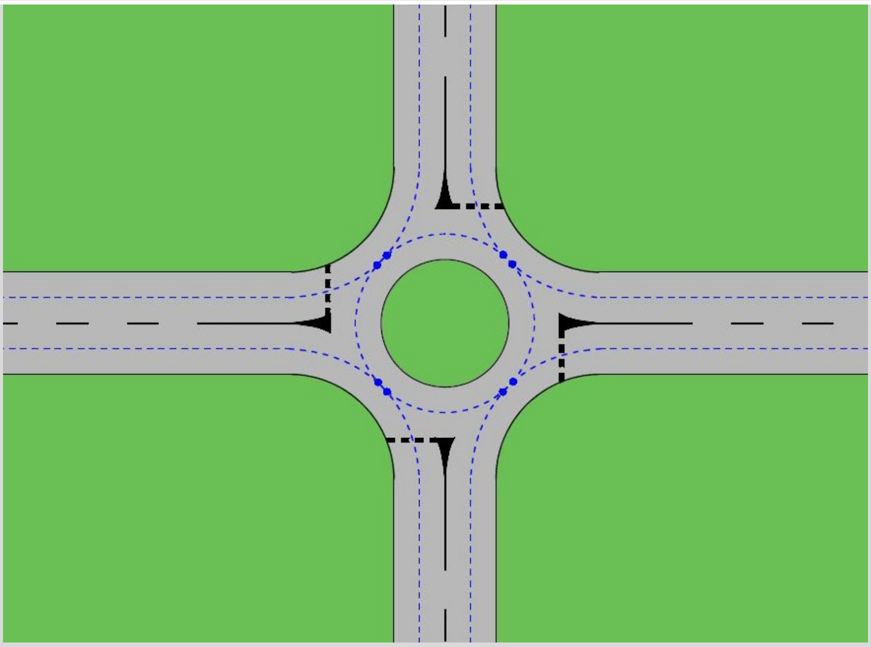
Grade separated intersections provide good Safe System alignment as points of conflict are eliminated from the system. Whilst good for motorized traffic, care is still required to ensure that pedestrians and cyclists are also catered for if in an urban environment. The cost, space and aesthetic considerations associated with grade separation mean that such treatments are only likely to be applied to very few locations in a road network.

For other intersection types, the emergent understanding of the nature of human errors and the circumstances that contribute to error, imply that more innovation will be required to deal with the burden of severe injury associated with intersections.

9.2.1 Roundabouts

Roundabouts have been in use in Australia and New Zealand for many decades and can be regarded as a primary safe system treatment. The reason for this is that they simplify decision making for road users, encourage appropriate behaviours (motorists have an expectation that slowing down or stopping is required on any approach), reduce points of conflict, virtually guarantee low interaction speeds through geometric design and avoid 90 degree impact angles (Table 9.5). When road users make errors they are unlikely to be seriously injured in the resulting collision.

Table 9.5: A comparison of a single lane cross road intersection with an equivalent roundabout

Scheme	Safety considerations	Example (geometries are intended to be illustrative only)
Conventional cross road	High impact angles Safe interaction speeds not assured Impacts may result in high injury severity Errors leading to inadvertent death and injury is possible 32 points of conflict	
Roundabout	Geometries that virtually guarantee low interaction speeds Reduced number of conflict points Reduced impact angles Impacts unlikely to result in high injury severity Errors leading to inadvertent death and injury are unlikely 8 points of conflict	

It is important to note that the combination of features in roundabouts can influence safety performance and roundabout design can vary considerably. Roundabouts differ by number of approach legs, number of traffic lanes, capacity and overall size. Design is influenced by vehicles types, circulating volumes and the speed environment.

There is a considerable amount of literature that demonstrates that roundabouts are effective in reducing fatal and serious injury crashes (Table 8.6). Although there is a wide variation in roundabout design and implementation, Austroads (2015) summarised their effectiveness as follows:

- Reductions in fatal crashes by 63 to 100%
- Reductions in severe crashes by 37 to 84%
- Converting a signalised intersection to a roundabout can reduce casualty crashes by 60 to 78%

- Single lane roundabouts were more effective in reducing crashes than multi-lane roundabouts
- Pedestrian injury crash rates can be significantly reduced (up to 89%).

Table 9.6: Fatal and serious injury data for signalised intersections and roundabouts

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

*Note: *Fatal and serious injury crashes per 10 million vehicles entering.*

Source: Austroads (2013)

Note that the Crash modification factor (CMF) represents the relative change in crash frequency that occurs due to a specific change in the road or its immediate environments.

An analysis of five years of Victorian casualty crash data from all roundabouts in the state revealed that 55% of severe crashes involved vulnerable road users with the majority being motorcyclists and cyclists. Motorcyclists were most commonly involved in off-path on straight (52%) and adjacent direction (36%) type crashes. Cyclists were mostly associated with adjacent direction (83%) and same direction (11%) crash types. Of 2089 casualty crashes, only 11 resulted in fatalities. Pedestrians featured in 7% of severe crashes with the bulk of these being on local road environments.

Studies exist that demonstrate that cyclist safety can be improved with certain design elements (Austroads 2014f).

There is still much scope to refine the design and use of roundabouts and some innovations and variations are shown in Figure 9.9. It is likely that the range of roundabout designs available in the future will increase as they find growing applications in more parts of the road network under a greater variety of circumstances.

X-KEMM-X analysis demonstrates that many roundabout designs approach Safe System performance in mitigating injury severity amongst passenger car types (as shown previously in Table 9.5 and Table 9.6).

Of the many innovative roundabout designs available, signalised roundabouts may be able to have the greatest effect on reducing fatal and serious injury crashes (Austroads 2017). The cost of implementing a signalised roundabout as an upgrade at an existing roundabout to increase capacity should be low, when compared with removal and upgrade to a large signalised intersection. When considered as a replacement for traffic signals, the cost is likely to be high (due to a potentially greater footprint) and capacity may be reduced. Note that roundabout metering is another variation that could be adopted to regulate the flow of traffic on individual legs as opposed to full control of the junction on each leg with full signalisation.

Figure 9.9: Examples of innovative roundabout design

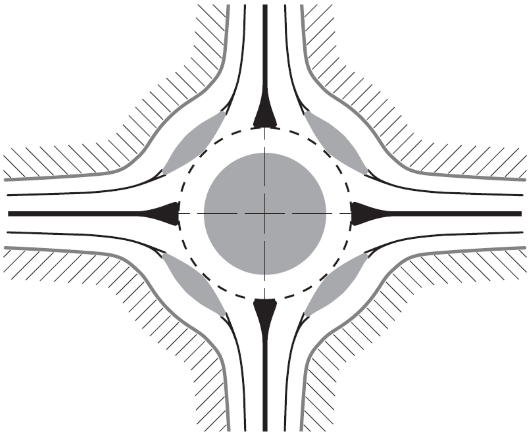
Signalised Roundabout (UK)

Mini roundabout (UK)

Hamburger Roundabout (USA)

Turbo Roundabout (The Netherlands)

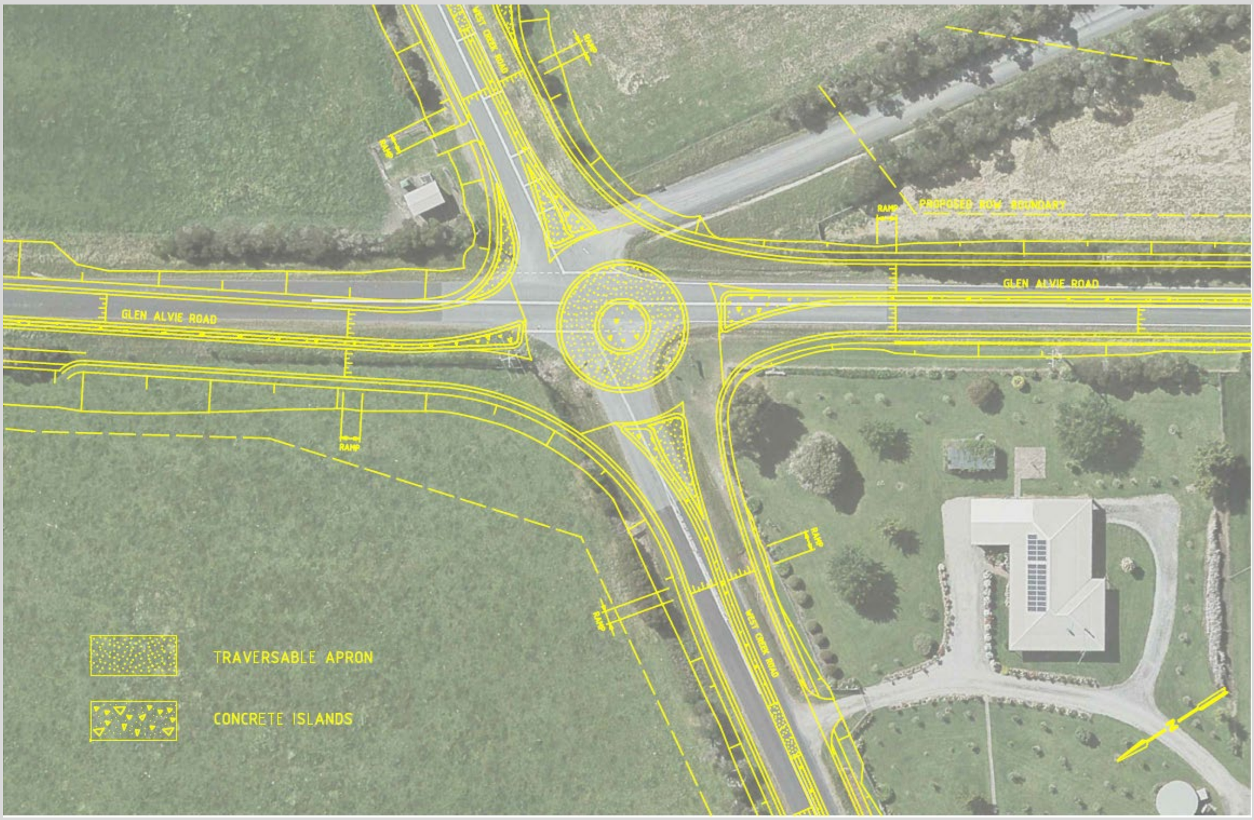
Flower Roundabout Concept (Slovenia)



C Roundabout (NZ)

Case study: The development of a lower cost compact roundabout

Figure 9.10: Proposed low-cost compact roundabout in Victoria



VicRoads is constructing a modified roundabout treatment as a trial at a troublesome intersection in its Eastern Region. The site is characterised by vertical curvature and the presence of a telephone exchange that would be extremely costly to relocate. Design vehicles include B-doubles, a 100 km/h rural speed environment and relatively low traffic volumes.

Usually a roundabout option would have been ruled out due to the cost implications of trying to meet current standards regarding geometry and footprint. Although providing designers with a challenging situation, the solution adopts the safety benefits of roundabouts to maintain a harm minimisation approach to the intersection upgrade. One feature of the design is to use plateaus with vertical deflection (raised safety platforms) on approach to and at the roundabout to manage speeds to safe levels.

With the construction scheduled for completion during 2017, the project will be subject to thorough before and after evaluations, particularly in relation to speed data, and in due course valuable learnings are anticipated (Austroads 2018a).

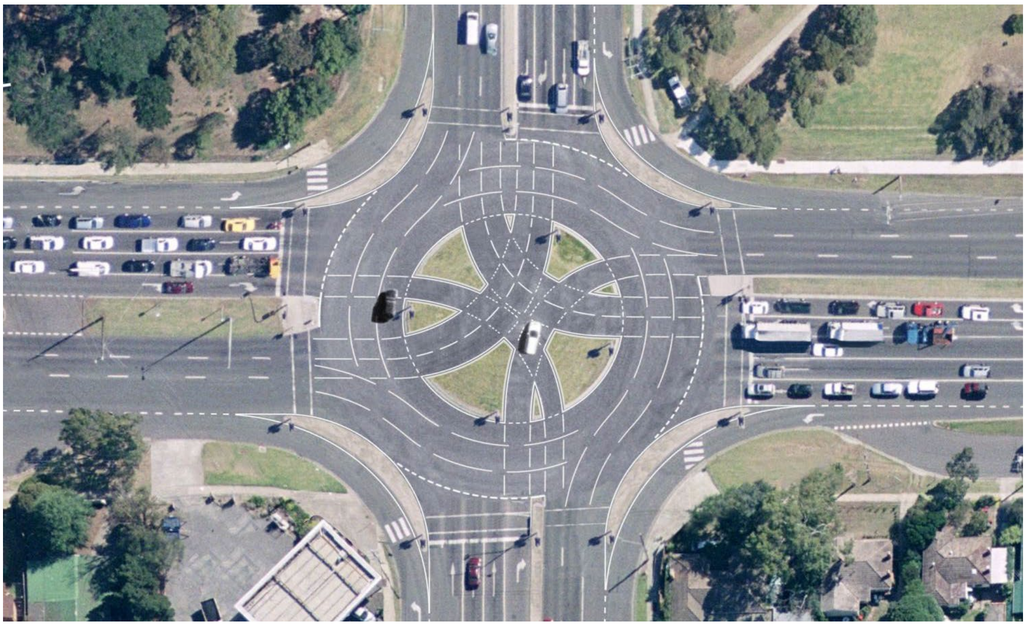
9.2.2 Innovation in intersection design

The following section highlights some of the innovations that are emerging in relation to intersection design. Many of these designs have features in common with roundabouts as they control speed and impact angles.

Corben et al. (2010) developed a project that considered the retrofit challenge of urban signalised junctions and derived two concepts that were capable of being constructed within current intersection footprints. The designs seek to take the best safety features of roundabout design and apply them to a signalised cross road environment as shown in Figure 9.11. Simulation modelling has also been conducted to ensure that road users reacted safely to the intersection layouts. Although not constructed, the exercise is indicative of the type of innovation that will be required to work towards Safe System solutions capable of delivering a harm minimisation dimension to traffic operations.

Figure 9.11: Examples of innovative signalised roundabout treatments

Retrofit concept design for large footprint signalised intersections (Victoria)



Retrofit concept design for small footprint signalised intersections (Victoria)

Case study: Tennis ball interchange, Forrestfield, Western Australia

The signalised, staggered T-junction intersections of the Roe Highway and Berkshire Road in Forrestfield, Western Australia are used by over 40,000 vehicles each day and was one of the worst black spots in Western Australia. In an effort to curb congestion and the crash trend at this location, an innovative “tennis ball” interchange was built (Gateway WA 2014; Gateway WA 2015; Gateway WA 2016).

Figure 9.12: Tennis ball interchange in Western Australia

The tennis ball interchange includes grade separation, with the Roe Highway being elevated and ramps provided for traffic moving onto Berkshire Road via the interchange. The “tennis ball” name is in reference to the reverse curves provided on the Berkshire Road legs, which are aimed at managing incident angles and approach speeds. Traffic signals will be used to control traffic through the interchange.

Where harm reducing geometries are not able to be included as a part of the intersection design, harm reduction needs to be achieved in other ways. Many such treatments are highlighted and discussed in Austroads (2014b and 2016b). Treatments that include vertical deflections (e.g. raised platforms and speed humps) have been used in Australia and New Zealand as part of local area traffic management (LATM) schemes for a number of decades on local roads. Designs that incorporate vertical deflection are now finding application on busier roads such as collectors and arterials for their harm minimization potential. In the two case studies presented below (“Slope Matters”), the vertical deflection profiles were purpose designed and refined according to their intersection context. Although application is somewhat new in Australia and New Zealand, speed humps at stop lines have been in use in some locations in the Netherlands for over a decade.

An analysis of innovative intersection designs by Austroads (2017) suggested that the implementation of speed humps on the approaches to a signalised intersection, compatible with a maximum through speed of 40 km/h for cars, may lead to moderate reductions in fatal and serious injury crashes. This solution was found to be one of the most promising non-roundabout solutions for signalised intersections.

Case study: Slope Matters

Completed in May 2015, the Department for Planning, Transport and Infrastructure (DPTI) installed a raised platform at the intersection of Rundle Street and The Parade West in Kent Town, South Australia. Between 2004 and 2013, there were 29 crashes at this intersection, with 18 of these involving collisions between cyclists and vehicles. Of the 29 crashes, 65% were either a right angle or right turn configuration. A raised platform has been installed to help facilitate reduced entry speeds, reducing both the likelihood and severity of crashes. This is especially important considering the types of crashes that have occurred and the high incidence of crashes with cyclists. Since completion of the project, there has been one minor injury crash, occurring between a cyclist and a left turning vehicle, at the intersection. The raised platform was installed at a T-junction and consists of 1:12 ramped approaches all three legs of the intersection. This slope was adopted following several iterations to obtain the desired speed reductions from motorists. Pavement marking and advisory speed signs of 20 km/h are used on each approach in what is a prevailing 50 km/h speed zone.

Figure 9.13: Raised safety platform in South Australia

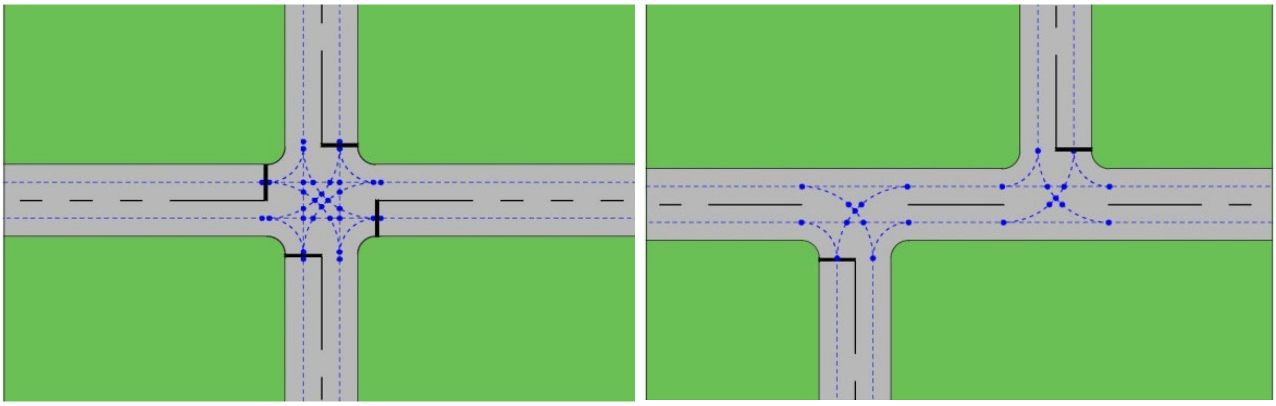
Following inspiration from Dutch practice, a new signalised T-intersection on a section of the Surf Coast Highway in Geelong, Victoria, features a purpose designed speed platform behind the stop line. Installed in a 60 km/h zone, the device is signed with 50 km/h advisory signs and was commissioned in 2015. The profile of the platform was refined in tests conducted at a test track for comfort and controllability with a motorcycle, a public transport bus, a truck and a passenger car. Ramp slopes of 1:30 were adopted in the final design. Design details are available on the VicRoads website: https://www.vicroads.vic.gov.au/planning-and-projects/regional-road-projects/surf-coast-highway-and-kidman-avenue-safety-improvements

Figure 9.14: Raised safety platforms in Victoria

Source: Safe System Solutions Pty Ltd

There are many treatments that are capable of improving intersection safety however they do not address the core harm minimisation principles of the Safe System. A good example is the conversion of a conventional cross road junction into a staggered T-junction. This is often performed at considerable expense and can lead to safety improvements because 10 points of conflict are removed from the system as shown in Figure 9.15. This treatment would be classified towards the bottom end of supporting treatments, as it does not deal with the core harm minimisation issues as effectively as other treatments. Into the future, serious severity crashes are still likely to occur as vehicles will collide at high impact angles and speed is not managed to survivable levels. Further treatment of the junction will be required to introduce harm reduction elements into the design.

Figure 9.15: Points of conflict associated with a conventional cross road junction (left) and a staggered T junction right)



This rationale also applies to the many innovative *Unconventional arterial intersection designs* (UAIDs) and freeway interchange designs that have mainly come out of North America in recent years. Many of the designs displace a conflicting manoeuvre, usually the left turn across traffic (right turn in Australia and New Zealand) away from the central area of at-grade intersections. The benefit of UAIDs is that they may lead to higher capacities, fewer delays and fewer crashes but the main motivation for their use is to improve traffic efficiency. In this regard they should not be misinterpreted as being Safe System solutions. El Esaway and Sayed (2013) conducted an operational review of 11 designs and acknowledged that many of the designs still maintained a high number of conflicts involving severe crash configurations and that the trade-offs between mobility and safety still existed. Austroads (2017) analysed a number of these designs and found that although the average probability of fatal and serious injury (FSI) crashes was somewhat reduced compared to conventional signalised intersections, they still allowed interactions to occur that had high probabilities of FSI outcomes when crashes do occur.

10. Harm Minimisation with High Speed Lane Departures

What do we know?

- Severe injury crashes on rural roads continue to be dominated by single vehicle lane departures and head-on collisions.
- Most benefit from clear zones is obtained within the first few metres of width and for vehicles that have "drift off" low angle departures, this is thought to represent in the order of 80% of departures.
- No matter how wide a clear zone or central median, the risk of incursion cannot be eliminated.
- A desired clear zone width (up to 12 m) will never be achieved on many parts of the road network.
- A high level of safety performance appears to be possible from the use of continuous lengths of crash barrier both in the centre of the road and on roadsides.
- Flexible barrier systems (e.g. wire rope safety barriers (WRSB) and emerging weak post flexible W-beam systems) have been shown to exhibit near Safe System performance and should be considered in preference to other barrier types (until better performing future equivalents emerge).
- Wide centreline treatments are capable of delivering considerable reductions in road departure and head-on crashes along a road corridor.
- Sealed shoulders and audio tactile line marking (ATLM) are also proven safety measures on rural roads and should continue to be used wherever possible.

What this means:

- The clear zone approach has contributed to safer roads in the past and will continue to do so, especially on lower order roads. However, if harm minimisation is to be achieved, we need to rethink the way in which we use the combination of clear zones and barriers on the rural road network.
- High levels of injury reduction can be achieved by adopting continuous (flexible) barriers.
- Clear zones should now be considered in the following light:
  - Clear zones cannot deliver Safe System outcomes in isolation and should be regarded as a supporting treatment
  - Some clear zone is better than none at all when continuous lengths of barrier cannot be installed
  - Clear zones should be regarded as holding the potential to be a hazard in their own right in the same way that barriers are afforded this attention
  - Clear zones should now be considered in the context of "run-out" areas where attention is focussed on ensuring safe vehicle departures free of non-survivable impacts and rollover.
- Wide centrelines are showing much promise yet they cannot deliver Safe System outcomes in isolation and should be regarded as (step towards) supporting treatment; they do have a potential benefit in that a barrier system might be retrofitted to achieve a primary Safe System treatment in future.
- Sealed shoulders and ATLM also cannot deliver Safe System outcomes in isolation and should be regarded as a supporting treatment.

In rural areas, for a multitude of reasons, vehicles leave the roadway and either collide with roadside hazards or rollover. Although horizontal curves are over-represented in such crashes, road departures on straights also constitute a significant problem. Death and serious injury may still occur at legal speeds in good quality vehicles. Rollovers are a particular problem as they are biased towards severe injury. There is yet no requirement for roof crush strength (although this is under consideration) and occupants can strike parts of the vehicle or each other, or be ejected during the rollover event. Worse still, vehicles can strike roadside hazards roof first. Figure 10.1 demonstrates a crash site where a vehicle has strayed onto an unsealed shoulder and the driver has lost control of the vehicle, yawed across the road and rolled several times into a paddock resting about 50 m from the road. It was fortunate that the only tree in the “clear zone” was not struck.

Figure 10.1: A typical rural road departure crash scene

Source: CASR

The irony in this crash situation is that the straight sections of rural road should represent locations where there is the least requirement of skill or attention needed on the part of the driver. However the bulk of the rural road safety problem is associated with single vehicles departing the road and colliding with roadside hazards or rolling over. In addition, many head on collisions involve this loss of control scenario when there happened to be another vehicle coming in the opposing direction.

Although the task of harm minimisation on rural roads appears daunting, there is scope to use existing treatments in ways that achieve much better safety outcomes than has historically been the case. There are several examples where deaths from head on collisions on two lane rural roads have been virtually eliminated with the use of flexible median barriers. New approaches are also using different cross sectional footprints and in the case of conversion to dual carriageway or greenfield scenarios, there are opportunities for considerable cost savings to be achieved.

Removing a tree or placing guardrail in front of it at discrete sites will not be sufficient to achieve a step change in network road trauma. Road departure crash locations are mostly random in nature; what will be required are systemic changes to road design and planning practices that pay attention to safely managing the departure of vehicles from the roadway or at least managing the kinetic energy transfer that occurs along entire corridors. Road design considerations (such as consistency in geometric design) will still be important; ways must be found that introduce the harm reduction element into road design as well.

As with intersections, our perspectives of road user errors will need to change. Rural roads need to be made more error tolerant and error resistant and deal more effectively with the consequences of a road departure.

10.1 Reducing the Harm of Road Departures

Run-off-road (ROR) crashes are a major type of road crash that results in death and serious injury. Across the Australian states and territories, and New Zealand, ROR crashes typically account for 40 to 65% of all rural crashes, while in urban areas (based on Victorian and New Zealand data) the proportion is 15 to 20%.

There are numerous reasons as to why vehicles leave the roadway and encroach onto the roadside environment. These include lack of driver concentration, driver inattention, driver fatigue, driving while intoxicated or under the influence of drugs, excessive speed, poor visibility, inadequate visual cues of the road path, poor road condition and vehicle failure (e.g. brake failure, worn tyres, etc.).

Ideally a roadside environment should be free of any hazards that may increase the severity of a crash, should it occur. Such a roadside would prevent injuries in run-off-road crashes by providing drivers with enough space to regain control of their vehicles and stop safely without colliding with any objects or the vehicle rolling over. However, it is usually not possible to construct a road environment completely free of hazards.

Speed is at the core of a forgiving road transport system. While many can relate to the physics of stopping associated with travelling speed, the intricate and non-linear relationship with crash energy and consequent injury is more difficult to appreciate.

To achieve zero fatal and serious injuries, the entire roadside environment must be considered to have an element of risk and designs must aim to eliminate risk (VicRoads 2019). This means solutions must be considered which go above and beyond the traditional clear zone approach to road safety, particularly for high speed environments.

Should a vehicle leave the roadway it is important that a strategic approach be taken to provide a forgiving roadside environment so as to minimise the risk of death or serious injury

10.1.1 Treatment hierarchy for road departures

What is evident from the research is that protected corridors can deliver better safety outcomes than unprotected ones. Examples are emerging where head-on crashes have been virtually eliminated on undivided rural roads by the use of median barriers. Continuous lengths of barrier are at present the only way to effectively mitigate the severe harm being caused by road departure and head on crashes and compensate for driver errors. Where this is not possible, wide centrelines currently offer the next best alternative. Sealed shoulders and audio-tactile line marking should also be a default feature of the safest rural roads.

The hierarchy of treatments for road departures is shown in Table 10.1. The few primary treatment options that exist are associated with kinetic energy management.

Table 10.1: Safe System Assessment Framework hierarchy of road departure crash treatments

Hierarchy	Treatment	Influence (E = exposure L = likelihood S = severity)
Safe System options ('primary' or 'transformational' treatments)	• Continuous lengths of flexible roadside and median barriers (or an equally / better performing future equivalent) • Very low speed environment/speed limit	S L, S
Supporting treatments which move towards better Safe System alignment (compatible with future implementation of Safe System options)	• Continuous lengths of flexible roadside barriers (or an equally / better performing future equivalent) • Continuous lengths of flexible median barriers (or an equally / better performing future equivalent) • High quality well maintained run-off areas consisting of compacted roadside surface, very gentle to flat side slopes • Wide sealed shoulders with audio-tactile edgeline • Lower speed limit	S L, S L, S L L, S
Supporting treatments (does not affect future implementation of Safe System options)	• Run-off areas, with well-maintained shallow drainage and gentle side slopes • Other safety barriers types • Consistent design along the route (i.e. no out-of-context curves) • Consistent delineation for route • Skid resistance improvement • Improved superelevation • Audio-tactile centreline • Audio-tactile edgeline • Vehicle activated signs	S L L L L L L L L L
Other considerations	• Speed enforcement • Rest area provision • Lane marking compatible with in-vehicle lane-keeping technology.	L, S L L

Note: The objective of the treatment hierarchy is to apply the primary treatments in a systematic, targeted way. Where it is not possible to apply these, or in the short term, other solutions should be used, working down through the options.

Source: Austroads (2016b)

10.1.2 Clear zones

A clear zone is an area adjacent to the traffic lane that should be kept free from features that would be potentially hazardous to errant vehicles. The clear zone is a compromise between the recovery area for every errant vehicle, the cost of providing that area and the likelihood of an errant vehicle encountering a hazard.

The concept of clear zones can be traced back to studies during the 1960s in North America (Stonex & Skeels 1963; Hutchinson & Kennedy 1966). The latter study investigated incursions into the central median of divided highways including tracks left in the snow during North American winter conditions. A finding from this study was that approximately 85% of vehicles recovered or stopped within 9 metres of the edge of the road. Based on this evidence, the clear zone philosophy was adopted in North America, Australia and New Zealand. While clear zones assist in making rural roads safer, the residual severe injury problem remains significant. In practice there are very few parts of the network where nine metre clear zones are likely to be achieved. It is also unlikely that "perfect" clear zones can be achieved on a widespread basis as ruts, dips, bumps and tyre soil forces may all contribute towards tripping vehicles into a rollover.

Case study: Forrest Highway, Western Australia

Opened in September 2009, the Forrest Highway project included the construction of 30 km of freeway standard and 38 km of dual carriageway standard roadway between Baldivis and Lake Clifton in Western Australia.

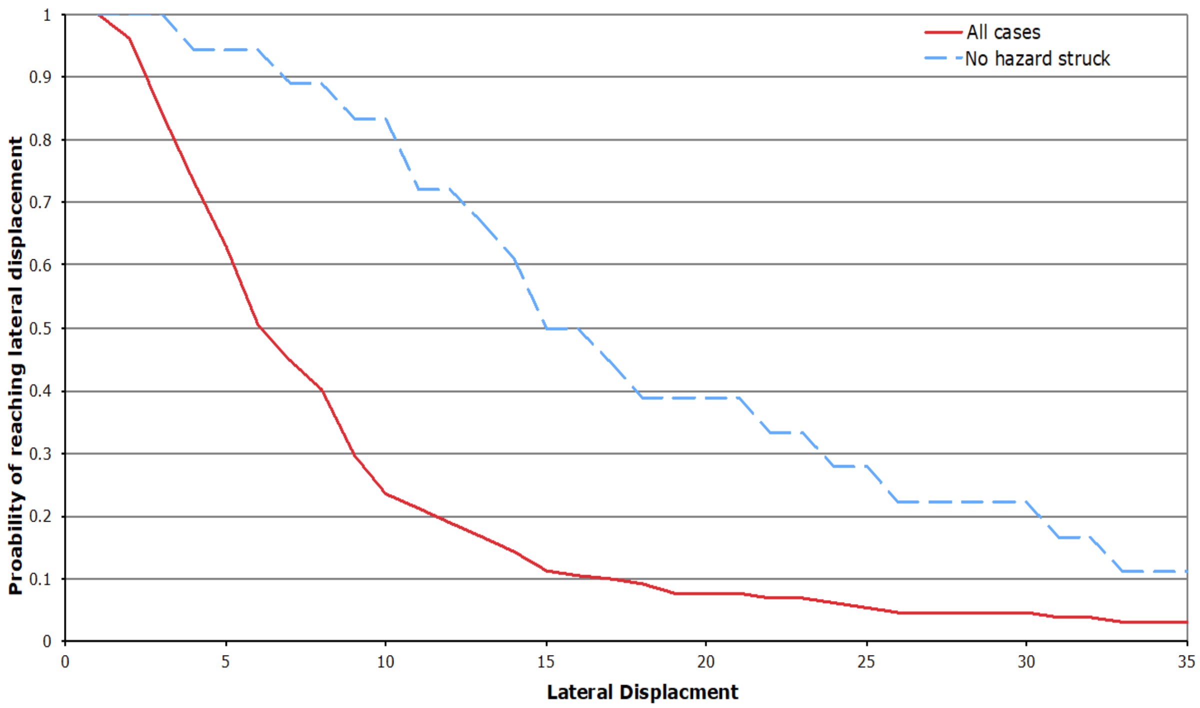
The Road was built to Austroads Guidelines and Australian Standards. Clear zone principles were applied along the road, with roadside barriers being used where clear zone widths could not be met. The total cross sectional construction footprint of the road ranges from 50 m to 60 m, incorporating a 20 m wide median. Despite this, in the past five years the road has been subject to 46 serious injury and fatal crashes, 21 of which were road departure crashes. Many sections of the road have crash densities more than three times higher than the network average for this type of road. It is likely that the use of continuous barriers on a narrower cross section could have resulted in a better safety performance (Austroads 2018a).

Figure 10.2: Example cross sections on Forrest Highway in WA following then-current clear zone guidelines

Doecke and Woolley (2011; 2013) have conducted studies into clear zones based on a sample of real world crashes in South Australia. It should be noted that the sample was not designed to be representative of all rural crashes. Crashes were included in the study if they involved ambulance transport of someone injured in the crash and the crash location was within 100 km of Adelaide. Figure 10.3 shows from a sample of 132 road departure crashes how vehicles that did not strike an object had much greater lateral displacements than those that did strike an object.

The work revealed that there are three predominant road departure types as shown in Figure 10.4. The drift off represents a low angle departure and is likely the departure best served by a clear zone. If the departure angle is low enough it is likely that a driver can successfully steer back onto the roadway. The other two departure types involve the vehicle yawing and therefore a loss of control on the part of the driver. In these cases the vehicles are likely to strike objects on the edge of a clear zone often in a side impact configuration.

Figure 10.3: Cumulative distribution of lateral displacement from edge of traffic lane for vehicles involved in road departure injury crashes where no hazard was struck



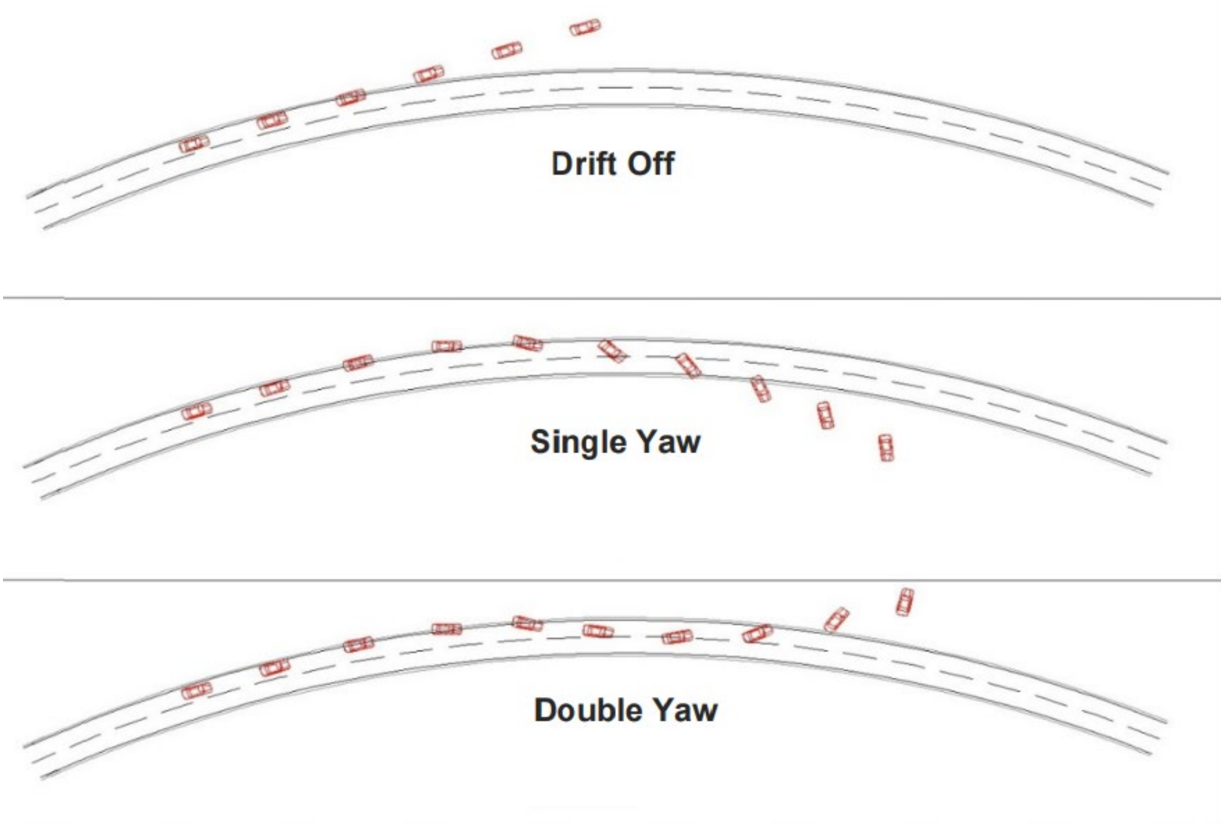
Source: Doecke and Woolley (2011)

Figure 10.4: The three key road departure types on straights

Source: Doecke and Woolley (2011)

In another study, Doecke and Woolley (2013) established that similar departure types existed on bends as shown in Figure 10.5. The single yaw scenario is noteworthy as attempts to upgrade bends are often focussed on providing protection on the outside of the bend. It is evident that protection at the centre or the inside of the bend should also be considered.

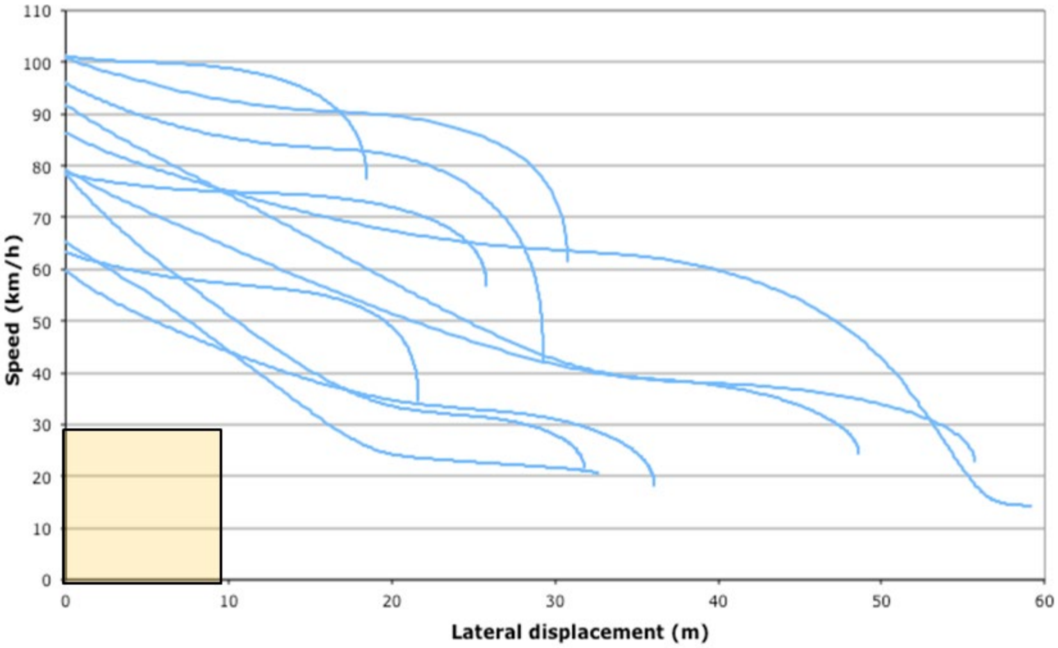
Figure 10.5: The three key road departure types on bends



Source: Doecke and Woolley (2013)

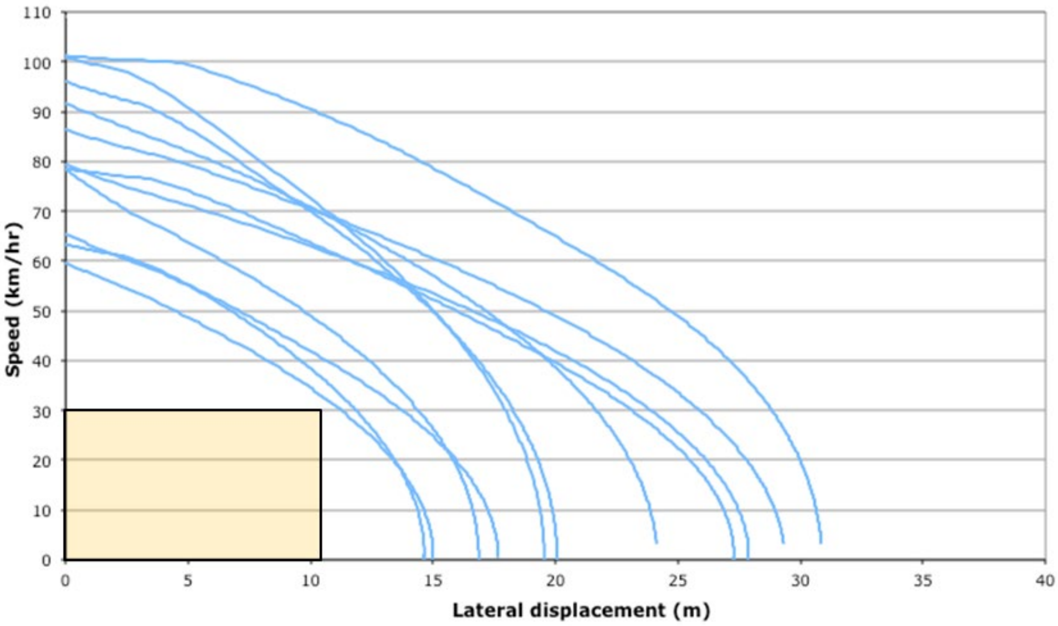
Doecke and Woolley (2013) also outlined the two types of driver actions likely in response to the road departure: steering input and emergency braking. In reality a driver may combine the two. However, modelling was performed independently the two extremes. Figure 10.6 and Figure 10.7 show the trajectories of road vehicles involved in road departures in terms of instantaneous speed and lateral displacement. The square on the figures represent a “safety envelope” defined by a 30 km/h side impact speed with a tree and a 10 m clear zone width. It can be seen that all departures modelled are beyond the safety envelope. The mean departure angle for vehicles that drifted off the road without losing control was 7.3 degrees and 17.6 degrees for those that were out of control and yawed.

Figure 10.6: Simulated trajectories of vehicles in road departures where the driver attempted steering recovery



Source: Doecke and Woolley (2011)

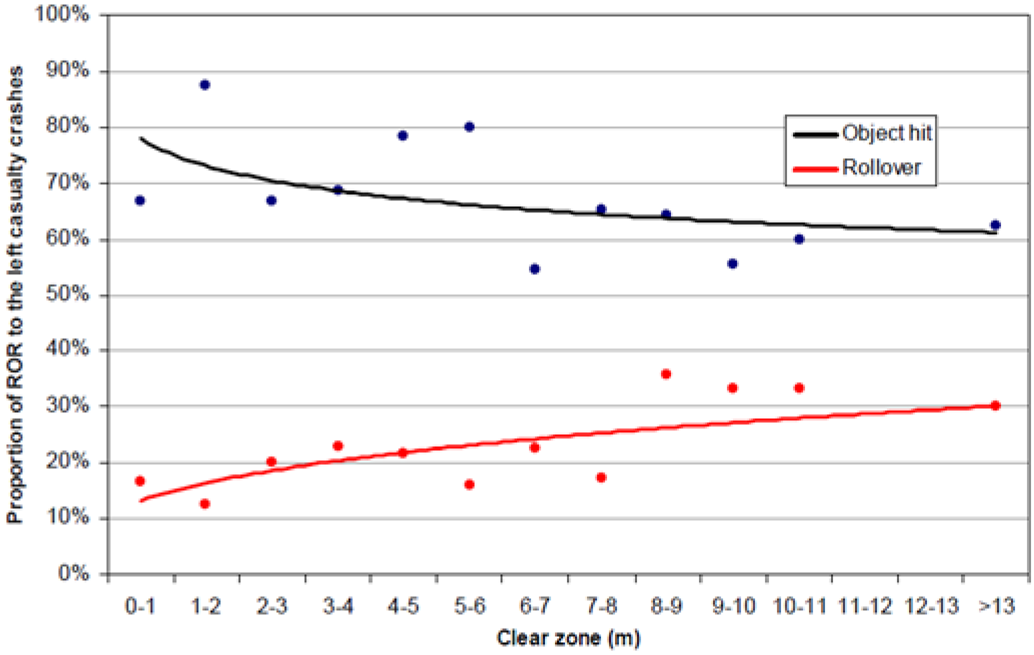
Figure 10.7: Simulated trajectories of vehicles in road departures where the driver attempted emergency braking



Source: Doecke and Woolley (2011)

In an approach using mass crash data, Austroads (2011a) presented the results of an analysis on road departure and rollover crashes in Victoria as shown in Figure 10.8. It is noted that objects continue to be struck at very large clear zone widths and a high threshold for the road departure to the left casualty crashes is observed. For rollover casualty crashes, the proportion appears to increase with very wide clear zones.

Figure 10.8: Proportions of Object hit and Rollover run-off-road crashes vs. clear zone in Victoria



Source: Austroads (2011a)

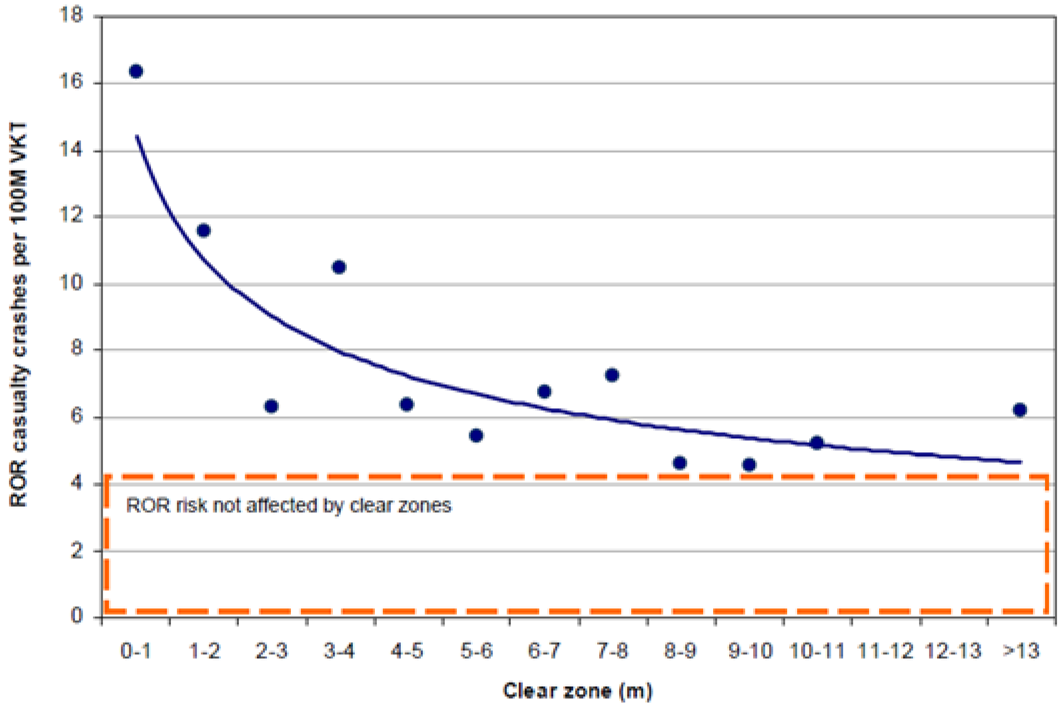
A presentation of the data in terms of vehicle kilometres travelled is shown in Figure 10.9. The casualty crash residual associated with clear zones is evident even when very wide clear zones are considered.

Jurewicz and Pyta (2010), and Jurewicz and Troutbeck (2012) modelled clear zone benefits and suggested an approach to clear zone selection based on rural crash data in the Austroads database (Austroads 2010e). As with Doecke and Woolley (2011) they also found evidence that mean departure angles were high (15 degrees). The modelling work demonstrated that there was considerable safety improvement in moving from a zero clear zone to a width of 4 m or greater (49% reduction in crashes on the treated side) and additional reduction from increasing to an 8 m width (54%). Despite the potential benefits, the authors concluded that clear zones could not be relied upon to deliver Safe System outcomes.

A limitation of the research work by Doecke and Woolley (2011; 2013), and Jurewicz and Pyta (2010) is that they are unable to quantify the benefit of departures where vehicles did successfully recover in the clear zone and the incident went unreported. Also, the prevalence of shallow drift off departures compared to yaw departures is not known. However, as discussed in the following sections, there is strong empirical evidence that corridors with continuous lengths of flexible barrier achieve better safety outcomes than those that rely on clear zones and wide medians.

It is now widely accepted that clear zones cannot deliver Safe System outcomes in isolation and should be regarded as a supporting treatment only.

Figure 10.9: Run-off-road crash rate vs. available clear zone



Source: Austroads (2012a)

10.2 Keeping Vehicles on the Road

The key first step in roadside hazard management is to provide a road environment that reduces the potential for road users to lose control of their vehicle and run off the road. Should a vehicle leave the road it is then essential that a roadside environment be provided that is free of hazards or is forgiving.

Roads should be designed with the objective of making it as easy as possible for drivers to keep their vehicles on-path. Visual cues, appropriate signing and linemarking, sealed shoulders and well maintained roads (i.e. road surface, road shoulders, line markings and signage) should all be provided so as to minimise the role of the road as a factor in causing a vehicle to leave the road.

Australian Standard AS 1742.2:2009, *Manual of uniform traffic control devices*, *Part 2 – traffic control devices for general use* set out requirements of all traffic control devices for use on roads other than freeways for Australia. In New Zealand the *Manual of traffic signs and marking;* (MOTSAM) Parts 1 (2010) and 2 (2010) are used.

These references provide detail associated with signage at intersections and along road segments, and pavement markings.

10.2.1 Delineation

Ensuring a high level of road delineation will assist to reduce the risk of vehicles losing control and running off the road. Delineation is used to provide road users with knowledge of:

- changes in road alignment
- presence of bends in roads and the severity of those bends
- the lanes to be travelled along

- road sections along which it is permissible to overtake and along sections where it is unsafe (not permissible) to overtake
- intersections and approaches to intersections.

Delineation may be provided or improved with the application of:

- line markings (i.e. centreline, lane lines, edge lines and audio-tactile lines)
- retroreflective raised reflective pavement markers (RRPMs) and non-retroreflective raised pavement markers (NRPMs)
- guide posts
- warning signs (e.g. advisory curve and speed signs and chevron alignment markers).

Centrelines and lane lines

Centrelines should be marked to separate opposing directions of traffic flow on sealed pavements at least 5.5 m wide. On pavements narrower than this, centrelines are not usually provided other than where sight lines for overtaking are deficient. Centrelines may be of the following types:

- a single broken line
- barrier lines – either a continuous single line, continuous double lines or single continuous with parallel broken line.

Barrier lines should not be used on pavements of insufficient width where it is not practicable for all vehicles to travel on their side of the line.

Edge lines

Edge lines are used to delineate the outer limits of the travelled way. The aim of this delineation is to discourage travel on the road shoulder, to assist drivers to track away from the edge of the road and to provide a visual cue of the path of the road. Edge lines are of greatest benefit during poor light conditions and weather conditions, and when approaching and driving through a curve.

Audio-tactile line markings

Audio-tactile line markings can be provided with raised, transverse bars of thermoplastic material placed at short intervals (Figure 10.10). This type of edge line provides an audio-tactile warning whenever a vehicle drifts across the line marking.

The purpose of this marking is to alert drivers that they are drifting out of their lane, either across the road shoulder, across into another lane or into the opposing lanes of traffic. Audio-tactile edge lines should be considered where there is a recorded history of fatigue related crashes, and may be considered on roads prone to fog.

Based on studies by Corben et al. (1996) and Cairney (1996) it has been estimated that tactile edge lines can reduce casualty crashes by 23%, while centreline tactile line marking may reduce casualty crashes by 15% (Persaud et al. 2003).

Although the sound generated by audio-tactile line markings is usually audible inside passenger vehicles, it is harder to hear in large vehicles such as four-wheel drives, and is often impossible to hear in heavy vehicles. The treatment therefore should not be relied upon to provide warning to heavy vehicle drivers.

Figure 10.10: Audio-tactile edge line

Source: Safe System Solutions Pty Ltd

Raised reflective pavement and non-retroreflective pavement markers

Based on a study Elvik and Vaa (2004) raised reflective pavement markers can reduce night time casualty crashes by 8%. Raised pavement markers can be used in conjunction with, or sometimes used instead of painted line markings. Section 4.6 of AS 1742.2:2009 discusses the use of non-retroreflective and retroreflective raised pavement markers. Non-retroreflective pavement markers (NRPMs) may be used in conjunction with retroreflective raised pavement markers (RRPMs) where it is intended that they simulate marked lines, for example, lane lines on freeways. NRPMs may also be used at intersections to provide guidance for drivers negotiating the intersection.

RRPMs may be used to augment painted lines or instead of painted lines for the provision of lane lines, separation and barrier lines, edge lines and traffic islands and medians. RRPMs are not obscured at night under wet conditions as the retroreflective panels sit above the surface and are more prominent than reflectorised painted markings (i.e. paint incorporating glass beads for added reflective capability). In addition, they provide an audible and tactile signal when traversed by vehicle wheels.

RRPMs are used in various colours as follows:

- **White** markers are used to augment lane lines, markings at traffic islands and freeway ramp gore areas.
- **Yellow** markers can be used to augment dividing lines, the right-hand edge lines of one-way carriageways and markings at median islands.
- **Red** markers are used where appropriate to augment left-hand edge lines of two-way and one-way carriageways.
- **Blue** markers are used to mark the location of fire hydrants on roads. In this case a single marker is placed near the road centre line opposite the position of the hydrant on that side of the road.
- **Green** markers may be used to denote freeway/motorway exits and entries.

Guide posts

Guide posts (known as edge marker posts in New Zealand) are used to show the edge of the road and enhance the delineation of the road's path for drivers. They should be installed at a uniform distance from the edge of the road and should be fitted with retro-reflective delineators (Figure 10.11). On narrower or lower volume roads where there is insufficient road width to mark a centre line, guide posts may be the only form of delineation provided. In Australia red delineators are used on the left side of the roadway, white delineators on the right side of two-way roadways and yellow delineators on the right side of one-way roadways (including divided roads), while in New Zealand white delineator strips are used on the left hand side and yellow delineators on the right hand side.

Requirements for the size, spacing and location of guide posts are detailed in AS 1742.2:2009 and MOTSAM Part 2 (2010). On straight road sections, guide posts should be arranged in pairs at a spacing of 150 m, although this spacing may be amended according to conditions outlined in the standard. The standard also specifies the spacing of guide posts on curves, crests, cuttings, bridges and culverts. Guide posts should be installed to be 1 m high above ground level.

Requirements for delineators, including details for mounting on guide posts, safety barriers and snow poles, are described in the Australian Standards series AS 1742 and MOTSAM for New Zealand.

Figure 10.11: Guide post and retro-reflective delineators providing delineation of a curve

Source: Safe System Solutions Pty Ltd

Warning signs

While guide posts and line marking can be used to delineate the path of a road, some of the more unexpected aspects of the road's geometry will require additional signage to convey its severity and nature to drivers. Curve warning signs, advisory speed signs and chevron alignment markers (CAMs) are all appropriate treatments for substandard curves (Figure 10.12)

Figure 10.12: Warning sign, advisory speed sign and chevron alignment markers (CAMs)

Source: Safe System Solutions Pty Ltd

On sections of road that have curved alignment, a crash history, and pass through an environmentally sensitive landscape, it may be desirable to provide an enhanced warning sign at both approaches to the road section (Figure 10.13)

Figure 10.13: Warning/advisory sign

Source: Austroads Ltd

Weather warning systems

A range of conditions related to weather can have an adverse effect on vehicles staying on the road through their impact on drivers or the road surface. Common conditions include:

- heavy rain
- ice and/or snow
- fog
- water on road
- strong winds.

Weather warning systems may be used on freeway and non-freeway arterial roads where the adverse effects of weather increase the risk of road crashes. The need may be identified through crash data, police reports or public feedback to road authorities. Such a system may be as simple as permanent signs, but more complex systems are also possible. For example, an ice warning system can consist of warning lights and signs that are activated by inputs from temperature and humidity sensors. Similarly, a fog warning system could activate advance warning signs and lights in response to inputs from a visibility detection device.

A weather warning system will generally be applicable to a specific location where a particular weather condition has been identified as a contributor to crash risk.

10.2.2 Road design elements

In order to give motorists the best chance of keeping their vehicles on the road, it is necessary to provide a geometric design conducive to safe travel. The principal factor influencing a vehicle's ability to traverse and remain on a road is the speed of the vehicle. Accordingly, it is necessary to take into account the operating speed of a road section when setting such parameters as curve radii, lane widths, shoulder widths, seal types and road surface drainage. For full information on the topics in this section the practitioner is referred to the Austroads *Guide to Road Design* series (Austroads 2013-2021) and the New Zealand Transport Agency's *Draft State Highway Geometric Design Manual* (NZTA 2000)

Lane widths

The width of a traffic lane influences the ease with which vehicles can operate in that lane. Higher traffic volumes and higher speeds demand wider lanes to allow more space between passing vehicles, and between vehicles and any roadside objects. Appropriate lane widths for urban and rural environments are specified in *Guide to Road Design Part 3: Geometric Design* (Austroads 2016a).

Road shoulders

Road shoulders have two key functions, namely, traffic and structure. The traffic function of shoulders is that they:

- provide a recovery area for errant vehicles
- provide a relatively safe area for stopped vehicles
- can be used by cyclists thus separating them from vehicles
- provide a trafficable area for emergency vehicle use
- provide clearance from roadside hazards.

From a structural perspective shoulders provide lateral support to pavement layers.

Shoulders may be wholly or partially sealed. Sealing of shoulders is frequently done to reduce maintenance costs and to improve moisture conditions under pavements, especially under the outer wheel path. However, a most important benefit of sealed shoulders is that they reduce crash rates, particularly with respect to run-off-road crashes, with most of the benefit being achieved by a shoulder seal width of 0.5 to 1.5 m.

It is noted that research in Queensland identified that rural undivided roads with little or no sealed shoulder (< 0.5 m category) had 1.7 times higher risk of casualty crashes (any type) than roads with 2.0 m sealed shoulders. Safety benefits of sealed shoulders were also evident on rural roads with lower speed limits, e.g. 80 km/h.

The width of shoulder sealing will depend on traffic speed, volume and composition, environmental conditions and the nature of the roadside area. Guidance on sealed shoulder widths is provided in Austroads (2016a).

Horizontal alignment and localised curve widening

The careful design of horizontal curves is one of the primary considerations in designing to minimise the danger of roadside hazards. In order for a vehicle to travel around a bend at a certain speed, the horizontal friction between the vehicle and the road pavement must be sufficient to counteract the inertial force that would maintain the vehicle's initial direction. Constructing a bend with as large a radius as the landscape allows is therefore the first step in providing a driveable path. However, it is desirable to have a consistent alignment standard over a section and well-designed transitions from generous to tighter alignments.

Widening of the road pavement may be required at curves in the road, dependent on curve radius, lane width and the design vehicle for the road. One reason for this localised widening is that all vehicles (particularly a truck or bus) travelling around a curve will occupy more of the lane width than the same vehicle travelling on a straight. This increased width occupied by vehicles also reduces the clearance between vehicles travelling in opposing directions. Extra lane width at curves maintains an acceptable clearance.

The second reason for localised widening on curves is that vehicles typically do not maintain the same lateral position in a curve that they would on a straight. This is due to the requirement that a driver steer through the curve. Some deviation from a perfect path must be expected.

Vertical alignment

Vertical alignment is an important consideration in road design. An adverse vertical road alignment may result in increased vehicle speeds along dips in a road, or poor sight distance on the approach to a crest, each situation potentially resulting in a vehicle losing control and running off the road.

Flat or almost flat grades should be provided where possible. Steep grades become prohibitive or even non-negotiable for heavy vehicles. Flat grades allow all vehicles sharing a road to travel at the same speed. Steep grades, on the other hand, cause different vehicles to travel at different speeds, which creates a higher risk of rear end crashes. Differences in vehicle speeds also contribute to queuing, which may be frustrating to drivers within the queue. Where vertical curves occur in conjunction with horizontal curves extra care in design needs to be taken.

Where it is necessary to have long steep grades, the provision of safety features such as passing bays and auxiliary lanes to allow light vehicles to safely overtake slower moving heavy vehicles, or the installation of safety ramps and arrester beds to safely bring a runaway vehicle to rest should be considered. Provision of such features may be particularly relevant to roads with a reasonably high proportion of heavy vehicles.

Road surface

A road surface needs to be constructed and maintained to a sufficient standard to ensure adequate skid resistance. Skid resistance is the frictional resistance provided by the pavement to vehicle tyres during braking or cornering manoeuvres, normally measured on wet surfaces. Situations where a pavement can hold water instead of draining properly can contribute to vehicles aquaplaning.

To be sure of the condition of an existing pavement it is necessary to conduct skid resistance measurements as well as an assessment of the level of rutting and the occurrence of potholes. Measurement of skid resistance and rutting can be undertaken using a number of methods, some of which are highly automated and efficient. The decision to act on the results of such measurements is left to the experienced practitioner; however a guide to the use of skid resistance values can be found in the *Guide to Pavement Technology Part 3: Pavement Surfacings* (Austroads 2009a).

Sight distance

It is important that adequate sight distance is provided whenever possible to allow drivers and other road users to safely negotiate the road. Sight distance is related to design speed for the road and can be affected by the road geometry (horizontal and vertical alignment), terrain (particularly on the inside of horizontal curves) and roadside objects (such as trees and signs).

Roadside features (such as embankments and vegetation) that prevent adequate sight distance being achieved should be removed or modified to ensure sufficient stopping sight distance on curves. If this is not practical, speeds should be reduced through such sections to compensate (for example, with warning signs). It is important that roadsides are maintained to ensure that sight distance requirements are sustained, for example by regularly pruning trees and cutting grass. On substandard curves it may be appropriate to cut benches in high batters in order to improve sight distance.

Drainage

Drainage of the road surface and surrounding areas is an important consideration for road design. A number of different aspects need be considered with regard to drainage. These include:

- drainage of the road pavement – by providing adequate grade and crossfall so that the pavement is able to drain and pooling of water is avoided, which allows maintenance of skid resistance
- appropriate infrastructure to collect and transfer the water from the pavement, which may include kerb and channel or table drains
- a road side or drainage system that can also accommodate water run-off from adjacent land uses.

If constructed across a flow path, a road may need to be designed to be able to handle the run-off from adjacent land for during a flood event.

10.3 Types of Hazards and their Treatments

The types of hazards that may be encountered on roadsides can be divided into six broad categories:

- rigid objects – trees, utility poles, culvert end-walls, etc.
- medians (cross median crashes)
- embankments and cuttings
- open drains
- bodies of water
- kerbs.

In priority order, the following approaches should be taken with these hazards:

- removal of the roadside hazard
- redesign of the hazard so as to make it traversable
- relocate hazard to a location where it is less likely to be struck
- replacement of the hazard so that it breaks away or is impact absorbing
- shield the obstacle with an appropriate barrier and/or a crash cushion
- if none of the above is attainable, delineate the obstacle.

Each option for hazard reduction is to be ranked according to benefit cost analysis techniques and engineering judgement.

10.3.1 Rigid objects

Poles

Poles are a common road furniture item used to support signs (regulatory, warning, guidance, informative), road lighting and various devices. In line with the preferred treatment for roadside hazards, the practitioner's aim should be to minimise the number of poles along the roadside and eliminate the risk of errant vehicles striking non-frangible poles in high-speed environments.

The hazard presented by a roadside pole is related to its location, size, type of construction and the prevailing traffic speeds. These contribute to the hazard the pole may pose and the consequences of an errant vehicle hitting the pole.

Where possible, poles should be located such that an errant vehicle is unlikely to hit them. Minimum lateral set back distances for signs and for road lighting poles are specified in Australian Standards AS 1742.2:2009 and AS/NZS 1158.1.2:2010 respectively.

Poles should be designed to be frangible in the event of collisions, i.e. poles that are designed to fracture, break away, give way or bend such that the damage to a colliding vehicle and risk of injury to vehicle occupants upon impact is minimised. Small signs are usually supported by poles that deform in a way that causes minimum damage to cars, whereas larger posts and supports (for larger signs) may be provided with mechanisms that are designed to yield in a controlled manner upon impact.

Sign poles

AS 1742.2:2009 provides longitudinal and lateral placement and mounting height for signs, orientation, post type and selection. Larger signs are often supported by a number of frangible sign posts for which the spacings of the posts and height of the sign are important considerations. A number of frangible post designs are used in Australasia.

Signs should be erected such that sight distance is not compromised. Longitudinally, signs should be located to provide enough warning for a driver to be able to make a decision and respond as necessary. It is also important that signs are spaced far enough apart longitudinally that drivers are able to process the information before encountering another sign.

In New Zealand the placement of poles is detailed in the *Manual of traffic signs and marking;* (New Zealand Transport Agency 2010).

Light poles

AS/NZS 1158.1.2:2010 discusses the use and placement of rigid and frangible road lighting poles.

Rigid poles do not deform to a great extent, but are designed such that they remain upright after an impact. Alternatively, frangible poles are designed to deform or dislodge upon vehicle impact. Types of frangible poles include:

- Slip-base poles: break away at the base upon impact, allowing the vehicle to pass beneath the pole and aiming to minimise or avoid injury to vehicle occupants (Figure 10.14).
- Impact absorbing poles: collapse over the colliding vehicle and are designed to bring the vehicle to a controlled stop at the base of the pole (Figure 10.15). Impact absorbing poles are designed to remain in the ground after being hit.

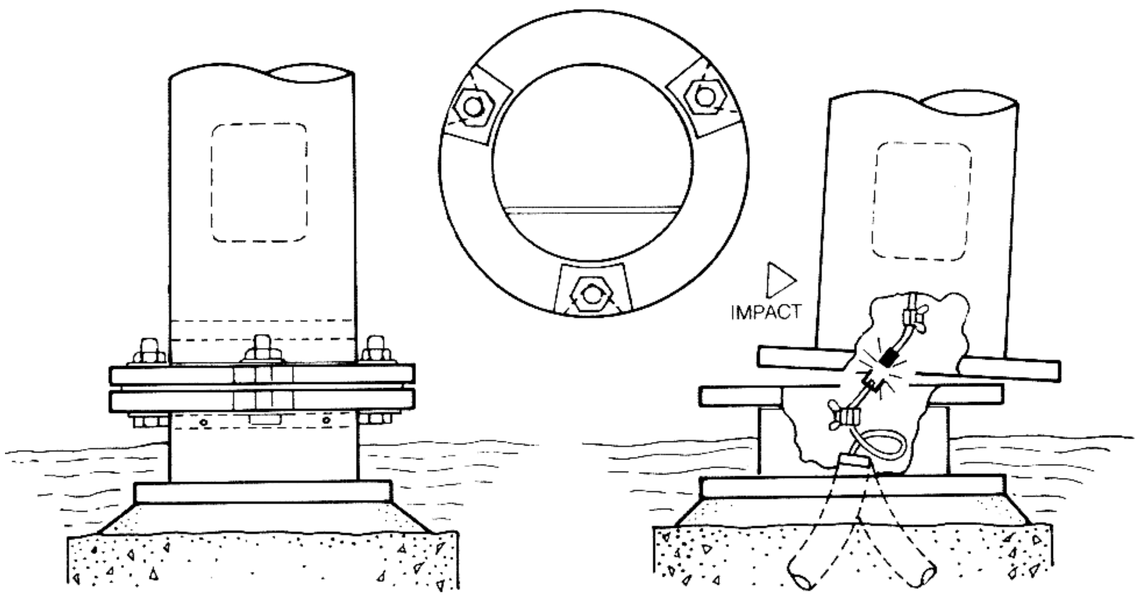
The decision to use slip-base poles will depend on the space available and the resultant likelihood that a falling pole would cause injury to other users of the road or roadside area. For example, a slip-base pole will usually be inappropriate where pedestrian or cyclist traffic is common because a falling pole would pose an unacceptable risk to those road users.

Aspects involved in the selection of pole type and set back from the carriageway include:

- surrounding land use
- pedestrian or cyclist activity
- speed limit
- whether road is kerbed or non-kerbed
- location – mid-block or intersection
- road alignment.

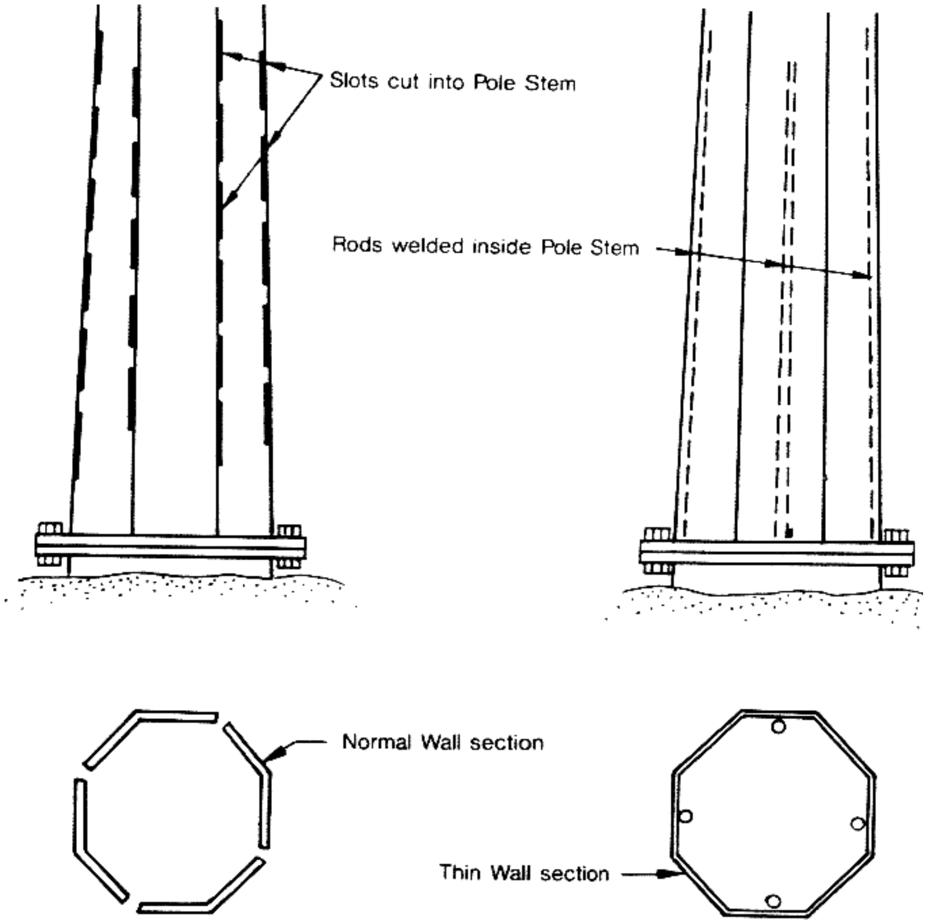
Refer to AS/NZS 1158.1.2:2010 for detailed information.

Figure 10.14: Slip-base pole



Source: Austroads 2004c

Figure 10.15: Impact absorbing pole



Source: Austroads 2010

Service poles

The ideal treatment of service poles is to remove them and relocate services underground. Where this is not possible, service poles should be located where it is least likely that they will be impacted by an errant vehicle and/or shielded by a safety barrier.

Trees

Trees greater than 100 mm in diameter that can foreseeably be struck by errant vehicles pose a potential hazard to motorists. New trees should be located where they do not pose a serious roadside hazard or should be shielded by a safety barrier.

Where existing trees are located near a roadway, treatment options include removing the tree, installing a safety barrier and measures to reduce the likelihood of vehicles leaving the road such as the provision of a wider shoulder. The decision to remove a tree or provide a safety barrier will depend on a number of factors relating to site conditions, crash history, economics and the environment.

It is also important that established clear zones are kept free from regrowth and that trees are pruned regularly enough to ensure that any growth does not restrict sight distance.

Other roadside obstacles (e.g. fire hydrants, mail boxes and fences)

Other roadside obstacles should be designed so they do not pose a serious risk to an errant vehicle. Objects containing horizontal rails capable of spearing vehicles (such as post-and-rail fences) can be particularly hazardous. Such objects should be located where they cannot be struck by an errant vehicle or such that impact with the object should not result in serious injury.

Traffic signal posts

Traffic signal posts can also pose a hazard for any errant vehicles. They are often necessarily located close to the carriageway of intersections, which could lead to a higher risk of impact, although some measures can be taken to minimise this risk. Such measures include not locating a signal post on the outside of a curve, setting posts as far back from the carriageway edge as practicable, minimising the number of posts and joint use of poles.

Culverts

The ends of culverts that cross under the road or are located parallel to the road constitute hazards for motorists. They should be relocated, treated or shielded wherever possible.

Traversable treatment (parallel to road)

Traversable treatments need to be installed wherever a culvert exists parallel to the road and is exposed to errant vehicles (Figure 10.16).

Figure 10.16: Traversable culvert situated parallel to road

Source: Safe System Solutions Pty Ltd

Headwall treatment (perpendicular to road)

Culverts that run perpendicular to the road (i.e. run under the road) need to be:

- traversable – if the fill batter is of a low enough slope
- protected with an appropriate barrier – if the slope is not traversable (or if corridor protection is desired).

Bridge end posts

Bridge ends need to be designed to prevent vehicles from running into the end support posts of the bridge barrier, being speared by any horizontal bridge members or simply crashing through any approach barrier and being exposed to a hazard (e.g. roll-over, water course).

Gradual stiffening needs to be provided on the transition from a non-rigid approach barrier to the rigid bridge barrier.

The piers of bridges over roads (at overpasses) should desirably be protected by a crash cushion or safety barrier.

10.3.2 Embankments and cuttings

Batter slopes

Guide to Road Design Part 3: Geometric Design (Austroads 2016a) provides guidance on use and design of batters. It is desirable that batters are constructed to allow errant vehicles to negotiate the slope safely in the event of a run-off-road crash. If there is a risk that a batter slope is severe/steep enough to cause an errant vehicle to overturn during a crash, installation of a safety barrier should be considered. Design slopes for both cut and fill batters are provided in the Austroads (2016a) guide.

An aspect of batter design relates to the concept of recoverable, non-recoverable/traversable and critical fill batter slopes. These terms refer to the likelihood of a vehicle overturning on various slopes.

After running off the road onto a recoverable batter slope, a driver will usually be able to regain control of the vehicle and return to the road or stop safely. On a non-recoverable/traversable slope, however, the driver is unlikely to be able to return to the road but will be able to stop safely at the bottom of the slope. A critical slope will probably result in the vehicle overturning.

The surface of the fill batters should be smoothly constructed so that errant vehicles are not thrown out of control by striking surface irregularities (e.g. large rocks or pot holes).

The *Roadside Design Guide* by the American Association of State Highway and Transportation Officials (AASHTO 2011) defines recoverable slopes as flatter than 1:4 (i.e. a fall of one metre for every four metres of width), non-recoverable/traversable as between 1:4 and 1:3, and critical as steeper than 1:3.

Treatment options for non-recoverable/traversable slopes and critical slopes include flattening batter and installing safety barriers.

Cuttings and rock faces

Cuttings and rock faces are generally expensive to construct. Economic and environmental constraints have often resulted in cuttings being as narrow as possible and prevented the provision of a cutting wide enough to allow for safety barriers or adequate recovery areas. Where safety barriers are not provided, cuttings and rock faces should be cut to provide a smooth face to act as a rigid barrier, allowing errant vehicles to slide along and stop gradually. Uneven surfaces may present a hazard to vehicles that happen to run off the road.

Deep, unprotected drains should not be provided at the base of unshielded cut batters. Effective redirection of vehicles requires a flat even surface approaching the embankment.

10.3.3 Open drains

Open drains are present on the majority of rural roadsides and also occur on urban freeways. Their primary function is to collect and carry the surface water away from the roadway. Open drains are designed to accommodate run-off from heavy rain storms with minimal road surface flooding or damage. Deep drains constructed close to the road may be the most efficient way of removing water but, unless they are of a suitable shape, they are a hazard for errant vehicles that leave the road.

Typical drains can be classified by whether they are designed with abrupt or gradual slope changes. Abrupt slope change designs include vee drains, rounded drains with bottom widths less than 2.4 m, and trapezoidal drains with bottom widths less than 1.2 m.

Vehicles leaving the roadway and encroaching into a drain face three hazard areas:

- **Drain front slope.** If the front slope is 1:4 or steeper, the majority of vehicles entering the ditch will be unable to stop and can be expected to reach the bottom.
- **Drain bottom.** Abrupt slope changes can result in errant vehicles colliding with the bottom of the drain.
- **Drain back slope.** Vehicles travelling through the drain bottom or becoming airborne from the front slope can collide with the back slope.

Drains can funnel a vehicle along the drain bottom. This increases the likelihood of impact with any fixed objects present on the bottom or side slopes of the drain. Breakaway hardware may not operate correctly if the vehicle is airborne or sliding sideways when contact is made. For these reasons, non-yielding fixed objects should not be located on the side slopes or bottom of drains.

Back slopes typically occur when roadways are constructed by cutting the existing terrain away to develop the roadbed. If the slope between the roadway and the base of the back slope is 1: 3 or flatter, and the back slope is obstacle free, then the back slope may not be a significant hazard regardless of its distance from the roadway. Back slopes that will not provide a relatively smooth redirection or that can cause vehicle snagging should be avoided or be shielded. This usually includes rough sided rock cuts when the rough face can cause excessive vehicle snagging.

10.3.4 Bodies of water

Bodies of water should be evaluated with respect to the degree of potential hazard they pose. This will be a combination of the amount of water and its accessibility. The depth may be ranked according to whether:

- a vehicle can completely submerge, resulting in the drowning of uninjured non-swimmers, disabled or elderly persons, or infants
- water could fill an upright car to a point where an unconscious or injured driver or passenger would drown (assumed depth of 0.6 m)
- an upside down car would be in water deep enough that an unconscious person would drown (assumed a depth of 0.3 m).

Fast moving bodies of water are considered to be more hazardous than those that are still. In general, practitioners should carefully consider the risk associated with bodies of water over 0.6 m deep, or water courses with a normal base flow depth greater than 0.6 m, as these could cause a stunned, trapped, or injured occupant to drown.

Other factors to consider include the:

- slope of the vehicle path to the water
- total distance available in which to stop
- persistent or intermittent presence (flooding potential) of the water hazard
- presence of intervening obstructions that would reduce the likelihood of an errant vehicle reaching the water.

The practitioner should visualise the paths that errant vehicles are likely to take in reaching the water. If the water hazard is substantial and likelihood of errant vehicles reaching that water is high enough, consideration should to given to the provision of shielding to prevent access to that water.

10.3.5 Kerbs

Where barrier kerb of a height greater than 100 mm runs along the side of a road, it can cause a sliding vehicle to 'trip' and roll over. For this reason, barrier kerb higher than 100 mm should be avoided except in low speed, urban settings. Ideally, the use of barrier kerb of any type should be avoided in high speed areas. In its place, semi-mountable kerb can be installed. This provides delineation and drainage without presenting a rollover hazard.

10.4 Safety Barriers

In instances where a roadside hazard cannot be made safe, removed or relocated, it may be necessary to provide physical protection from the hazard. Safety barriers are available for a variety of applications and this section provides advice on selecting, installing and maintaining safety barriers.

The Australian and New Zealand AS/NZS 3845.1:2015 *Road Safety Barrier System*s details the design and application of safety barriers.

Performance standards for safety barriers provide a guide to the type of road and traffic environment for which various barrier types are suitable. There are a number of *test levels* signifying different levels of barrier performance. Barrier systems used in Australia and New Zealand must have been tested and certified according to the Manual for Assessing Safety Hardware (MASH) by the American Association of State Highway and Transportation Officials (AASHTO 2016), or National Co-operative Highway Research Program system (NCHRP 1993).

The testing of safety barriers system examines the:

- structural adequacy of the barrier system
- risk to vehicle occupants and the impact velocity and ride down acceleration limits
- trajectory of the vehicle after impact.

10.4.1 Decision to install a safety barrier

Safety barriers are potential roadside hazards. When considering whether to install a safety barrier, it is important to remember that the barrier will present some danger to the occupants of errant vehicles, and especially to unprotected road users such as motorcyclists. A barrier should only be installed if collision with it will present less of an injury risk to vehicle users and occupants than would result from collision with the roadside hazard that is to be shielded by the barrier.

It is important to consider the danger posed to motorcyclists by both the hazard and the intended safety barrier. Motorcyclists are particularly vulnerable to unforgiving roadside environments; any obstacle in the path of an errant motorcyclist has the potential to cause severe injury. If it is decided that a safety barrier is necessary at a site, attention should be paid to the design of the barrier to ensure that it poses as little risk as possible to colliding motorcyclists.

The installation of increased amounts of barrier also leads to increased maintenance requirements and costs. Maintaining a roadside environment in the presence of a barrier as opposed to a clear zone can require heightened work, health and safety risk for maintenance workers in some circumstances. Ideally these issues are taken into account when considering barrier implementation.

10.4.2 Barrier failures

It is also important to note that barriers lie on a risk continuum and occasional failures are possible. These can occur in two main ways; breaches due to mechanical failure and rollovers (Ray et al. 2012). Practical information regarding the risk of breaches and rollovers, including methods for mechanistic evaluation, is provided in Ray et al. (2012). A number of historical crash data evaluations are also reported; a study of data from 12 US states suggests an average cable median barrier penetration rate of 2.6%, ranging up to 5.3% for states with a more than 100 recorded barrier strikes. Another study of nearly three thousand barrier crashes in Washington State suggests a relative failure rate (measured as uncontained median crossovers) of 6.0% and 3.7% for low- and high- tension cable barriers, respectively, and 2.2% for concrete barriers. It should also be noted that in the same study, cable barriers resulted in non-containment (i.e. vehicle redirection) at a substantially reduced rate (8.1% and 24.8% for low- and high-tension cable barriers, respectively) compared to concrete barriers (63.6%).

10.4.3 Barriers and motorcyclists

All roadside furniture is expected to be hazardous to motorcyclists. When considering the roadside environment and motorcyclists safety, road designers should ensure that:

- measures are undertaken that assist motorcyclists maintain control of their motorbikes (e.g. adequate and consistent skid resistance, and removal of loose gravel on road surfaces)
- the roadside is clear of obstructions and is smooth
- the quantity of roadside furniture is minimised
- roads including intersections are designed to ensure that gravel does not migrate onto road surfaces.

Where a barrier is used, the practitioner should bear in mind that barrier posts are the main cause of injury to motorcyclists. Other barrier attributes that are considered to be dangerous to motorcyclists include upper and lower edges (particularly if jagged edges exist), protruding reflectors and low barrier mounting height (as motorcyclists can be thrown over the barrier). It is therefore essential that the barrier is correctly designed and installed. To minimise the severity outcome for motorcyclists impacting with barriers, barriers need to be smooth, be free of any sharp edges or corners, have a continuous surface, and be located close to and be near parallel to the traffic flow.

Bambach and Grzebieta (2015) found that continuous barriers (rub-rails and concrete barriers) provide substantially lower injury potential than W-beam barriers, since the motorcyclist is redirected along/away from the barrier and does not impact the barrier posts. The most effective method for protecting around half of the motorcyclists who potentially can impact a W-beam barrier is to install rub-rails. A steel W-beam barrier with rub-rails is shown to provide lower injury potential to motorcyclists than concrete barriers (when the motorcyclist slides into the barrier, which is around half of the motorcycle-into-barrier crashes). Such a system is shown to prevent serious motorcyclist injuries for most practical collision orientations and speeds. Post paddings are shown to be marginally effective since a post impact is not prevented and are only effective at very low impact speeds.

A number of measures have also been developed for existing safety barriers so as to better protect impacting motorcyclists. The methods, which generally involve proprietary products, include:

- installation of additional rails to reduce the risk of a motorcyclist from striking posts eg. rub rails on W-beam systems (Figure 10.17).
- covering of posts with energy absorbing material eg. post cushions for wire rope safety barrier (WRSB).

Figure 10.17: W-beam barrier with rub rail on a popular motorcycle route

Source: Safe System Solutions Pty Ltd

10.4.4 Safety barrier types

The following sections describe a number of roadside safety barriers and end-treatments. This list does not contain all available types of barrier, and the practitioner should be aware that manufacturers continually develop new or improved barrier designs. Accordingly, the information presented here refers to testing procedures, the results of which can be used to determine the suitability of proposed barriers. No barrier should be installed unless it has been shown to meet the applicable standards and can therefore be expected to perform satisfactorily.

Barrier types include rigid barriers, semi-rigid and flexible barriers. Flexible barriers are preferred as they are the most forgiving on vehicle occupants during a crash, while a rigid barrier may be suitable where space is limited and it is placed relatively close to the traffic lane (e.g. narrow median).

Some commentary is provided here regarding background information on crash barriers for the benefit of practitioners not familiar with barrier types and their specific characteristics. It should be noted that *Guide to Road Design Part 6: Roadside Design, Safety and Barriers* (Austroads 2020a) provides further information on barrier types and guidance on their selection and application. The following section highlights the evidence behind their performance in a Safe Systems context.

When selecting a barrier type a variety of factors need to be considered. These factors include:

- performance capability and level of containment requirements
- clearance to hazard requirements and the dynamic deflection characteristics of the barrier
- site conditions (i.e. vertical and horizontal alignments, and cross-slopes)
- compatibility with adjacent barriers
- installation and maintenance costs
- aesthetics and environmental impact.

Flexible barriers

Flexible barriers currently include wire rope systems and flexible W-beam systems. Wire rope safety barriers (WRSB) contain tensioned steel wire rope that is supported by posts and anchored into the ground at the end of each section (Figure 10.18). Upon impact, the posts deflect back and the vehicle is engaged by the steel wires which go into tension thus containing and re-directing the vehicle. This type of barrier contains the largest dynamic deflections of the three barrier types and consequently has the lowest peak impact forces and acceleration on vehicle occupants of the three barrier types (Hammonds & Troutbeck 2012). Wire rope barriers are usually cheaper than the other barrier types to install but can be the most expensive to maintain as even low force impact will require repairs and wire tension must be monitored. Once struck, posts must be replaced, wires put back in place and re-tensioned. One disadvantage of a flexible barrier is that it has less ability to contain a secondary impact than the other barrier types (i.e. once struck it will not be able to contain another striking vehicle in the same location). It is therefore important that repairs are performed in a timely manner.

There has been much attention on the performance of flexible barrier systems over the past decade and they have been found to deliver exceptional safety performance in reducing severe crash injury (Austroads 2014a). It should be noted that flexible W-beam systems (also sometimes referred to as weak post systems) also deliver close to flexible barrier performance. At the time of writing there was little published evidence regarding the use of these systems in a corridor treatment context, however they are beginning to find increasing application amongst road authorities. A particular advantage of these new systems is that they can be easily combined with motorcycle rider underrun protection.

Figure 10.18: Examples of flexible barrier designs

(a) Flexible W-beam **(b) Wire rope safety barrier (WRSB)**

Source: Safe System Solutions Pty Ltd (2015)

Limitations:

- Generally, flexible barriers are installed on slopes no steeper than 1 in 10. The maximum lateral slope of 1 in 10 also applies to the area immediately behind the barrier for a distance equal to the likely deflection of the fence under vehicle impact.
- The minimum length of flexible barrier (excluding end terminals) should comply with the manufacturer's specifications and jurisdictional requirements (e.g. not less than 60 m).

- WRSB should generally not be installed on curves that have a horizontal radius of less than 200 m, as the required rope tension and height may not be maintained during or after an impact.
- WRSB systems should not be installed on sag vertical curves where the K[2] value is less than 30. This is because the tension in the ropes may cause the posts at the bottom of the dip to lift out of their sockets, especially in cold weather. This, combined with the possibility of the suspension of an errant vehicle being compressed at the bottom of a vertical sag curve, may cause a vehicle to pass beneath the cables, rather than being captured.
- WRSB systems should not be connected directly to any other barrier or bridge parapet as an impact vehicle may 'pocket' as it 'runs' along the barrier and strikes the connected more rigid barrier or bridge parapet. They may, however, be installed in close proximity to other barriers (refer to Section 10.4.5).

Case study: Reducing asset maintenance costs

In 2012, the Department for Planning, Transport and Infrastructure in South Australia installed 2.3 km of median wire rope safety barrier (WRSB) along a section of the Victor Harbor Road known locally as Willunga Hill (Dua & Anderson 2013). The section of undivided four-lane/two-way roadway has a steep grade combined with several horizontal curves over a short distance. This section was chosen for treatment as it had experienced a number of fatal and serious crashes due to vehicles crossing over the centreline. The MWRSB is installed in the middle of a 2.0 m wide flush sealed median along with roadside wire rope and W-beam barrier. Audio-tactile edgeline and centreline markings were also installed as part of the project.

Figure 10.19: Automated measurement of tension in wire rope safety barriers

A novel approach was used to address asset maintenance issues by installing a load cell monitoring system. The system measures the tension of the MWRSB wire ropes and can be monitored via an app on a mobile phone. Maintenance costs have been reduced as the critical condition of the facility can be monitored remotely and crews only sent out when required (Dua & Anderson 2013). Notifications can be triggered when wire tension changes beyond a threshold level possibly indicating a vehicle collision; at this stage, the value of this approach is limited by the close proximity to a load cell in which crashes need to occur to be detected (O'Callaghan 2015). The design of this system nonetheless demonstrates the value of novel approaches for overcoming such practical issues.

[2] The K value is the length of a vertical curve in metres divided by the change of grade expressed as a percentage.

The evidence for using flexible barriers as roadside protection is presented in Table 10.2. In all cases the flexible barrier system has been a wire rope system. A study by Chow and Meuleners (2016) looked at the safety effects of three types of barriers widely used in Western Australia; flexible wire-rope safety barriers (WRSBs), beam (such as W-beam and Thrie-beam) barriers and concrete barriers. Comparisons of crash rates were made before and after the installation of barriers at 133 sites (87 metro and 46 rural). When the three barrier types were considered together, the results suggested that on average crashes reduced after the installation of barriers and that fatal and serious injury (FSI) crashes reduced to an even greater extent. This effect was largely observed in rural areas and less so on metropolitan roads. WRSB was found to be the most successful in reducing single vehicle FSI crashes (84%). The study also found that at all 27 sites treated with Concrete Barriers only (all were metropolitan sites) there was a significant 26.2% reduction in Run-off Road Crashes per million vehicles and a significant 12.9% reduction in Run-off Road FSI Crashes per million vehicles.

Table 10.2: Evidence for the high safety performance of flexible wire rope barrier systems (Australian and New Zealand literature)

Literature	Evidence
Candappa et al. (2011)	• 100 km of flexible barrier on Victorian roads • 60% on roadsides / 40% on medians • 42% crash reductions in all severe crashes • 56% for severe head on and road departure crashes • Where barriers were applied on a more continuous basis: • 87% for severe head on and road departure on the Hume Hwy • 83% for severe head on and road departure on the Eastern Fwy
Austroads (2018a)	• Concluded that the risk of a severe injury outcome in a single vehicle road departure collision with a flexible barrier was exceptionally low on urban freeways • Risk was also higher in similar collisions where no object was hit and vehicles presumably run out into the available roadside space
Austroads (2014a)	• Flexible wire rope barrier had the lowest fatal and serious injury ratio per crash • Can achieve a close alignment with the Safe System
Chow and Meuleners (2016)	• Reductions in run-off-road Killed and Serious Injury crashes per million vehicles in Western Australia: • Flexible wire-rope barriers only 83.4% • Beams only 74.5% • Concrete barriers only 12.0% • All barriers of interest 73.9%

Austroads (2014a) found that flexible wire rope barrier systems had the lowest fatal and serious injury ratio per crash of the barrier systems. It was concluded that flexible wire rope systems could achieve close alignment with the Safe System in Figure 10.20 and Figure 10.21.

In a study of 100 km of wire rope barrier, (Candappa et al. 2011) concluded that flexible barriers were superior to W-beam and concrete barriers due to their ability to capture vehicles, even well beyond the systems design speeds and mass, and minimise overturning. It was shown that although good safety performance was obtained from discrete use of the barriers, continuous application yielded much higher safety outcomes for severe head-on and road departure crashes.

Austroads (2015) also identified that over a ten year period, 32% of single vehicle casualty crashes into flexible barrier on urban freeways were severe. More research was suggested to better understand the problem; however, tension force and high impact angles were regarded as contributors. This raises the issue that ongoing monitoring of the infield performance of barrier installations is required. If under the Safe System transition scenario more safety barrier is to be used throughout the network, it is likely that increasingly more collisions exceed current barrier test configurations. Barrier failures need to be better understood and barrier application fine-tuned in order to get closer to Safe System aspirations.

Figure 10.20: Wire rope safety barrier – roadside

Source: Safe System Solutions Pty Ltd

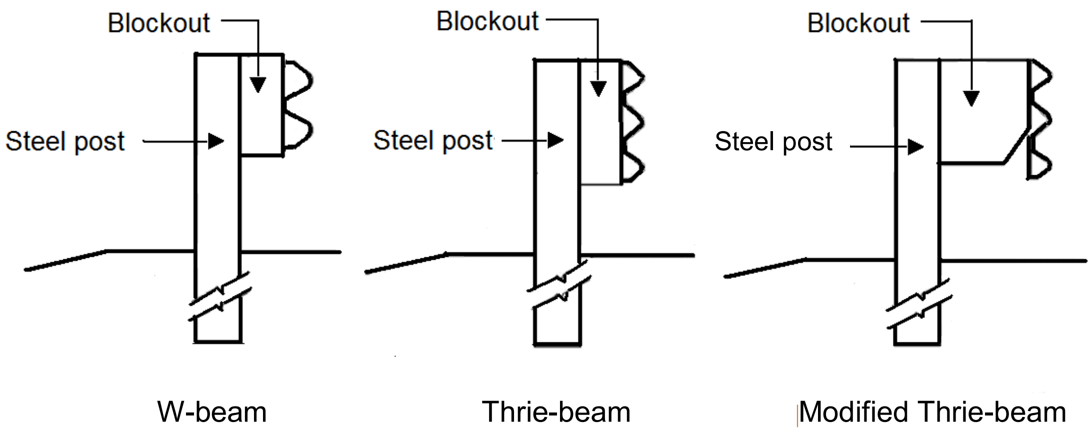
Figure 10.21: Wire rope safety barrier – median

Source: Safe System Solutions Pty Ltd

Semi-rigid barriers

Semi-rigid barriers most commonly consist of overlapping steel W-beam sections connected by bolts and supported by hard posts. The most prevalent type in Australia utilise C-section posts with block outs (Figure 10.22). In very simplistic terms, the W-beam sections go into tension when struck and have a deflection "pocket" at the impact point that propagates along the barrier eventually redirecting the vehicle back on path. At the same time the posts rotate backwards and the block outs raise the height of the W-beam on rotation assisting to prevent the striking vehicle from rolling over the barrier. There is moderate dynamic deflection with these barrier types and energy is dissipated over a longer period of time and therefore with less peak load on vehicle occupants when compared to that of a rigid barrier. Once struck, the W-beam section and posts need to be replaced. Semi-rigid barriers are less expensive to install than rigid barriers but are more costly to maintain. They are particularly well suited to hills environments where small radii curves are encountered and tend to have a lower rate of death and serious injury than rigid barriers (Chow & Meuleners 2016).

Figure 10.22: Profiles of different semi-rigid barrier designs



Source: Austroads (2020a)

Figure 10.23: W-beam safety barrier

In some situations a stiffer barrier may be necessary, when more restraint is needed for heavy vehicles, or where reduced deflection is required (e.g. narrow medians with restricted cross-sections). In such situations a barrier that provides a greater level of containment such as a 'thrie-beam' barrier may be installed. The thrie-beam has two indentations and is stiffer than W-beam which has one indentation.

Both the W-beam and thrie-beam barriers are designed to deform and to retain their tensile strength when struck, to prevent the vehicle from passing through. The deformation of the barriers gradually dissipates the energy of the vehicle impact and aids in redirecting and stopping the vehicle.

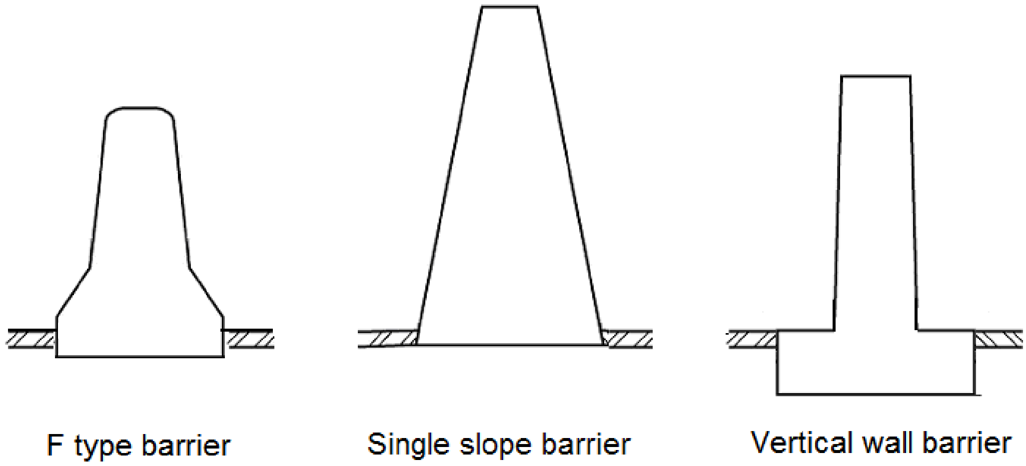
Limitations:

- While W-beam and thrie-beam barriers perform well on the outside of curves, even those of relatively small radius, they may not perform well on the inside of small curves. The convex when applied on the inside of small radius curves can mitigate against the development of tension in the rail. This is generally only a problem for very small radii, such as those on the corners of intersections, and is addressed by weakening of the rail.
- The minimum length of W-beam is dependent on the particular application and is determined by aggregation of the various components. As a general guide, 30 m can be taken as the minimum length of barrier that should be installed (including terminals), however this length may be much greater for proprietary products.
- Where a kerb exists at the edge of the road, it is desirable for a semi-rigid barrier to either be placed as close as practicable to the face of the kerb or a sufficient distance behind it to ensure that impacting vehicles do not vault over the barrier.

Rigid barriers

Rigid barriers are most commonly made from concrete and generally have zero or minimal dynamic deflection behind the barrier when struck. This can result in high peak load impact forces on vehicle occupants and riders. To reduce impact forces on vehicle occupants, a sloped face is often added to the barrier (as is usually the case in motor racing). Examples include the F-type and single slope barrier (Figure 10.24). Studies have shown that collisions with rigid barriers tend to result in more severe injury outcomes than other barrier types (Chow & Meuleners 2016) and there can be a propensity for vehicles to roll over as a result of impact. One study by Hammonds and Troutbeck (2012) concluded that for a 20 degree impact angle at 100 km/h, the tested F-type barrier showed a consistently higher ride down acceleration than the tested wire rope barrier but still conformed to maximum values for a successful test as documented in National Cooperative Highway Research Program Report 350 (NCHRP 1993) and the Manual for Assessing Safety Hardware (MASH) US based barrier testing standards (AASHTO 2016). Rigid barriers tend to be used in situations where there is insufficient space for deflection or where a high level of protection and containment is required. Although expensive to install, they have the lowest maintenance costs and are most useful where collisions are frequent. They also do not have posts that can be struck by motorcyclists and are the only barrier that can be used when heavy vehicle containment must be assured.

Figure 10.24: Profiles of different rigid barrier



Source: Austroads (2020a)

Limitations:

- They should generally not be used where likely vehicle impacts will occur at angles greater than or equal to 15°, as this could subject vehicle occupants to high severity crashes.
- They should not be used on the outside of small radius horizontal curves as vehicle occupants may be subjected to high severity crashes. It is noted though that this is not possible in all situations (e.g. adjacent to 'loop' ramps at urban freeway interchanges).

It should be noted that there is no minimum length requirement for rigid barrier (with appropriate end treatments).

10.4.5 Layout and design of safety barriers

Installation of a longitudinal safety barrier will usually require a leading terminal, a section of longitudinal safety barrier and a trailing terminal. The exact layout of these components will depend on the individual site and barrier type. A number of the key considerations are discussed in this section.

Note that detail related to the design of barriers is not provided in this guide. This information may be sourced from the Austroads *Guide to Road Design*, the New Zealand Transport Agency *Draft State Highway Geometric Design Manua*l (NZTA 2000), and the Australian and New Zealand Standard, AS/NZS 3845.1:2015 *Road Safety Barrier Systems*.

Appropriate lengths

There is no minimum length requirement for rigid barriers. The length is determined by the need to effectively shield the hazard, allowance for appropriate end terminals and to provide structural stability.

Semi-rigid and flexible barrier types rely on a degree of tensile strength to enable them to restrain vehicles. They must be of a certain minimum length in order to develop sufficient tension. A barrier that is too short will not be able to deform around a colliding vehicle without breaking off its posts. As a general rule the minimum length for a semi-rigid barrier is 10-20 m plus appropriate end terminals. The minimum lengths for flexible barrier systems vary. Practitioners will need to seek advice on minimum lengths directly from barrier manufacturers or from the relevant road authority.

End treatments

Classification of safety barrier terminals is covered in AS/NZS 3845.1:2015. Terminals may be either 'gating' or 'non-gating'. Gating terminals are designed to allow a vehicle to pass through the leading end of the barrier and come to rest in the run-out area (6 m wide by 22.5 m long for 100 km/h operating speed) behind the terminal. Installation of a gating terminal should only be used if a driveable run-out area exists behind the barrier terminal. There should be no hazards behind the gating treatment. If the intended position for a gating terminal is such that a colliding vehicle would pass through the terminal and strike a hazard, the barrier needs to be longer so that the terminal is in front of a more forgiving roadside.

Non-gating terminals are designed to arrest the errant vehicle when impacted or redirect it along its length, without allowing it to pass through the terminal. This type of terminal is appropriate if a hazard exists behind the terminal, where vehicle penetration is not acceptable, and it is not possible to extend the barrier to accommodate a gating terminal.

Barriers have evolved significantly since their introduction however a historical problem has been the safety performance of terminal end treatments. The use of the terminology "continuous lengths of barrier" relates to reducing the number of terminal end treatments along a corridor to reduce injury risk and maximise the protection offered by barrier spans.

Terminals for rigid barriers

Where it is necessary to protect road users from head-on impacts with the ends of rigid barriers, a non-gating, re-directive crash cushion is the normally recommended treatment.

For the ends of rigid barriers, sloped ends and even mounds of earth can be seen in use on the road network. Occasionally however it is desirable that energy absorbing crash cushions be used instead or the barrier blended into a cutting face. The interface between the crash cushion and rigid barrier forms a gradually stiffening surface to guide vehicles towards the rigid barrier after they first make contact with the crash cushion. An extensive range of proprietary crash cushion products are available to suit site conditions. All such devices are designed to absorb the energy of an impacting vehicle.

The end of a rigid barrier may also be treated by the installation of a semi-rigid barrier fixed to the rigid barrier with an appropriately designed transition.

It is not acceptable to use a concrete sloped end as a rigid barrier terminal. Such designs have been found to increase the risk of vehicles becoming airborne on impact. When a ramped end exists it should be removed and replaced with an appropriate approved terminal treatment.

Terminals for semi-rigid barriers

Semi-rigid barriers such as W-beam can be terminated with a number of different terminal designs. The type used will depend on the characteristics of the installation.

There have been many treatments applied over the decades in Australia and New Zealand and many obsolete examples can still be found in the field. These have ranged from the fishtails, turndowns and drum ends to sophisticated loading terminals with engineered structural elements designed to allow the system to collapse in a predictable, reliable and consistent manner.

Terminals including the breakaway cable terminal (BCT) and the Modified Eccentric Loader Terminal (MELT) are common on the road network but are no longer accepted for use for reasons including safety. The use of these products has generally been superseded by the use of terminals that are designed to redirect or contain an impacting vehicle and absorb part of the energy of the impacting vehicle.

Figure 10.25: Redirective energy absorbing terminal

Source: Safe System Solutions Pty Ltd

A variety of terminals are available from a number of commercial manufacturers. The practitioner should consult barrier manufacturers and the relevant road authority for information regarding appropriate applications. Any terminal used must be accepted for use by the relevant road authority.

Terminals for flexible barriers

AS/NZS 3845.1:2015 details the general requirements for terminals for wire rope barriers.

Unlike terminals for other road safety barrier types, the use of a terminal for a wire rope barrier that has not been evaluated under this Standard on the departure can still cause injuries to vehicle occupants hitting the terminal in the approach direction as the vehicle can get wedged under the ropes causing sudden deceleration or roll-over (AS/NZS 3845.1:2015).

Some terminals may release the cables from the end anchor during impact. This can result in a loss in tension in the wire rope system and may hinder the ability of the barrier to withstand secondary impacts occurring downstream of the impacted end anchor (AS/NZS 3845.1:2015).

Wire rope barrier end treatments need to be provided in accordance with the manufacturer’s specification. It is important that wire rope barrier end treatments are considered as an integral part of the barrier system.

Transitions between barrier types

Where two different types of barrier meet, a transition treatment is required. For example, to connect a W-beam (semi-rigid) barrier to the concrete (rigid) barriers on a bridge requires a transition element stiff enough to ensure that a vehicle sliding along the deforming semi-rigid barrier does not suddenly become snagged on the unforgiving end of a rigid barrier. The transition piece in this case is formed by a progressive stiffening of the W-beam for a short distance leading up to the rigid barrier. The additional stiffness is generated by closer spacing of support posts and nesting of two layers of W-beam or a Thrie-beam. These features are shown in Figure 10.26

Figure 10.26: Semi-rigid (W-beam) to rigid barrier (bridge barrier) transition

A transition between flexible and semi-rigid barriers can be constructed by overlapping the flexible barrier in front of the other barrier. A vehicle sliding along the flexible barrier will be travelling in a reasonably straight line and, at the end of the flexible barrier, will continue to slide along the semi-rigid barrier.

A transition from flexible to rigid can be achieved in a similar manner, by overlapping the departure end of the flexible barrier with the start of the rigid barrier, although some jurisdictions do not favour the use of WRSB to rigid transitions. The posts of the flexible barrier will need to be positioned closer together on the approach to the rigid barrier to reduce deflection and thereby prevent a vehicle colliding with the end of the rigid barrier.

In an overlap transition, the terminating safety barrier system is located in front by at least its dynamic deflection. The points of need for both systems should be positioned opposite one another within the overlap.

The overlapping of semi-rigid/flexible barriers with rigid barriers is only possible if the semi-rigid/flexible barrier precedes the rigid barrier and there is no possibility of a collision from the opposite direction (i.e. generally only appropriate on a one-way carriageway).

10.4.6 Continuous safety barriers (protected corridors)

Continuous safety barrier refers to the design and installation of barrier along the entire road length. Rather than designing a barrier to shield a specific hazard(s), continuous safety barrier is designed as a longitudinal element of the road to maximise driver protection and to contain errant vehicles before they roll, impact a hazard or cause a head-on collision (VicRoads 2019).

With high speed lane departures, harm is being caused in interactions with the roadside (even when clear zones are present) or in head-on collisions. Protected corridors using continuous lengths of flexible barrier have been proven to dramatically reduce injury; in many locations the centre barrier has virtually eliminated death from head-on collisions and lane departures to the right.

There is growing evidence that better safety outcomes for road users on road corridors can be obtained with the use of continuous lengths of well-designed safety barriers rather than the historical reliance on a clear zone and hazard protection approach (Jurewicz & Steinmetz 2012). There is also strong evidence that flexible barrier systems can deliver near safe system performance for car occupants. As new treatments continue to be implemented, further evidence on effectiveness is likely to emerge. It is noted however that while safety barriers present better safety outcomes for most road users, they can also be a serious hazard for certain user types such as motorcyclists. Table 10.3 and Table 10.4 provide an overview of the key evidence relating to corridor protection philosophy.

Table 10.3: Overview of key research evidence in relation to road departures (International literature)

Location	Study	Indication	References
France Southern motorways	Lane departures from 11 years of crash data	Better safety outcomes when barriers present Terminal ends particularly hazardous Use of continuous lengths of barrier protection is advocated	Martin et al. (1997)
Italy Motorways near Naples	Study of road departure crashes	Crashes with walls, ditches foreslopes and backslopes were more severe than crashes with barriers Median concrete New Jersey barriers showed greater crash severity and higher proportion of rollovers compared to W-beam median barriers Collisions with blunt end terminal ends are particularly hazardous	Montella and Pernetti (2010)
France Southern Motorways	Crossover crashes	In collisions with median barrier, 7% trucks crossover vs 0.5% light vehicles Crossover crashes are much more severe Concrete barriers (New Jersey Type) crossed in 0.3% cases vs 1.3% for guardrail but concrete 1.7 times more casualties “the extensive use of concrete barriers in median strips to a great extent solves the problem of crossings, but leads to an increase in casualties which, even if this increase is basically because of light casualties, does not appear very satisfactory from the point of view of motorway user safety”	Martin & Quincy (2001) Martin et al. (1997)

Table 10.4: Overview of key research evidence in relation to road departures (Australian and New Zealand literature)

Location	Study	Indication	References
Australia SA rural roads	Detailed investigation of road departures in South Australia using crash investigation data and crash reconstructions	Virtually all vehicles that did not strike a hazard travelled more than 10 m laterally 10 m clear zones are insufficient to allow safe impact speeds to be achieved In practice, the desired clear zone width is rarely achieved and clear zone surfaces are rarely free of imperfections that provide rollover trip hazards; tyre soil forces can still build up to cause rollover on flat surfaces Clear zones cater well for low angle departures (drift off) but not yawing vehicles Barriers as close as practicable to the edge of road are likely to result in better safety outcomes than clear zones	Doecke and Woolley (2011) Doecke and Woolley (2013)
Australia Mass crash data		Diminishing returns with clear zone width	Jurewicz and Pyta (2010)
New Zealand	Use of roadside barriers versus clear zones	Flexible barriers should be considered for use before other barrier types Application of a clear zone of any width must take into account the severity of hazards that lie beyond it More cost effective to provide flexible barriers on rural roads than clear zones	Jamieson, Waibl and Davies (2013)
Austroads reports	Improving Roadside Safety Evaluation of centre WRB on undivided rural roads Improving the performance of Safe System Infrastructure (Stage 1 interim report)	Flexible barrier systems have close to Safe System safety performance Ongoing use of flexible barrier systems in centre of the road is supported	Austroads (2014a) Austroads (2009b) Austroads (2013)
Australia SA Rural Roads Austroads Report	Providing for road user error in the safe system	Small number of errors accounted for majority of crashes. Small number of treatments would mitigate these errors – continuous barrier protection the most cost effective approach available	Austroads (2014e)
Australia Victoria	Crossover crashes on medians	Medians wider than 15 m are still at risk of cross-median crashes (noting that medians in the study under 15 m tended to have barriers installed)	Candappa (2012)
Australia SA rural roads	Median and centreline incursions Detailed investigation of road departures in South Australia using crash investigation data and crash reconstructions	Many vehicles departing road to left still crossed over the centreline due to the double yaw manoeuvre Incursions to the right over the centreline occurred up to 3 m for 50% of modelled cases and up to 2 m for 90% of cases Current range of median widths accompanying MWRSB are likely to interact with vehicles departing left in yaw manoeuvres	Doecke and Woolley (2011) Doecke and Woolley (2013)

Jamieson, Waibl and Davies (2013) considered the issue of clear zones and barriers in the New Zealand context based on a literature review, the creation of a specialised dataset and statistical modelling. The study found that:

- Flexible barriers should be considered for use before other barrier types
- Application of a clear zone of any width must take into account the severity of hazards that lie beyond it
- It is more cost effective to provide flexible barriers on rural roads than clear zones.

Of note is the study reported by Martin et al. (1997) based on 11 years of crash data from 1000 km of the inter-urban motorway system between Paris and Perpignan (near the Spanish border to the South of France). The database consisted of approximately 50,000 crashes brought to the attention of the motorway patrol where the involved vehicles were unable to be driven away by their own means following a collision. Average traffic flow on these roads ranged from 18,000 to 50,000 vehicles per day with approximately 20% heavy vehicles. Road cross sections consisted of two or three lanes in each direction with a 3 to 12 m central median with a continuous barrier. A fundamental question of the research was "*Should the hard shoulders be systemically equipped with safety barriers*?"

For motorways with two lane carriageways, crash types remained stable over the 11 year study period with approximately 45% of crashes occurring on the roadway, 28% onto the shoulders (road departure) and 27% into the median. For motorways with three lane carriageways, 50% of crashes occurred on the roadway, 26% onto the shoulders (right side road departure) and 24% into the median. Single vehicles constituted 95% of the crashes over the right shoulder and 86% in the median.

Table 10.5 shows the crash severity according to the first impact.

Table 10.5: Severity in vehicles according to type of 1st impact

Scene of 1st impact [right shoulder]	% with casualties	% with fatalities	Number of vehicles
With guard rails			
Length of need	9.3	1.2	6,385
Ends	25.3	6.9	553
Without guard rails			
Right-side profile: flat	18.0	2.6	1,095
Above road level	20.8	2.2	2,111
Below road level	22.5	2.5	1,856
Right shoulder total	14.9	2.0	12,000
Central reservation	9.7	1.1	12,382
In lane	11.3	1.2	47,402

It can be seen that the severity is lowest when there are safety barriers present, both for roadside and median collisions. The ends of barriers were associated with the highest severities and especially fatalities. Severities where vehicles had gone over the right shoulder with no barrier were also high.

Vehicle rollovers (the authors referred to this as overturns) were the most frequent event following a road departure and was associated with increased severity outcomes.

Table 10.6 shows the number and proportion of rollovers following a road departure. It is evident that rollovers occur significantly more often where there are no roadside safety barriers present.

Table 10.6: Overturns after 1st impact on right-side profile

Scene of 1st impact [right shoulder]	Cars		Trucks and buses	
	% overturn	Number	% overturn	Number
With guard rails				
Length of need	8.1%	5,674	25.2%	667
Ends	21.4%	449	34.0%	103
Without guard rails				
Right-side profile: flat	22.6%	935	30.9%	152
Above road level	32.4%	1,857	39.7%	237
Below road level	22.1%	1,606	19.1%	243
Total	16.4%	10,521	30.3%	1,402

The following was concluded from the study:

- Severity remains significantly higher in the absence of safety barriers
- Ditches and embankments were associated with higher severity levels
- Severity is notably higher when barrier ends are involved
- Motorcyclists had higher injury severities when a roadside barrier was present (although absolute numbers were small)
- The presence of a small number of secondary impacts once vehicles had been redirected from a barrier impact (4.6% of cases).

Martin et al. (1997) commented that there would be benefit in eliminating terminal ends and aiming for the provision of continuous lengths of barrier instead. It was concluded that:

> *"Equipping motorway hard shoulders systematically with average safety barriers seems on a whole to be beneficial to the user".*

A study on the Naples Candela motorway in Italy by Montella and Pernetti (2010) also produced findings consistent with the Martin et al. (1997) study.

10.4.7 Work zone barriers

During works on or near a roadway, protection of workers needs to be ensured, as well as maintaining a safe environment for pedestrians and motorists. The purpose of any temporary safety barriers at a work zone is therefore to redirect errant vehicles, preventing them from entering the works area, and minimising injury to the vehicle's occupants as well as work zone personnel.

Safety barriers for work zones are designed to be portable, providing for quick installation and removal or relocation.

Work zone barriers may be necessary for a number of reasons:

- protecting workers by preventing vehicles from driving into works areas
- protecting road users by preventing them from entering a hazardous work area (e.g. trenches and material stockpiles)
- separating opposing flows of traffic on a temporarily constricted carriageway
- protecting incomplete structures from vehicle impact
- reducing or eliminating the need for temporary reductions in speed limit.

Temporary safety barriers that are commonly used are:

- pre-cast concrete safety shape units (e.g. F type, single slope or proprietary units)
- longitudinal steel barriers (proprietary products)
- water filled plastic barriers (proprietary products).

The minimum length of temporary barrier installed shall not be less than the length of system recommended by distributors and based on successful crash tests. At a particular site the installation must:

- be adequate to shield the hazard (e.g. roadworks)
- have sufficient strength to redirect an impacting vehicle and not move into the work area on impact.

The length and type of temporary barrier required to shield the hazard should also be determined from the length of need for the particular site plus the additional lengths necessary to provide end treatments.

Temporary barriers should also be well delineated. This will assist in guiding road users through the work site, particularly at night.

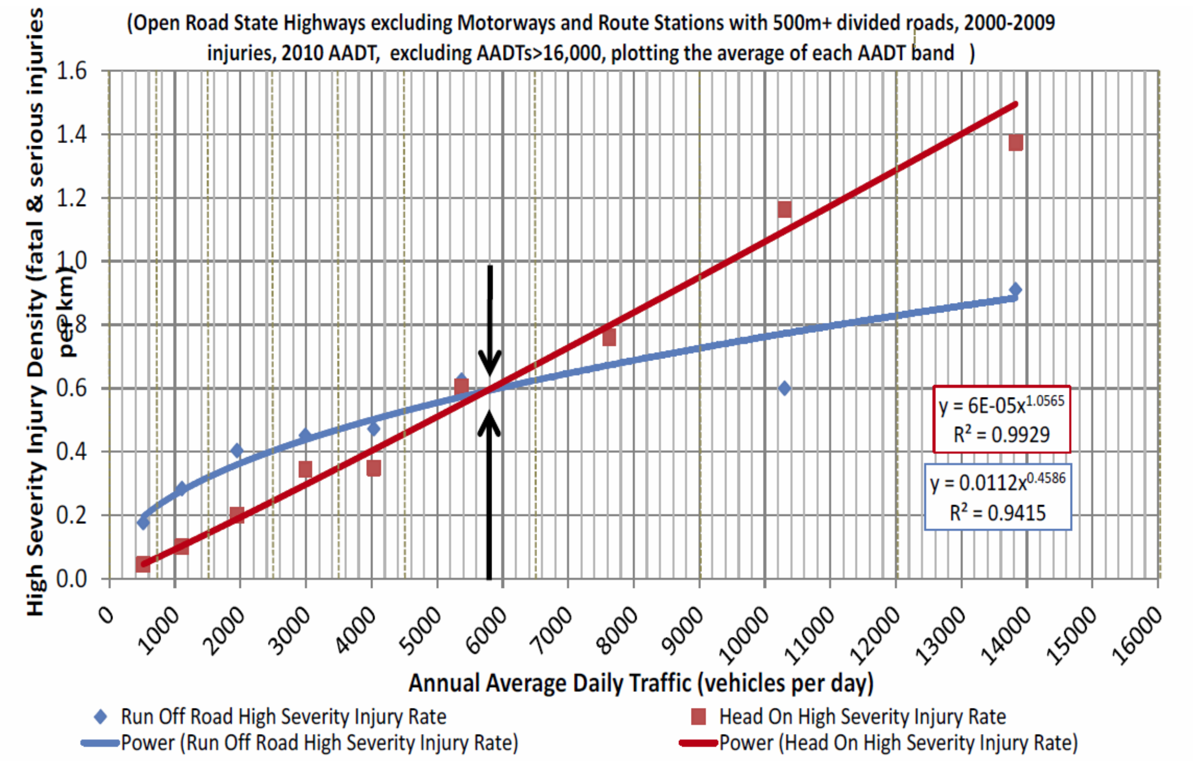
The decision to install temporary safety barriers at work zones must be made as part of a full assessment of the traffic management needs of an individual work zone. The temporary barriers used must also meet the same test levels as those for permanent barriers and be installed to meet manufactures' specifications.

10.5 Reducing the Harm from Head-on Crashes

For the speeds encountered on rural roads, head-on collisions tend to result in severe injury as vehicles are unable to manage impact forces to safe levels for occupants. There are also many collision orientations that can occur between vehicles including full frontal, offset-frontal and side impacts one of the vehicles is yawing. The latter two configurations are particularly difficult for vehicle manufacturers to mitigate crash forces in an effective manner in order to prevent severe injury to occupants.

A study by Austroads (2018a) shows that on New Zealand roads with an Annual Average Daily Traffic (AADT) of 6000 vehicles per day, the density of FSI head-on crashes per kilometre exceeds that of run off road FSI (see Figure 10.27). Other findings have been established in Victoria (7000 vehicles per day) and Sweden (4000 vehicles per day). These findings point to the need for median treatments as a priority over roadside treatments where volumes become high.

Figure 10.27: Head-on and run off road FSI injuries per kilometre for rural undivided state highways in New Zealand



Source: Austroads (2018a)

10.5.1 Treatment hierarchy for head-on crashes

The hierarchy of treatments for head-on crash types is shown in Table 10.7.

Table 10.7: Safe System Assessment Framework hierarchy of head-on crash treatments

Hierarchy	Treatment	Influence (E = exposure L = likelihood S = severity)
Safe System options ('primary' or 'transformational' treatments)	• One-way traffic • Continuous lengths of flexible median barrier (or an equally / better performing future equivalent) • Very low operating speed.	L S S L, S
Supporting treatments (compatible with future implementation of Safe System options)	• Very wide median • Painted median / wide centrelines • Frangible delineation posts on the centreline	L L L
Supporting treatments (does not affect future implementation of Safe System options)	• Wide median • Non-flexible barrier provision • Lower speed environment/speed limit • Ban overtaking • Skid resistance improvement • Audio-tactile centreline • Audio-tactile edgeline • Roadside barriers • Consistent design along the route (i.e. no out-of-context curves) • Consistent delineation for route • Overtaking lanes* • Improved superelevation.	S L, S L L L L S L L L L L
Other considerations	• Speed enforcement • Rest area provision • Lane marking compatible with vehicle-lane-keeping technology.	L, S L L

Note: The objective of the treatment hierarchy is to apply the primary treatments in a systematic, targeted way. Where it is not possible to apply these, or in the short term, other solutions should be used, working down through the options.

Source: Austroads (2016b)

There has been much innovation in relation to median treatment schemes on undivided rural roads. Considerable lengths of continuous barrier protection and wide centreline treatment are being implemented throughout Australia and New Zealand. Table 10.8 provides an overview of much of this activity identified in the literature.

There is some evidence from overseas that centreline barrier treatments associated with 2+1 roads that restrict vehicle lateral movement may result in increased pavement wear (McGarvey 2017). There has, however, been no evidence of this issue with the wide centreline treatments that have been implemented in Queensland (Bobbermen, D. personal communication).

Case study: Swedish 2+1 roads

In 1998, the Swedish National Road Administration (SNRA) decided to trial the retrofitting of Sweden's 13 m rural roads (two-lane/two-way roads with 3.75 m traffic lanes and 2.75 m hard shoulders) with low cost measures for reducing the number of severe off road and head on crashes that occur along these roads (Bergh & Carlsson 2001). Four existing 13 m roads were upgraded to "2+1" (three-lane/two-way) roads with median wire rope safety barrier (MWRSB) covering 120 km total length. Two further roads were upgraded to four-lane/two-way roads with median wire rope safety barrier totalling 30 km in. Due to the success of these trials, the SNRA decided to replace 13 m roads with the new 2+1 solution on a widespread basis (Bergh & Carlsson 2001).

A full description of the 2+1 treatment used in Sweden can be found in (Bergh & Carlsson 2001). 2+1 roads consist of three lanes implemented across the 13 m footprint of the old 13 m roads. The cross section alternates between a 2+1 and a 1+2 configuration every 1.5 km to 2.5 km to permit regular overtaking. The 1.25 m median and transition zones have median WRSB installed. Lane widths are 3.25 m (for the two lane direction) and 3.75 m (for the single lane direction) with 0.75 m hard shoulders provided.

For the trial study of six upgraded 13 m roads, there was a 20-50% reduction in the number of crashes causing severe injuries and fatalities (Bergh & Carlsson 2001). Carlsson (2009) reported that since the full scale replacement of 13 m roads with the 2+1 solution, there was a 76% reduction in fatal crashes equating to 54 fatalities, compared to a projection of 228 without replacement. If fatalities occurring at intersections are discounted, the reduction in fatalities would be 79%.

The scheme represents a systemic approach to the head-on and road departure injury problem based on the unique situation presented by a legacy 13 m wide rural road cross section. Key to success was the acknowledgement that kinetic energy had to be managed and hence the adoption of the continuous median barrier between opposing traffic flows on a very narrow median. It should be noted that public opinion of the scheme was very low when first introduced and soared to very high levels once the scheme had settled in. The Swedish experience has provided inspiration in Australia and New Zealand to innovate and try new rural road design cross sections.

Figure 10.28: 2+1 section on a Swedish road

Table 10.8: Examples of innovation in road design to reduce the harm of head on collisions

Location	Scheme	Trending Evidence	References
Sweden	1300 km of 13 m wide road treated with centre and roadside flexible barriers as alternating "2+1" configuration	• High safety performance and significant injury reductions • Increase in traffic efficiency • Benefit for motorcycles • Theory of same crash occurrence but better outcome management • Low public approval initially then very high approval 12 months later	Carlsson (2009) Bergh and Carlsson (2001)
Australia NSW – Newell Hwy	Wide centreline treatment with Audio Tactile Line Markings (ATLM)	• Reduced speeds • Drivers more likely to remain entirely within their lane (reduced crossing of centreline)	Connell (2011)
Australia NSW – Pacific and New England Highways	Mix of centreline treatments (various widths of centreline to flexible barrier)	• Improved safety for all treatments except 0.5 m centreline which had no effect	Levett, Job and Wang (2009)
Australia SA – Pt Wakefield Rd	1.7 km Centreline flexible barrier treatment	• F/SI reduced from 1/3 to 0/0 in 5 years before/after • Barrier struck 41 times since installation in 2009 on a 1.4 m median	Anderson (2010)
New Zealand Centennial Hwy	3.5 km Median wire rope safety barrier Reduced speed limit	• Initial centreline widening unsuccessful • Median WRSB installed in 2004-07 • F/SI 12/4 in 8 years before 2004, 0/0 between 2005-10	Marsh and Pilgrim (2010)
New Zealand Waikato Expressway near Rangiriri	Centreline flexible barrier	• Virtual elimination to date of head on collisions • F/SI decreased from 10/9 to 1/7	Crowther and Swears (2010)
New Zealand SH1 between Hamilton and Auckland	9 km section of 2+1 including roadside barriers in high risk locations	• 63% reduction in rate of fatal and serious injury crashes	Crowther and Swears (2010)
Victoria South Gippsland Hwy	2.3 km centreline barrier	• Small reduction in speeds • Lateral lane position shift away from centreline barrier	Lim and Phillips (2011)
Australia Queensland – Bruce Hwy	56 km wide centreline treatment with ATLM 700 km wide centreline rollout	• Head on and loss of control over centreline crashes reduced by 75%. F/SI crashes reduced • Reduced fatal crashes by 75%	Whittaker (2012) Bobbermen (2016)
Australia SA – Dukes Hwy	Wide centreline treatment	• No crash evaluations yet • Positive acceptance by public	Bishop, Butler and Jervis (2013)
Australia SA – Victor Harbor Rd	2+2 overtaking lane	• Collision detection equipment installed for remote monitoring (cable tension monitor) • Positive feedback from public	Dua and Anderson (2013)

10.5.2 Centreline barriers on undivided roads

In Australia and New Zealand, structural rural road pavement widths often vary up to 7 m. If sealed shoulders are present, they usually are not constructed to the same structural capacity as the regular traffic lane pavement. As current practice is to try to achieve 3.5 m wide traffic lanes, a narrow median with a barrier would necessitate a narrowing of traffic lanes. The width of a narrow median barrier for undivided rural roads has been a topic of much debate and different values have been adopted by jurisdictions. Several considerations listed below appear to dominate discussions with items 4-7 being additional issues in New Zealand:

1. That the median width be able to accommodate the dynamic deflection of the barrier during impact to prevent opposing traffic being struck
2. That the posts and cables of a struck barrier do not remain as a hazard in the traffic lane
3. That a wider median will reduce frequency of nuisance hits and hence ongoing maintenance costs
4. Agricultural Machinery (slow moving vehicles)
5. Broken down vehicles
6. Over dimension vehicles
7. Maintenance repair space.

If the second consideration is followed a 1.6 m median is required to accommodate a 0.8 m barrier post folded down horizontally and at 90 degrees to oncoming traffic. The narrow median width is critical as it ultimately determines how much road widening is required to incorporate a structural pavement to include the two traffic lanes and the narrow median. Additional paving may be required to maintain sealed shoulders as well. This has major implications for cost effectiveness and therefore amount of median barrier that can be installed.

There is to date little evidence to inform the third consideration. However, Austroads (2015) reports an increase in average crash severity of 3% per metre in the context of roadside barriers. The New Zealand Transport Agency has also developed a tool to assist practitioners make decisions in relation to nuisance hits on WRSB and semi-rigid barriers (Smith et al. 2016).

The ongoing maintenance of flexible barriers continues to be of major concern to road authorities and in one jurisdiction ongoing maintenance costs have been included as part of the initial funding allocation for the project. Some road managers are also using the additional cost of audio tactile line marking (ATLM) to offset costs of barrier maintenance.

Doecke, Mackenzie and Woolley (2013) performed some reconstruction modelling of real world road departure crashes to determine the influence of potential median widths and therefore centreline barrier offsets to the right of the traffic lane on crash outcomes. They showed that a high proportion of manoeuvres resulting in road departures to the left involve incursion over the road centreline (see Figure 10.30). This suggests that aside from the prevention of head-on and road departures to the right, some road departures to the left are also likely to be prevented.

Case study: New Zealand an early adopter of median wire rope barrier treatment

In the year 2000, a package of safety improvements was implemented along a winding 3.5 km coastal section of the Centennial Highway, running between Pukerua Bay and Paekakariki, New Zealand. These improvements included removal of a southbound passing lane, signs advising of speed and entry into a high crash area, passing and parking restrictions, wide yellow coloured barrier centrelines with audio tactile line markings (ATLM) and red coloured edgeline retro-reflective pavement markers (RRPMs). Further improvements were implemented in 2001. Between 2001 and 2003, the safety improvements appeared to have the desired effect, with the number of serious injury crashes reducing significantly. However, in 2004, a series of three fatal crashes instigated debate and initiated the planning for further safety upgrades (Marsh & Pilgrim 2010). In 2004, work started on the installation of 700 m of 1.5 m wide painted medians incorporating median WRSB. Installation over the remaining 2.8 km section of road was undertaken in 2006-07. In 2004, when the centreline treatment works began, the speed limit over this section of the highway was reduced to 80 km/h.

Between 1996 and 2004 (when the first 700 m length of median WRSB was installed), there were 12 fatal and four serious injury crashes along this section of the highway. 12 of these, including all four serious injury crashes, were the result of head on collisions. Between 2005 and 2010, there were no fatal or serious injury crashes, nor any head on collisions, along this treated section of the Centennial Highway (Marsh & Pilgrim 2010).

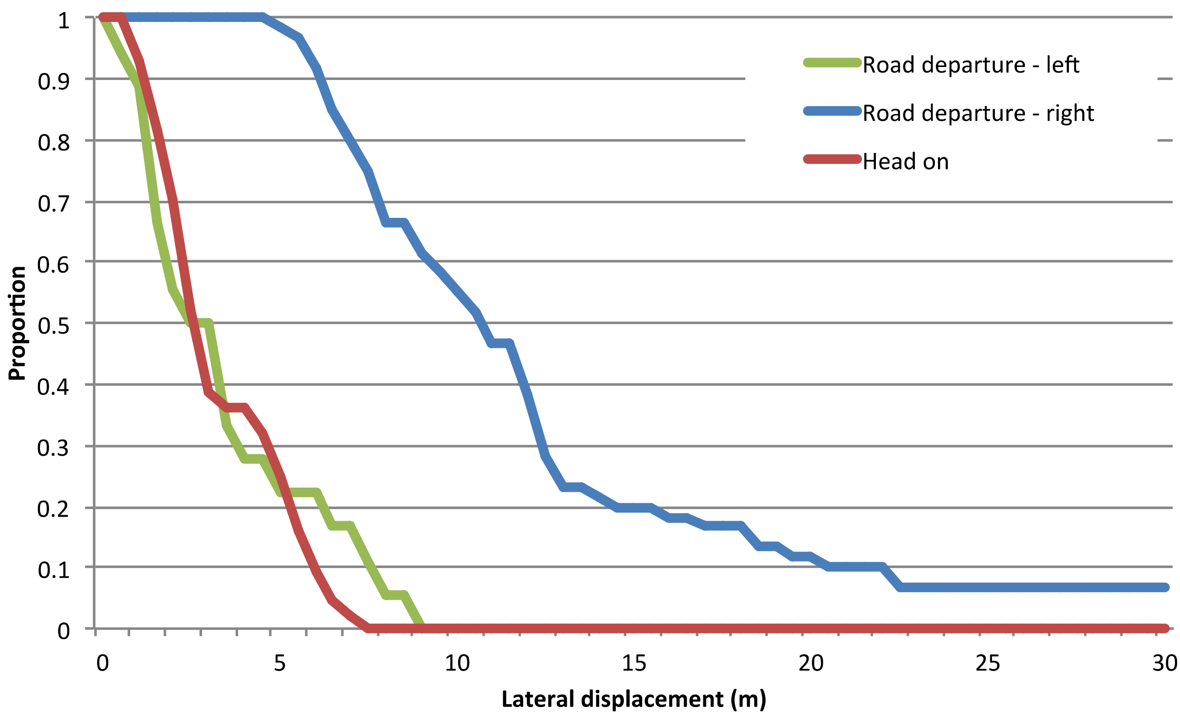
Prior to safety improvements in the year 2000, the average social cost of crashes along the 3.5 km section of the Centennial Highway was estimated to be in excess of $6.8 million annually (NZD) (Marsh & Pilgrim 2010). Between 2001 and 2004 (inclusive), this reduced to $4.4 million annually; no doubt worsened by the fatal crashes in 2004. Between 2005 and 2009, the social cost of crashes has reduced significantly to an average of $65,400 per year. In comparison, a total of $15.5 million was spent to upgrade the 3.5 km section of the Centennial Highway.

Figure 10.29: Early wire rope safety barrier project in New Zealand

Source: Marsh and Pilgrim (2010)

A risk management approach might conclude that the benefit of having a narrow median outweighs the dis-benefit of the dynamic deflection and debris on the road in the traffic lane. Sight distance might be another consideration. Sweden, New Zealand, NSW and Tasmania have used very narrow median widths and in doing so have maintained the most flexibility as to where and how much barrier can be installed. Supporting this is the work of Stigson (2009) that highlighted that divided roads were the strongest factor in eliminating fatalities among car occupants in their analysis of Swedish fatality data.

Figure 10.30: Cumulative distributions showing lateral displacement over the centreline by road departure type including those resulting in head on collisions



Source: Doecke and Woolley (2013)

10.5.3 Flexible barriers on divided roads

Current practice suggests the use of median barriers where medians are less than 15 m wide on divided rural roads. Research shows that even on high standard divided roads with wide medians there is still a measurable risk of road departure and cross over crashes resulting in fatal and serious injury outcomes.

Flexible barriers in wide medians have been proven to be highly effective in mitigating cross median incursions and dramatically reduce road departures onto the opposing side. Table 10.9 outlines some of the research evidence supporting this (Austroads 2015d):

Table 10.9: Literature regarding the use of barriers on divided roads

Literature	Use of barriers on divided roads
Ray et al. (2009)	• 100% reduction in median cross over incursions • >90% reduction in cross median road departures
Washington State Department of Transport (2009)	• 64% reduction in severe injury median crashes • 44% reduction in fatal median crashes
Federal Highway Administration and Turner-Fairbank Highway Research Centre (2008)	• 83% reduction in fatal cross median crashes • 89% reduction in all cross median casualty crashes

10.5.4 Wide centreline treatment

Wide centreline treatment on undivided rural roads is showing good potential to improve head-on and road departure injury outcomes. Although the mechanisms for success are yet to be fully understood scientifically, virtually all applications have been associated with reductions in all crash types and not just head-on collisions. One advantage of the treatment is that if there is sufficient road width, traffic lanes can be narrowed to fit the wide centreline into the cross section without the need to undertake expensive pavement widening. The treatment also has an advantage if sight distance issues are present or many access points are needed to be maintained. In the hierarchy of treatments, a wide centreline can be considered as a supporting treatment that provides a step towards the Safe System because it is capable of being retrofitted with a barrier to upgrade it to a primary treatment.

Wide centreline treatment was first adopted in NSW on the Pacific and New England Highways following the success of a median wire rope barrier treatment on a section of the Pacific Highway (Nilsson & Prior 2004) that virtually eliminated head on fatalities. Wide centrelines were considered for their potential to mitigate head on collisions and road departure crashes at a lower cost than median barriers.

Levett, Job and Wang (2009) compared centreline treatments along the Pacific and New England highways in New South Wales. All test sites (apart from the control sites) banned overtaking along the full length of the sites. The test sites for the Pacific Highway/New England Highway included:

- 24.87 km/18.37 km of standard centreline and barrier line (control sites)
- 16.44 km/5.27 km of 0.5 m wide painted median
- 2.97 km/1.88 km of 1.0 m wide painted median
- 1.16 km (Pacific Highway only) of 0.5 m to 1.0 m wide ATLM painted median
- 11.15 km (Pacific Highway only) of 2.0 m wide painted median with MWRSB.

The control site showed only minor variations in crash numbers and types over eight years. Crashes for the other sites were evaluated for four years before installation and four years after installation of the treatments.

For 0.5 m wide painted medians, the number of crashes were 55 in total and one fatal before installation to 37 total and two fatal crashes after installation (Figure 10.31). The authors concluded that along the Pacific Highway, the 0.5 m wide painted medians had no effect on reducing crashes. It should be noted that ongoing trials from Queensland and New Zealand are showing positive results from the use of 0.5 m wide centrelines (Austroads 2018a).

Figure 10.31: 0.5 m wide painted median along the Pacific Highway

Source: Levett, Job and Wang (2009)

For 1.0 m wide painted medians, crashes reduced from 26 in total and one fatal before installation to 10 in total with no fatals after installation (Figure 10.32). The authors concluded that the treatment had a positive effect on reducing crossover centreline crashes, though crash numbers were not high enough to have a high statistical level of confidence in the result.

Figure 10.32: 1.0 m wide painted median along the Pacific Highway

Source: Levett, Job and Wang (2009)

For the ATLM painted medians, crashes reduced from 19 in total and one fatal before installation to 5 in total and one fatal after installation. Crossover centreline crashes reduced from 14 before installation to two after installation. The authors concluded that the treatment had a positive effect on reducing both total and crossover centreline crashes.

For the painted median with median WRSB treatment, crashes reduced from 46 total and two fatals before installation to 33 in total and one fatal after installation (Figure 10.33). 12 crossover centreline crashes resulted in injuries (with two resulting in fatalities) before installation. There was only one injury crash and one fatal involving a crossover after installation. Presumably, crossover crashes refer to vehicles hitting the median WRSB, though this is not explained. Total crossover centreline crashes did not appear to reduce (23 before and 22 after), though none of the treated sites featured centreline ATLM. The authors concluded that both total crashes and injury crashes involving centreline crossover reduced after installation of the treatment.

Figure 10.33: Painted median with median WRSB along the Pacific Highway

Source: Levett, Job and Wang (2009)

Wide centreline with ATLM treatments were also trialled along two sections of the Newell Highway in New South Wales. These are a 5.7 km section, 12 km north of Parkes and a 5.8 km section, 15 km north of West Wyalong (Figure 10.34). The trialled centreline treatment consists of two 100 mm wide painted centrelines and two 100 mm wide ATLMs separated by 800 mm, giving a total lane separation of 1.2 m. This setup allows for the retrofitting of MWRSB and was available to use without requiring widening of the road (Connell 2011). Both overtaking and non-overtaking (barrier line) sections are provided. It was noticed that, from a distance, the 6.0 m plus 6.0 m configuration used for broken sections of line marking (where overtaking is allowed) looked to be unbroken line.

Figure 10.34: Newell Highway wide centreline treatment

Evaluations of the trials showed that the proportion of vehicles crossing the centreline significantly reduced. Average speeds also reduced, except for heavy vehicles at Parkes, where speeds increased (Connell 2011). While this anecdotal evidence is suggestive of the safety benefits of the trialled treatments, it was still too soon to derive robust evidence of crash reductions.

Between 2012 and 2013, the Department of Planning, Transport and Infrastructure installed approximately 91 km of 1.2 m wide painted centreline treatments along the Dukes Highway in South Australia (Figure 10.35). The treated sections of the highway extended from Tailem Bend to the Victorian Boarder (Bishop, Butler & Jervis 2013). ATLM was incorporated into the centreline markings in addition to the edgelines. A formal evaluation has yet to be conducted on safety outcomes.

Figure 10.35: Wide centreline with ATLM along the Dukes Highway

Source: Department of Planning, Transport and Infrastructure (2011)

Wide painted medians incorporating median WRSB have been installed along the Waikato Expressway near Rangiriri, New Zealand (Figure 10.36). In the period from 1999 to 2003 (before construction), there were 10 deaths and nine serious injuries resulting from crashes along the expressway. Between 2006 and 2011 (after construction), there was one death and seven serious injuries. This represents a 65% reduction in deaths and serious injuries. In the period after construction, deaths and serious injuries resulting from head on crashes were eliminated.

Commencing in 2009 with a planned completion date of 2019, a total of 114.9 km of the Waikato Expressway is currently being upgraded to four-lane/two-way roadway with wide medians and median WRSB.

Figure 10.36: Before (left) and after (right) installation of wide painted medians and median WRSB along the Waikato Expressway

Source: New Zealand Transport Agency

10.6 Safe Rural Road Stereotypes

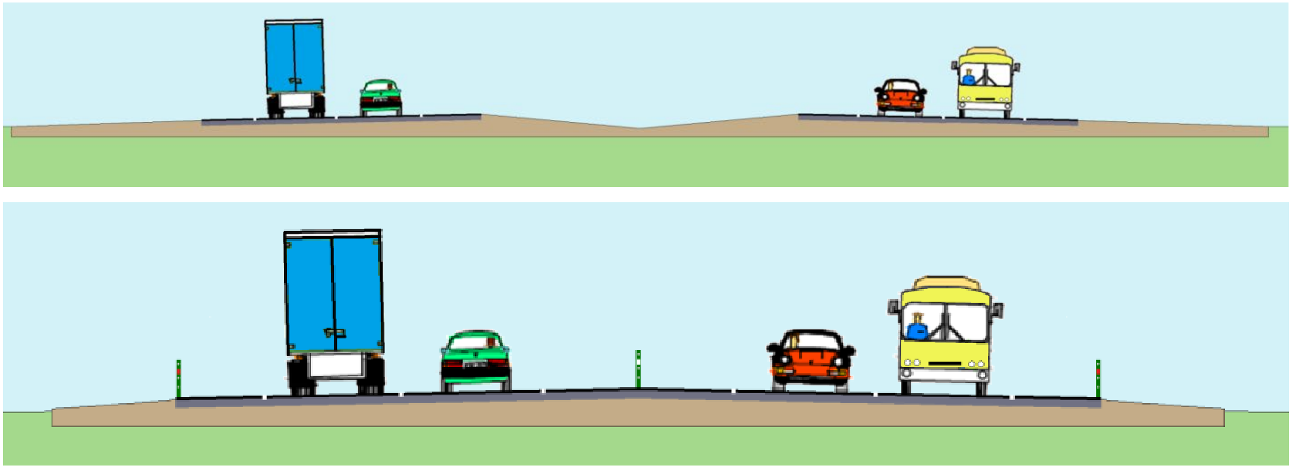
Austroads is currently in the process of establishing rural road stereotypes to provide practitioners with better guidance on how to transition in steps from current road layouts towards the aspirational Safe System designs shown here.

The difference in cross sections between a typical high standard rural road and an aspirational Safe System road is shown in Figure 10.37. It can be noted that the overall width of the Safe System road can be reduced considerably as reliance is primarily placed on roadside and median barriers to mitigate crash injury outcomes. This can lead to considerable costs savings that could be reinvested into the barrier installation.

A comparison between a typical high standard rural road corridor and a Safe System road is shown in Figure 10.38 and Figure 10.39. The conventional road relies on wide clear zones for maximum protection and barrier protection for any hazards that lie within the clear zone. Opposing traffic is also separated by a wide median. In both cases a sealed shoulder and ATLM is present.

The safe system road is characterised by continuous lengths of flexible barrier (or a future well performing equivalent) on the roadsides and between opposing lanes of traffic. Where barrier cannot be provided, a run-out area exists where design focuses on managing the safe departure of a vehicle. This may mean a compacted surface free of rollover trip hazards and very gentle slopes (perhaps in the order of 1:10). Consideration also needs to be given to hazards that exist beyond the limits of the run out area and therefore no ideal width is specified. A risk assessment is required by the designer as to the appropriate width to manage vehicle departures in the absence of barrier protection.

Figure 10.37: Difference in cross section between typical (top) and proposed (bottom) high standard rural roadways



The barrier offset from the edge of the road is not specified as it may need to vary dependent on circumstances but is suggested to be between 1 and 4 m. Simulations of real world crashes by (Doecke & Woolley 2013) showed that the closer the barrier is to the edge to the road, the less force will be on the occupants of the striking vehicle. In other words colliding vehicles are going to have shallower impacts with the barrier. However, an offset may be required:

- to accommodate stationary or broken down vehicles
- to accommodation of sealed shoulders if present
- to reduce the frequency “nuisance” barrier collisions
- to assist with maintenance requirements
- to accommodate wide and over-dimension loads.

A comparison between a typical undivided rural road corridor and a safe system road is shown in Figure 10.39. The conventional road relies on wide clear zones either side of the road for maximum protection and barrier protection for any hazards that lie within the clear zone. In both cases a sealed shoulder and ATLM is present.

The attributes and features of the safe system road are identical to the multilane counterpart shown in Figure 10.38 with the exception that the number of lanes has reduced from four to two.

Figure 10.38: Comparison between a typical divided road and an example of a Safe System road

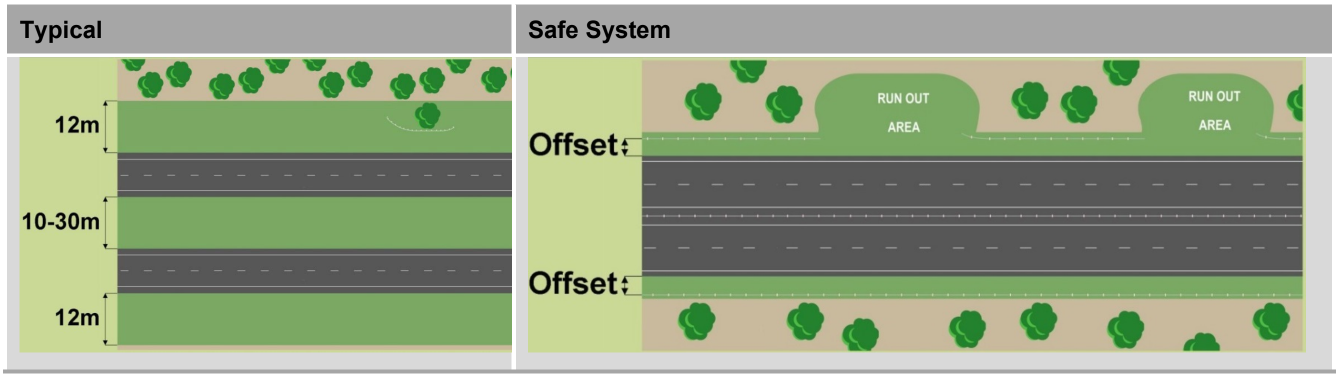
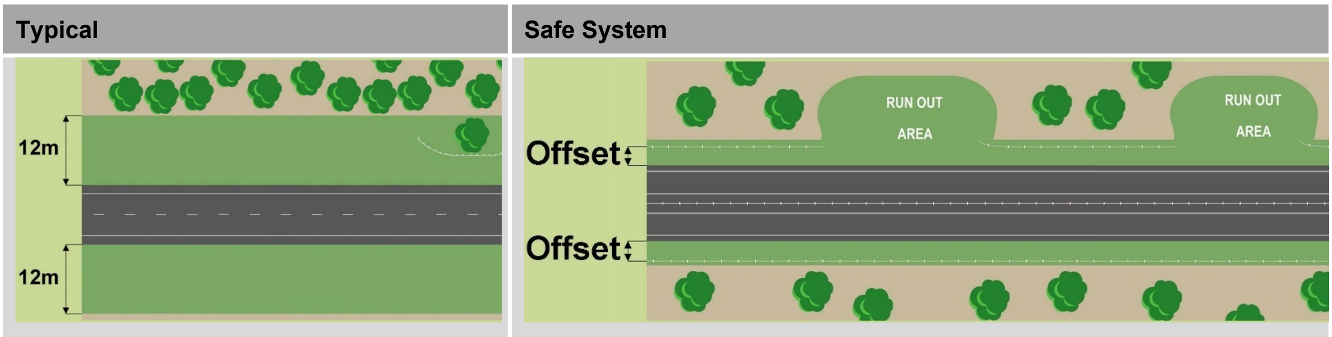


Figure 10.39: Comparison between a typical undivided rural road and an example of a Safe System road



10.7 New Thinking About Road Corridors - Movement and Place

Urban planning and design have transformed in relation to the principles that govern the design of public spaces. Greater consideration is now given to the desired functionality of the space and how certain streets and their surrounds can be desirable destinations in their own right. Allied with this is a strong understanding that good community health outcomes can be achieved through the creation of vibrant neighbourhoods and adoption of active transport modes. In addition, environmental sustainability objectives can also be addressed through urban design practices and support for active transport modes.

Much of this transformation has been in response to poor public space outcomes using past approaches. Road hierarchies were often based on movement function alone and less consideration was given to the needs of non-motorised modes. Beyond the movement function, other street functions received less attention. There was a realisation that Australian and New Zealand practices were falling behind international best practice and that standards and guidelines were inhibiting progress and required revision to reflect the new philosophies.

In South Australia, a response to this situation was the creation of a compendium of best practice (Government of South Australia 2012). This has attracted international interest and the principles are now being picked up by other jurisdictions in Australia, New Zealand, the United Kingdom and by Austroads (2020d). In North America, a similar response can be viewed in three documents published by the National Association of City Transportation Officials (NACTO). These guides discuss ways in which urban roads can be designed to incorporate functionality beyond passenger cars alone. The guides include: Urban Street Design Guide, Transit Street Design Guide and Urban Bikeway Design Guide.

Link and Place – also referred to as Movement and Place – is a relatively new method for establishing the strategic role of roads. The approach balances the need for movement and accommodates destination requirements. Academic and government organisations from nine European countries were involved in the development of the concept, developed originally for South Australia in 2012 (Government of South Australia 2012; Austroads 2020d).

For Movement, the role of a road is to accommodate through traffic, thereby forming part of the wider traffic network. The road may be used by different modes, including private vehicles, heavy vehicles, buses and light rail. In this role, the primary function of the road is to provide a conduit for traffic from origin to destination with as little disruption as possible to minimise travel time.

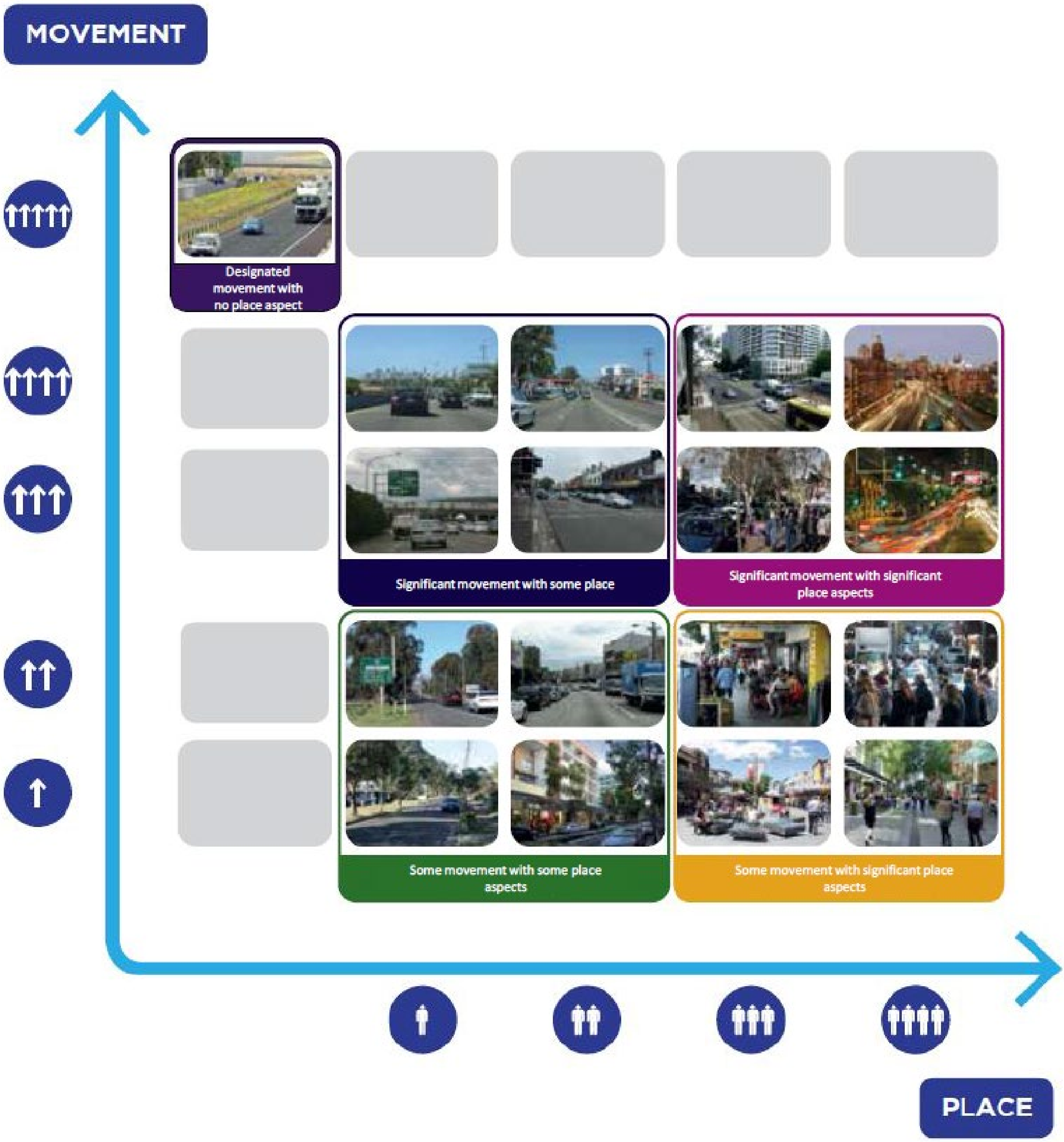
As a Place, the role of a road is as a destination. This is a location where activities occur along or adjacent to the road. As a Place, the primary function of the road is to provide an amenable and accommodating location for people wishing to access activities along the road for a variety of reasons – such as to access a private residence, shops and cafes, or public attractions.

The Movement and Place matrix (Figure 10.40) was developed as a way to classify a road in two-dimensions. The two axes are used to represent the relative priorities of roads to facilitate the movement of people and goods, and to act as destinations for people. The position of the road on the “movement axis” is based on the strategic importance of the road in terms of moving traffic across the broader network. The position of the road on the “place axis” is based on the strategic importance and community value of the road as a place (Figure 10.40). The process of how to determine the Movement and Place status for a road is discussed in further detail in (Government of South Australia 2012; Austroads 2020d).

There are a number of benefits to using the Movement and Place approach (Government of South Australia 2012). Firstly, both movement and place functions are measured using similar units, removing the tendency to measure the link function quantitatively while measuring the place function on a qualitative basis that is often not given the same level of consideration. Secondly, both the link and place functions of a road are considered independently, lessening the risk that the dominant function will take precedence, with space only being assigned to the other function where it is not needed for the dominant function. Thirdly, the recognition of both functions encourages interdisciplinary approach to deciding the strategic role of a road.

Speed limits and speed management are essential factors in determining how road space is utilised in respect of Movement and Place. Broadly speaking, speed limits are likely to be higher on roads where movement is the primary function and lower speed limits are likely to be important in creating a sense of ‘place’.

Figure 10.40: An example of a Movement and Place matrix



Source: Government of South Australia (2012)

11. Road Safety for Regional and Remote Areas

Road safety for regional and remote areas can present unique situations, and thus require specific treatments. This section presents the road safety situations often encountered in regional and remote areas and their countermeasures.

11.1 Safe Roads – Road Safety Risk Factors

Designing roads that are ‘forgiving’, self-explaining, and provide protective infrastructure has the potential to encourage safe driving and reduce the incidence of crashes and lessen the severity of injury in the event of a crash. The design and maintenance of safe roads is particularly important in regional and remote areas, which are characterised by a high incidence of run-off road and head-on crashes and severe injury outcomes (Austroads 2015).

11.1.1 Road condition

The National Road Safety Strategy 2011-2020 (Australian Transport Council 2011, p.51) makes the following comments about the condition of Australia’s roads, many of which are pertinent to regional and remote roads:

> *“There are many uncontrolled accesses to the arterial high-speed network per kilometre.”*
>
> *“A low proportion of the network is fitted with median barriers to separate opposing flows and side barrier protection.”*
>
> *“There are many high-speed intersections in regional and remote areas and limited use of roundabouts and raised platforms at intersections.”*
>
> *“There are many narrow traffic lanes and unsealed and narrow shoulders on many routes.”*
>
> *“There is limited use of tactile line treatments (rumble strips) on road medians and edges.”*
>
> *“Many roads have insufficient clear zones, which can be treated with increased clear zones, sealed shoulders and/or appropriate barriers.”*
>
> *“Roads in Aboriginal communities are generally not included in government road construction and maintenance programs. Many of these roads are of a very poor standard, which is one of the contributors to the higher rates of road trauma for Aboriginal people.”*

In addition to these issues, there is a greater likelihood of encountering livestock and wildlife on regional and remote roads as well as heavy agricultural vehicles, mining vehicles and road trains. Also, a high proportion of roads in regional and remote areas are unsealed, which increases the risk of skidding and losing control and can cause visibility issues as a result of dust and flying pebbles. Surfaces may also be unpredictable as a result of the type and volume of traffic and weather conditions such as heavy rain and seasonal flooding.

The default speed limit of 100km/h on regional and remote roads in all states and territories, other than WA and the NT where it is 110 km/h, together with a lack of road infrastructure means that vehicle occupants are at greater risk of fatal or serious injury if they should crash.

Further information on the condition of the Australian road network is provided by the Australian Road Assessment Program (AusRAP), which examined 21,921 kilometres of national highway with a speed limit of 90 km/h or above during 2013 and awarded star ratings from 1 (poor) to 5 (high quality) based on safety (Australian Automobile Association 2013). The majority of roads fell into the 2-star or 3-star category.

Examination of crashes on regional and remote roads indicates that there are a disproportionately high number of fatal and serious crashes on regional and remote roads in comparison to the proportion of the population that live there, and that there are some predominating crash types. Australian national data shows that 65% of fatal crashes occur on regional and remote roads, compared to 39% of serious injuries and 28% of other injuries (Austroads 2019c). Furthermore, in 2016, 81% of fatal head-on crashes, 78% of fatal single vehicle crashes, and 37% of fatal intersection crashes occurred in regional and remote areas (Table 2.2, Austroads 2019c).

The different features of roads and their surroundings have individually been shown to affect crash risk. The following section reviews how each aspect of road design may reduce or increase the risk of a crash.

11.1.2 Road design

A lack of energy management design features to manage the forces on a human body, should a crash occur, can result in fatal or serious injury. This is discussed in relation to speed in Section 2.3.2. The main geometric elements impacting on safety include (Austroads 2015):

- cross-section (e.g. widths of lanes, shoulders, medians and verges)
- horizontal curves
- vertical curves and gradients
- intersections.

Results of data analysis conducted by Austroads showed that during 2005-2009 most regional and remote casualty crashes occurred on mid blocks, and those on straight road sections slightly outnumbered those occurring on curves. However, as curves are relatively rare in relation to mid-blocks, this indicates that curves represent a greater risk. There were fewer intersection crashes and these were dominated by those at T intersections and then cross-intersections. This reflects the most common types of intersections in regional and remote areas (Austroads 2015).

Road cross-section

Sealed pavement width, lane width and shoulder width have been shown to have an effect on the risk of a run-off-road crash. Narrow pavements (< 6m), narrow lane width (2.5m) and narrow shoulders (< 0.5m) have all been shown to be associated with a higher crash risk (Austroads 2014a).

Casualty crash risks are also higher on undivided regional and remote roads as opposed to divided roads. Increasing median width is associated with crash reduction of up to 54% in rural areas (Elvik et al. 2009).

Traffic volume

Data from New Zealand for the time period 2000-2009 shows that fatal and serious injury run-off road and head-on crashes increase with traffic volume (New Zealand Transport Agency 2011). However, the fatal and serious injury rate decreases rapidly for run-off road crashes from around 10 crashes to 3 crashes per 100M VKT (Vehicle kilometres travelled) as AADT (Average annual daily traffic) increases from 500 to 5500, probably as a result of reductions in excessive speed. The rate is fairly stable for head-on crashes at around 2.5-3 per 100M VKT across all traffic volumes, reflecting the necessity for an opposing vehicle to be present for this type of crash, (New Zealand Transport Agency 2011).

Intersections

Most regional and remote intersections in Australia are priority-controlled and tend to have a relatively high crash rate (Austroads 2017). Regional and remote roundabouts have been shown to be less safe than urban roundabouts. This is thought to be a result of higher approach, entry and circulating speeds (Austroads 2017).

Road alignment

Horizontal curves increase the casualty crash risk, particularly if associated with high approach speed and speed change across the curve (Austroads 2015). Casualty crashes also increase with increasing grade, particularly with downhill grade and grade greater than 6% (Austroads 2015).

11.1.3 Roadside environment

Roadside features

Clear zones of greater than 2m at the side of the road are associated with a decreased risk of run-off-road crashes (Austroads 2011a; 2014a) but a small increase in crash severity with increasing clear zone width has been reported by Doecke and Woolley (2011) as a result of an increased risk of high severity rollover crashes. Steep roadside slopes (gradient 1:3.5) compared to a flat road side (1:6 or flatter) have been shown to double the rate of run-off road casualty crashes (Austroads 2011a). Hazard density of greater than 50 per 100m of roadside compared to less than 25 per 100 m is also associated with an increased risk of casualty run-off-road crashes (Austroads 2014a).

Animals on the road

In addition to vehicles colliding with immovable roadside objects, vehicles are at risk of colliding with wildlife and livestock, which can behave unpredictably and appear on roads without warning. Crashes may also occur as a result of vehicles swerving to avoid colliding with an animal (Rowden, Steinhardt & Sheehan 2008). The majority of animal/vehicle collisions in Australia occur on regional and remote roads and most often take place around dawn and dusk or during the darker hours. Data from motor vehicle insurers in Australia indicate that upwards of 80% of animal collisions on Australian roads involve kangaroos (e.g., 83% in NSW), with wombats, dogs, cats, and cattle also commonly hit by vehicles (NRMA Insurance 2018; RACV 2016). Rowden, Reinhardt and Sheehan (2008) reported a significant over-representation of motorcyclists compared to other vehicle occupants in animal-related crashes.

Fencing is one of the most effective means of keeping animals away from traffic but requires regular maintenance to repair damage which otherwise would allow animals to pass through it. Fencing is generally not effective to deter kangaroos, which are able to leap over it. Fencing is usually required in combination with animal overpasses or underpasses as animals are likely to break through it if no alternative route is provided (Ascensao et al. 2013; Huijser et al. 2008). While fencing and underpasses/overpasses have been shown to be effective, they are also relatively expensive, particularly in the context of regional and remote Australia.

References

Abbess, C. R., Jarrett, D. F. & Wright, C. C. 1981, *Accidents at blackspots: estimating the effectiveness of remedial measures, with special reference to the regression to the mean effect*, Traffic Engineering and Control, vol. 22(10), pp. 535-42.

Al-Ghamdi, A. & Al-Gadhi, S. 2004, *Warning signs as countermeasures to camel-vehicle collisions in Saudi Arabia,* Accident Analysis and Prevention, vol. 36(5), pp. 749-760.

Alsop, J. & Langley, J. 2001, *Under-reporting of motor vehicle traffic crash victims in New Zealand*, Accident Analysis and Prevention, vol. 33(3), pp. 353-359.

American Association of State Highway and Transportation Officials 2011, *Roadside design guide*, AASHTO, Washington DC, USA.

American Association of State Highway and Transportation Officials 2016, *Manual for assessing safety hardware*, 2nd edition, AASHTO, Washington DC, USA.

Anderson, C. 2010, *IPWEA submission - median wire rope safety barrier,* Department for Transport, Energy and Infrastructure, Adelaide, SA.

Andreassen, D. C. 1989, *Strategies for safety problems*, Research Report 163, Australian Road Research Board, Vermont South, VIC.

Andreassen, D. C. 1991, *Model guidelines for road accident data and accident types,* Report ATM29, Australian Road Research Board, Vermont South, VIC.

Andreassen, D. C. 1992a, *A guide to the use of road accident cost data in project evaluation and planning*, Research Report 226, Australian Road Research Board, Vermont South, VIC.

Andreassen, D. C. 1992b, *Costs for accident-types and casualty classes,* Research Report 227, Australian Road Research Board, Vermont South, VIC.

Andreassen, D. C. 2001, *Crash costs – 2001: costs by accident-type: a report*, Data Capture and Analysis, Ringwood, VIC.

Ascensao, F., Clevenger, A., Santos-Reis, M., Urbano, P. & Jackson, N. 2013, *Wildlife–vehicle collision mitigation: Is partial fencing the answer? An agent-based model approach*, Ecological Modelling, vol. 257, pp. 36-43.

Australian Automobile Association 2013, *Star rating Australia's national network of highways*, AAA, Canberra, ACT.

Australian Transport Council 2006, *National guidelines for transport system management in Australia volume 3: Appraisal of initiatives,* ATC, Canberra, ACT. Available from: <https://www.atap.gov.au/technical-support-library/ngtsm/files/National_Guidelines_Volume_3.pdf>.

Australian Transport Council 2011, *National Road Safety Strategy 2011-2020,* ATC, Canberra, ACT.

Austroads 2009a, *Guide to pavement technology part 3: Pavement surfacings,* AGPT03-09, Austroads, Sydney, NSW.

Austroads 2009b, *Evaluation of the safety impact of centre-of-the-road wire rope barrier (WRB) on undivided rural roads,* AP-T135-09, Austroads, Sydney, NSW.

Austroads 2010a, *Road safety engineering risk assessment: part 1: Relationships between crash risk and the standards of geometric design elements,* AP-T146-10, Austroads, Sydney, NSW.

Austroads 2010b, *Road safety engineering risk assessment part 2: Crash risk migration,* AP-T147-10, Austroads, Sydney, NSW.

Austroads 2010c, *Road safety engineering risk assessment part 4: Treatment life for road safety measures,* AP-T149-10, Austroads, Sydney, NSW.

Austroads 2010d, *Road safety engineering risk assessment part 6: Crash reduction factors,* AP-T151-10, Austroads, Sydney, NSW.

Austroads 2010e, *Road safety engineering risk assessment part 7: Crash rates database,* AP-T152-10, Austroads, Sydney, NSW.

Austroads 2011a, *Improving roadside design stage 2: Interim report,* AP-R387-11, Austroads, Sydney, NSW.

Austroads 2011b, *Documentation and quality control of benefit-cost analyses,* AP-R390-11, Austroads, Sydney, NSW.

Austroads 2012a*, Guide to project evaluation part 2: Project evaluation methodology*, edn 2.0, AGPE02-12, Austroads, Sydney, NSW.

Austroads 2012b, *An introductory guide for evaluating effectiveness of road safety treatments,* AP-R421-12, Austroads, Sydney, NSW.

Austroads 2012c*, Effectiveness of road safety engineering treatments,* AP-R422-12, Austroads, Sydney, NSW.

Austroads 2013-2021, *Guide to road design,* Parts 1-8, AGRD-SET, Austroads, Sydney, NSW. Available from: <https://austroads.com.au/publications/road-design/agrd-set >.

Austroads 2013, *Improving the performance of Safe System infrastructure: Stage 1 interim report,* AP-T256-13, Austroads, Sydney, NSW.

Austroads 2014a, *Improving roadside safety: Summary report,* AP-R437-14, Austroads, Sydney, NSW.

Austroads 2014b, Methods for reducing speeds on rural roads: Compendium of good practice, AP-R449-14, Austroads, Sydney, NSW.

Austroads 2014c, *Australian national risk assessment model,* AP-R451-14, Austroads, Sydney, NSW.

Austroads 2014d, *Model national guidelines for setting speed limits at high-risk locations,* AP-R455-14, Austroads, Sydney, NSW.

Austroads 2014e, *Providing for road user error in the Safe System,* AP-R460-14, Austroads, Sydney, NSW.

Austroads 2014f, *Cycling infrastructure: Selected case studies,* AP-T282-14, Austroads, Sydney, NSW.

Austroads 2015, *Road geometry study for improved rural safety,* AP-T295-15, Austroads, Sydney, NSW.

Austroads 2016a, *Guide to road design part 3: Geometric design,* AGRD03-16, Austroads, Sydney, NSW.

Austroads 2016b, *Safe System assessment framework,* AP-R509-16, Austroads, Sydney, NSW.

Austroads 2017, *Understanding and improving safe system intersection performance,* AP-R556-17, Austroads, Sydney, NSW.

Austroads 2018a, *Towards Safe System infrastructure: A compendium of current knowledge,* AP-R560-18, Austroads, Sydney, NSW.

Austroads 2018b, *Best practice in road safety infrastructure programs,* AP-R562-18, Austroads, Sydney, NSW.

Austroads 2019a, *Guide to road safety part 6: Managing road safety audits,* AGRS06-19, Austroads, Sydney, NSW.

Austroads 2019b, *Guide to road safety part 6A: Implementing road safety audits,* AGRS06A-19, Austroads, Sydney, NSW.

Austroads 2019c, *National view on regional and remote road safety,* AP-R603-19, Austroads, Sydney, NSW.

Austroads 2020a, *Guide to road design part 6: Roadside design, safety and barriers,* AGRD06-20, Austroads, Sydney, NSW.

Austroads 2020b, *Guide to traffic management,* Parts 1-13, AGTM-SET, Austroads, Sydney, NSW. Available from: <https://austroads.com.au/publications/traffic-management/agtm-set >.

Austroads 2020c, *Guide to traffic management part 5: Link management*, edn 4.0, AGTM05-20, Austroads, Sydney, NSW.

Austroads 2020d, *Guide to traffic management part 8: Local street management,* AGTM08-20, Austroads, Sydney, NSW.

Austroads 2020e, *Integrating Safe System with movement and place for vulnerable road users,* AP-R611-20, Austroads, Sydney, NSW.

Austroads 2020f, *Network design for road safety (stereotypes for cross-sections and intersections),* AP-R619-20, Austroads, Sydney, NSW.

Austroads 2021a, *Guide to road safety part 1: Introduction and the Safe System,* AGRS01-21, Austroads, Sydney, NSW.

Austroads 2021b, *Guide to road safety part 3: Safe speed,* AGRS03-21, Austroads, Sydney, NSW.

Austroads 2021c, *Guide to road safety Part 7: Road safety strategy and management,* AGRS07-21, Austroads, Sydney, NSW.

Bahouth, G., Graygo, J., Digges, K., Schulman, C. & Baur, P. 2014, *The benefits and tradeoffs for varied high-severity injury risk thresholds for advanced automatic crash notification systems.* Traffic Injury Prevention, vol.15, sup. 1, pp. S134-S140.

Bambach, M. & Grzebieta, R. 2015, *Motorcyclist collisions with roadside barrier motorcyclist protection systems*, Paper presented at the Australasian Road Safety Conference, Gold Coast, QLD.

BBC 2017, *Volvo's driverless cars 'confused' by kangaroos*. Available from: <https://www.bbc.com/news/technology-40416606>.

Beer, K. & Beer, T. 2017, *Innovative estimation of crash reduction factors: Application to horizontal curves,* Proc. Australian College of Road Safety, Available from: <https://acrs.org.au/files/papers/arsc/2017/Beer_00141_FP.pdf>.

Benekohal, R. F. & Hashmi, A. M. 1992, *Procedures for estimating accident reductions on two-lane highways*, ASCE Journal of Transportation Engineering, vol. 118(1), pp. 111-129.

Bergh, T. & Carlsson, A. 2001, *2+ 1-roads with cable barriers-safety and traffic performance results,* Paper presented at the Traffic Safety on Three Continents, Moscow, Russia.

Bishop, I., Butler, R. & Jervis, M. 2013, *RAA highway assessment Dukes Highway*, Royal Automobile Association, Adelaide, SA.

Bobbermen, D. 2016, *Safe System complementary thinking: A step change using an integrated approach,* Department of Transport and Main Roads, QLD.

Boyle, A. J. & Wright, C. C. 1984, *Accident migration after remedial treatment at accident blackspots*, Traffic Engineering and Control, vol. 25(5), pp. 260-267.

Bureau of Infrastructure, Transport and Regional Economics 2006, *Road crash costs in Australia 2006*, Report 118, BITRE, Canberra, ACT.

Bureau of Infrastructure, Transport and Regional Economics 2012, *Evaluation of the national Black Spot program*, Report 126, BITRE, Canberra, ACT.

Cairney, P 1996, *Evaluation of audible edge lines*, Contract Report C5567, Australian Road Research Board, Transport Research Ltd, Vermont South, VIC (unpublished).

Candappa, N. 2012, *The effectiveness of wire rope barriers in Victoria,* Journal of the Australasian College of Road Safety, vol(23), pp. 27-37.

Candappa, N., D'Elia, A., Corben, B. & Newstead, S. 2011, *Wire rope barrier effectiveness on Victorian roads,* Paper presented at the Proceedings of the Australasian Road Safety Research, Policing and Education conference, Perth, WA.

Carlsson, A. 2009, *Evaluation of 2+1 roads with cable barriers: Final report*, Swedish National Road and Transport Research Institute, Sweden.

Cercarelli, L. 1998, *The role of police and hospital data in road safety research and strategy development,* Research Report 75, Accident Prevention Research Unit, The University of Western Australia Road, Perth, WA.

Chow, C., Meuleners, L. & Hendrie, D. 2015, *A preliminary evaluation of the effectiveness and cost-effectiveness of the State Black Spot program in Western Australia 2011-2012,* Curtin-Monash Accident Research Centre, Perth, WA.

Chow, K. & Meuleners, L. 2016, *An evaluation of the effectiveness of flexible and non-flexible road safety barriers in Western Australia*, Curtin-Monash Accident Research Centre, Main Roads Western Australia, Perth, WA.

Connell, D., Smart, W., Levett, S., Cleaver, M., Job, R., De Roos, M. & Saffron, D. 2011, *Trial evaluation of wide, audio-tactile, centreline configurations on the Newell Highway*, Paper presented at the Proceedings of the Australasian Road Safety Research, Policing and Education conference, Perth, WA.

Corben, B., Newstead, S., Diamantopoulou, K. & Cameron, M. 1996, *Results of an evaluation of TAC funded accident black spot treatments*, Combined 18th Australian Road Research Board Transport Research Conference and Transit New Zealand Land Transport Symposium, vol.18(5), pp.343-359.

Corben, B., Van Nes, N., Candappa, N., Logan, D. & Archer, J. 2010, *Intersection study task 3 report - Development of the kinetic energy management model and safe intersection design principles*, Monash University Accident Research Centre, Melbourne, VIC.

Council, F. M., Reinfurt, D. W., Campbell, B. J., Roediger, F. L., Carroll, F. L., Dutt, A. K., Dunham, J. R. 1980, *Accident Research Manual,* RD-08-016, Federal Highway Administration.

County Surveyors' Society 1991, *Monitoring the effectiveness of remedial measures*, CSS, London, UK.

Crowther, S. & Swears, R. 2010, *Longswamp to Rangiriri wire rope barrier: increased crash numbers but improved road safety,* Paper presented at the Australian Road Research Board Conference, Melbourne, VIC.

Davis, G. 2001, *Relating severity of pedestrian injury to impact speed in vehicle-pedestrian crashes: Simple threshold model*. Transportation Research Record, vol. 1773(1), pp. 108-113.

Department of Infrastructure, Regional Development & Cities 2017, *Roads to recovery program*. Available from: <https://investment.infrastructure.gov.au/infrastructure_investment/roads_to_recovery/>.

Doecke, S. & Woolley, J. 2011, *Further investigation into the effective use of clear zones and barriers in a safe system's context on rural roads*. Paper presented at the Australasian Road Safety Research, Policing and Education Conference, Perth, WA.

Doecke, S. & Woolley, J. 2013, *Adequacy of barrier and median separation on rural roads*, CASR087, Centre for Automotive Safety Research, University of Adelaide, Adelaide, SA.

Doecke, S., Mackenzie, J. & Woolley, J. 2013, *Post impact trajectory of vehicles at rural intersections*, Centre for Automotive Safety Research, Adelaide, SA.

Dua, A. & Anderson, C. 2013, *Wire rope barrier monitoring system (load cell communication) – An overview,* Paper presented at the Australasian College of Road Safety Conference, Adelaide, SA.

El Esaway, M. & Sayed, T. 2013, *Analysis of unconventional arterial intersection designs (UAIDs) state-of-the-art methodologies and future research directions*, Transportmetrica A: Transport Science, vol. 9(10), pp. 860-895.

Elvik, R. & Vaa, T. 2004, *The handbook of road safety measures*, Elsevier, Amsterdam, The Netherlands, pp. 285-290.

Elvik, R. 1997, *Evaluations of road accident blackspot treatments: a case of the iron law of evaluation studies?* Accident Analysis and Prevention, vol. 29(2), pp. 191-199.

Elvik, R. 2006, *The Empirical Bayes method for road safety estimation,* 1st Ripcord Iserest Conference.

Elvik, R., Hoye, A., Vaa, R. & Sorenson, M. 2009, *The handbook of road safety measures,* 2nd ed, Emerald Publishing Group, Bingley, UK.

Eveleigh, M., Abeysekera, R., Tang, J. 2014, *Investigation into the application of the Australian National Risk Assessment Model (ANRAM) to a route safety review.* Australasian Road Safety Research, Policing and Education Conference, Melbourne, VIC.

Federal Highway Administration / Turner-Fairbank Highway Research Centre 2008, *Oklahoma's experience with wire rope safety fence,* FHWA / TFHRC, Washington DC, USA.

Galpin, A., Underwood, G. & Crundall, D. 2009, *Change in blindness in driving scenes,* Transportation Research Part F, vol. 12, pp. 179-185.

Gateway WA 2014, *Roe Highway/Berkshire Road interchange underway,* Forrestfield, WA.

Gateway WA 2015, *Roe Highway/Berkshire Road interchange fact sheet,* Forrestfield, WA.

Gateway WA 2016, *Roe Highway/Berkshire Road interchange,* Forrestfield, WA.

Government of South Australia 2012, *Streets for people*, Adelaide, SA.

Grace, M., Smith, D. & Noss, R. 2017, *Reducing the threat of wildlife-vehicle collisions during peak tourism periods using a roadside animal detection system*, Accident Analysis and Prevention, vol. 109, pp. 55-61.

Haddon, W. 1980, *Advances in the epidemiology of injuries as a basis for public policy*, Public Health Reports, vol. 95(5), pp. 411-421.

Haight, F. A. 1981, *Pedestrian safety in the United States: some recent trends*, Accident Analysis and Prevention, vol. 13(1), pp. 43-45.

Hammonds, B. & Troutbeck, R. 2012, *Crash test outcomes for three generic barrier types*. Paper presented at the 25th Australian Road Research Board Conference, Perth, WA.

Hauer, E. 1980, *Selection for treatment as a source of bias in before-and-after studies,* Traffic Engineering and Control, vol. 21(8/9), pp. 419-421.

Hauer, E. 1988, *A case for science-based road safety design and management*, in RE Stammer (ed), Highway Safety: At the Crossroads, American Society of Civil Engineers, New York, USA, pp. 241-278.

Hensher, D., Rose, J., Ortúzar, J. & Rizzi, L. 2009, *Estimating the willingness to pay and value of risk reduction for car occupants in the road environment*, Transportation Research Part A: Policy and Practice, vol. 43a(7), pp. 692-707.

Huijser, M., & McGowen, P. 2003, *Overview of animal detection and animal warning systems in North America and Europe*, Paper presented at the International Conference on Ecology and Transportation, New York, USA.

Huijser, M., McGowen, P., Fuller, J., Hardy, A., Kociolek, A. & Clevenger, A. 2008, *Wildlife-vehicle collision reduction study: Report to Congress,* HRT-08-034, Federal Highway Administration, McLean, VA.

Hutchinson, J. W. & Kennedy, T. W. 1996, *Medians of divided highways – Frequency and nature of vehicle encroachments,* Engineering Experiment Station Bulletin 487, University of Illinois, Illinois, USA.

Institution of Highways and Transportation 1990, *Guidelines for urban safety management,* IHT, London, UK.

International Transport Forum 2016, *Zero road deaths and serious injuries: Leading a paradigm shift to a Safe System*, Paris, France

James, G. 1983, *A study of damage costs and accident types*, in D. Andreassen & P. Gipps (eds), *Esso-Monash civil engineering workshop on traffic accident evaluation*, Monash University, Clayton, VIC.

James, H. F. 1991, *Under-reporting of road traffic accidents,* Traffic Engineering and Control, vol. 32(12), pp. 573-583.

Jamieson, N., Waibl, G. & Davies, R. 2013, *Use of roadside barriers versus clear zones*, New Zealand Transport Agency, Wellington, New Zealand.

Job, R. F. S. & Sakashita, C. 2006, *Category shift: A methodological problem in road safety evaluations and how to address it,* Paper presented at the 8th World Conference on Injury Prevention and Safety Promotion, Durban, South Africa.

Jurewicz, C. & Pyta, V. 2010, *Effect of clear zone widths on run-off-road crash outcomes*, Paper presented at the Australasian Road Safety, Policing and Education Conference, Canberra, ACT.

Jurewicz, C. & Steinmetz, L. 2012, *Crash performance of safety barriers on high-speed roads,* Journal of the Australasian College of Road Safety, vol. 23(3), pp. 37.

Jurewicz, C. & Troutbeck, R. 2012, *A safe system-based approach to selection of clear zones, safety barriers and other roadside treatments*, Paper presented at the Australasian Road Safety, Policing and Education Conference, Wellington, New Zealand.

Jurewicz, C., Sobhani, A., Woolley, J., Dutschke, J. & Corben, B. 2015, *Proposed vehicle impact speed-severe injury probability relationships for selected crash types*, Paper presented at the Australasian Road Safety Conference, Gold Coast, QLD.

Klocker, U., Croft, D. & Ramp, D. 2006, *Frequency and causes of kangaroo-vehicle collisions on an Australian outback highway*, Wildlife Research, vol. 33(1), pp. 5-15.

Levett, S., Job, R. & Tang, J. 2009, *Centreline treatment countermeasures to address crossover crashes,* Paper presented at the Australasian Road Safety Research, Policing and Education Conference, Sydney, NSW.

Lim, A. & Phillips, C. 2011, *Centre-line wire rope barrier operation evaluation*, Post treatment report 001664-2, Australian Road Research Board, Melbourne, VIC.

Mackie, H., Brodie, C., Scott, R., Hirsch, L., Tate, F., Russel, M. & Hoist, K. 2017, *The signs they are a a-changing: Development and evaluation of New Zealand's rural intersection active warning system,* Journal of the Australasian College of Road Safety, vol. 28(3), pp. 11-21.

Mackie, H., Hoist, K., Brodie, C., Tate, F. & Scott, R. 2016, *Long-term speed and safety outcomes from New Zealand's rural intersection active warning system*, Paper presented at the Australasian Road Safety Conference, Canberra, ACT.

Maher, M. J. 1987, *Accident migration: a statistical explanation?* Traffic Engineering and Control, vol. 28(9), pp. 480-483.

Marsh, F. & Pilgrim, M. 2010, *Evaluation of narrow median wire rope barrier installation on Centennial Highway, New Zealand,* Journal of the Australasian College of Road Safety, vol. 21(2), pp. 34-42.

Martens, M. 2011, *Change detection in traffic: Where do we look and what do we perceive?* Transportation Research Part F, vol. 14, pp. 240-250.

Martin, J, L. & Quincy, R. 2001, *Crossover crashes at median strips equipped with barriers on a French motorway network,* Transportation Research Record, National Research Council, Washington DC, USA, vol. 1758, pp. 6-12.

Martin, J., Huet, R., Boissier, G., Bloch, P., Vergnes, I. & Laumon, B. 1997*, Evaluation of the consequences of systematically equipping the highway hard shoulder with safety barriers,* Paper presented at the Annual proceedings of the Association for the Advancement of Automotive Medicine, Orlando, USA.

McGarvey, T. 2017, *Barrier separated road type design: Accelerated degradation*, VTI Rapport 925A, Swedish Transport Administration, Sweden.

McGuigan, D. R. D. 1981, *The use of relationships between road accidents and traffic flow in 'black spot' identification*, Traffic Engineering and Control, vol. 22(9), pp. 448-453.

McGuigan, D. R. D. 1982, *Non-junction accident rates and their use in 'black spot' identification,* Traffic Engineering and Control, vol. 23(2), pp. 60-65.

Miller, A. J. 1983, *Selection of appropriate statistical tests*, in D. Andreassen & P. Gipps (eds), *Esso-Monash civil engineering workshop on traffic accident evaluation,* Monash University, Clayton, VIC.

Ministry of Transport 2013, *Motor vehicle crashes in New Zealand 2012: statistical statement calendar year 2012,* Ministry of Transport, Wellington, New Zealand.

Montella, A. & Pernetti, M. 2010, *In-depth investigation of run-off-the-road crashes on the motorway: Naples-Candela,* Paper presented at the Proceedings of the 4th International Symposium on Highway Geometric Design, Valencia, Spain.

National Cooperative Highway Research Program 1993, *Recommended procedures for the safety performance evaluation of highway features,* Report 350, NCHRP, Transportation Research board, Washington DC, USA.

New Zealand Transport Agency 2000, *Draft State Highway Geometric Design Manual*, NZTA, Wellington, New Zealand

New Zealand Transport Agency 2004, *A New Zealand guide to the treatment of crash locations,* NZTA, Wellington, New Zealand.

New Zealand Transport Agency 2010, *Manual of traffic signs and marking (MOTSAM); part 1: Traffic signs and part 2: Markings,* NZTA, Wellington, New Zealand.

New Zealand Transport Agency 2011, *High-risk rural roads guide,* NZTA, Wellington, New Zealand

New Zealand Transport Agency 2013a, *High-risk intersections guide*, NZTA, Wellington, New Zealand.

New Zealand Transport Agency 2013b, *Economic evaluation manual*, vol. 2, NZTA, Wellington, New Zealand,

Nicholson, A. 1987, *The estimation of accident rates and countermeasure effectiveness*, Traffic Engineering and Control, vol. 28(10), pp. 518-523.

Nicholson, A. 1988, *Accident count analysis: the classical and alternative approaches,* Traffic safety theory and research methods, SWOV Institute for Road Safety Research, Amsterdam, The Netherlands.

Nilsson, K. & Prior, N. 2004, *Wire rope safety barriers and the Pacific Highway program: RTA research and investigations,* Paper presented at the Road Safety Research, Policing and Education Conference, Perth, WA.

NRMA Insurance 2018, *Road roos a risk this long weekend*. Available from: <https://www.nrma.com.au/road-roos-risk-winter>.

O'Callaghan, N. 2015, *Measuring cable tensions in wire rope barriers during in-service conditions,* Paper presented at the Transport Research Circular: Roadside Safety Design and Devices International Workshop, Melbourne, VIC.

Ogden, K. W. 1996, *Safer roads: A guide to road safety engineering,* Aldershot, London, UK.

Organisation for Economic Cooperation and Development 1981, *Methods for evaluating road safety measures*, OECD, Paris, France.

Organisation for Economic Cooperation and Development / European Conference of Ministers of Transport, Joint Transport Research Committee 2006, *Speed management*, OECD / ECMT, Paris, France.

Persaud, B. N., Retting, R. A. & Lyon, C. 2003, *Crash reduction following installation of centerline rumble strips on rural two-lane roads*, Insurance Institute for Highway Safety, Arlington, VA.

PIARC 2012, *State of the practice for cost-effectiveness analysis (CEA), cost-benefit analysis (CBA) and resource allocation*, World Road Association (PIARC), Paris, France.

Professional Engineers Ontario 1997, *Highway 407 safety review: A safety review of the first phase of the Highway 407 Project carried out for the Ministry of Transportation Ontario,* Association of Professional Engineers Ontario, North York, Canada.

RACV 2016, *Risk of animal collisions increases, warns RACV*. Available from: <https://www.racv.com.au/about-racv/our-business/media-releases/risk-of-animal-collisions-increases-warns-racv.html>.

Ray, M., Carrigan, C., Plaxico, C., Miaou, S. & Johnson, T. 2012, *Roadside Safety Analysis Program (RSAP) update*, Report 22-27, National Cooperative Highway Research Program, Maine, USA.

Ray, M., Silvestri, C., Conron, C. & Mongiardini, M. 2009, *Experience with cable median barriers in the United States: Design standards, policies, and performance*, Journal of Transportation Engineering, vol. 135(10), pp. 711-720.

Rizzi, L. & Ortuzar J, D, D. 2005, *Estimating the willingness-to-pay for road safety improvements,* Transport Reviews, vol. 26, no. 4, pp. 471-485.

Rowden, P., Steinhardt, D. & Sheehan, M. 2008, *Road crashes involving animals in Australia,* Accident Analysis and Prevention, vol. 40(6), pp. 1865-1871.

Rumar, K. 1982, *The human factor in road safety*, Australian Road Research Board Conference, Melbourne, VIC, vol. 11(1), pp. 65-80.

Saleh, K., Hossny, M. & Nahavandi, S. 2018, *Effective vehicle-based kangaroo detection for collision warning systems using region-based convolutional networks*, Sensors (Basel), vol. 18(6).

Scully, J., Newstead, S., Corben, B. & Candappa, N. 2006, *Evaluation of the effectiveness of the $240M Statewide Blackspot Program - Accident Blackspot component*, Monash University Accident Research Centre, Melbourne, VIC.

Sevefelt, B. & Wessel, P. 2012, *Variable speed limits in unprotected intersections: Implementation and evaluation of 12 sites in Sweden*, Paper presented at the 19th ITS World Congress, Washington DC, USA.

Smith, D., Hyde, R., O'Neill, C. & Corben, B. 2016, *Quantifying the likelihood of barrier strike maintenance*, Research Report 580, New Zealand Transport Agency, Christchurch, New Zealand.

Stigson, H. 2009, *A safe road transport system - Factors influencing injury outcome for car occupants*, Department of Clinical Neuroscience Karolinska Institutet, Stockholm, Sweden.

Stonex, K. & Skeels, P. 1963, *Development of crash research techniques at the General Motors proving ground*, Highway Research Board, no. 4, pp. 32-49.

Transport and Infrastructure Council 2015, *National guidelines for transport system management in Australia: PV2- Road parameter values*, TIC, Canberra, ACT.

Transport and Infrastructure Council 2015, *National remote and regional transport strategy,* TIC, Canberra ACT. Available from: <https://www.transportinfrastructurecouncil.gov.au/sites/default/files/National_Remote_and_Regional_Transport_Strategy_2015.pdf>.

Transport for New South Wales 2012, *NSW road safety strategy 2012-2021,* NSW. Available from: <https://roadsafety.transport.nsw.gov.au/aboutthecentre/strategies/nswroadsafetystrategy/index.html>.

Transport for New South Wales 2013, *Principles and guidelines for economic appraisal of transport investments and initiatives*, TfNSW, Sydney, NSW.

Turner, B. & Tziotis, M. 2006, *Road safety engineering risk assessment: recent and future research,* Australasian Road Safety Research, Policing, Education Conference, Able Video and Multimedia, Gold Coast, QLD.

Turner, B., Tziotis, M., Cairney, P. & Jurewicz, C. 2009, *Safe system infrastructure national roundtable report,* ARR 370, Australian Road Research Board, Vermont South, VIC.

Umstatter, C. 2011, *The evolution of virtual fences: A review*, Computers and Electronics in Agriculture, vol. 75(1), pp. 10-22.

VicRoads 2019, *Road Design Note 06-15: Continuous safety barrier for high speed roads,* VIC

Vincent, E. N. 1996, *Collection and use of road crash information*, in K. W. Ogden & S. Y. Taylor (eds), *Traffic engineering and management*, Monash University, Clayton, VIC, pp. 509-529.

Ward, H. & Allsop, R. 1982, *Area-wide approach to urban safety: evaluation of schemes by monitoring of traffic and accidents*, Traffic Engineering and Control, vol. 23(9), pp. 424-428.

Washington State Department of Transport 2009, *Cable median barrier report,* WSDoT, Washington DC, USA.

White, M. 2006, *Sorry, mate. I didn't see you: A plausible scientific explanation,* Paper presented at the Australasian Road Safety Research, Policing and Education Conference, Gold Coast, QLD.

Whittaker, A. 2012, *The safety benefit of continuous narrow painted median strips,* ENG4111/2, Bachelor of Engineering (Civil), University of Southern Queensland, QLD.

Wohl, M. & Hendrickson, C. 1984, *Transportation investment and pricing principles: An introduction for engineers, planners and economists*, Wiley, New York, USA.

Wong, Y. D. & Nicholson, A. J. 1992, *Driver behaviour at horizontal curves: Risk compensation and the margin of safety*, Accident Analysis and Prevention, vol. 24(4), pp. 425-436.

Wramborg, P. 2005, *A new approach to a safe and sustainable road structure and street design for urban areas,* Paper presented at the Proceedings of the Road Safety on Four Continents Conference, Warsaw, Poland.

Wright, C. C. & Boyle, A. J. 1987, *Road accident causation and engineering treatment: a review of some current issues,* Traffic Engineering and Control, vol. 28(9), pp. 475-479.

Ydenius, A., Kullgren, A., Rizzi, M., Engstrom, E., Stigson, H. & Strandroth, J. 2017, *Fatal car to moose collisions: Real-world in-depth data, crash tests and potential of different countermeasures,* Paper presented at the 25th Enhanced Safety of Vehicles (ESV) Conference Proceedings, Detroit, USA.

Zegeer, C. V. 1982, *Highway accident analysis systems*, National Cooperative Highway Research Program (NCHRP), Synthesis of highway practice 91, Transportation Research Board, Washington DC, USA.

Australian Bureau of Statistics

1244.0.55.001:2011, *Information paper: Measures of socioeconomic status.*

3218.0:2017a, *Regional population growth, Australia, 2016-17.*

9303.0:2017b, *Motor vehicle census, Australia, 2017*.

1270.0.55.005:2018, *Australian statistical geography standard (ASGS): Volume 5 - Remoteness structure, July 2016.*

Standards Australia

AS 1742.1:2014, *Manual of uniform traffic control devices part 1: General introduction and index of signs.*

AS 1742.2:2009, *Manual of uniform traffic control devices part 2: Traffic control devices for general use.*

AS 1742.4:2008, *Manual of uniform traffic control devices part 4: Speed controls.*

Standards Australia and Standards New Zealand

AS/NZS 1158.1.2:2010, *Lighting for roads and public spaces: Vehicular traffic (category V) lighting – Guide to design, installation, operation and maintenance*.

AS/NZS 3845.1:2015, *Road safety barrier systems*.

Appendix A Crash Codes for Australian Jurisdictions

Figure A 1: Transport for NSW

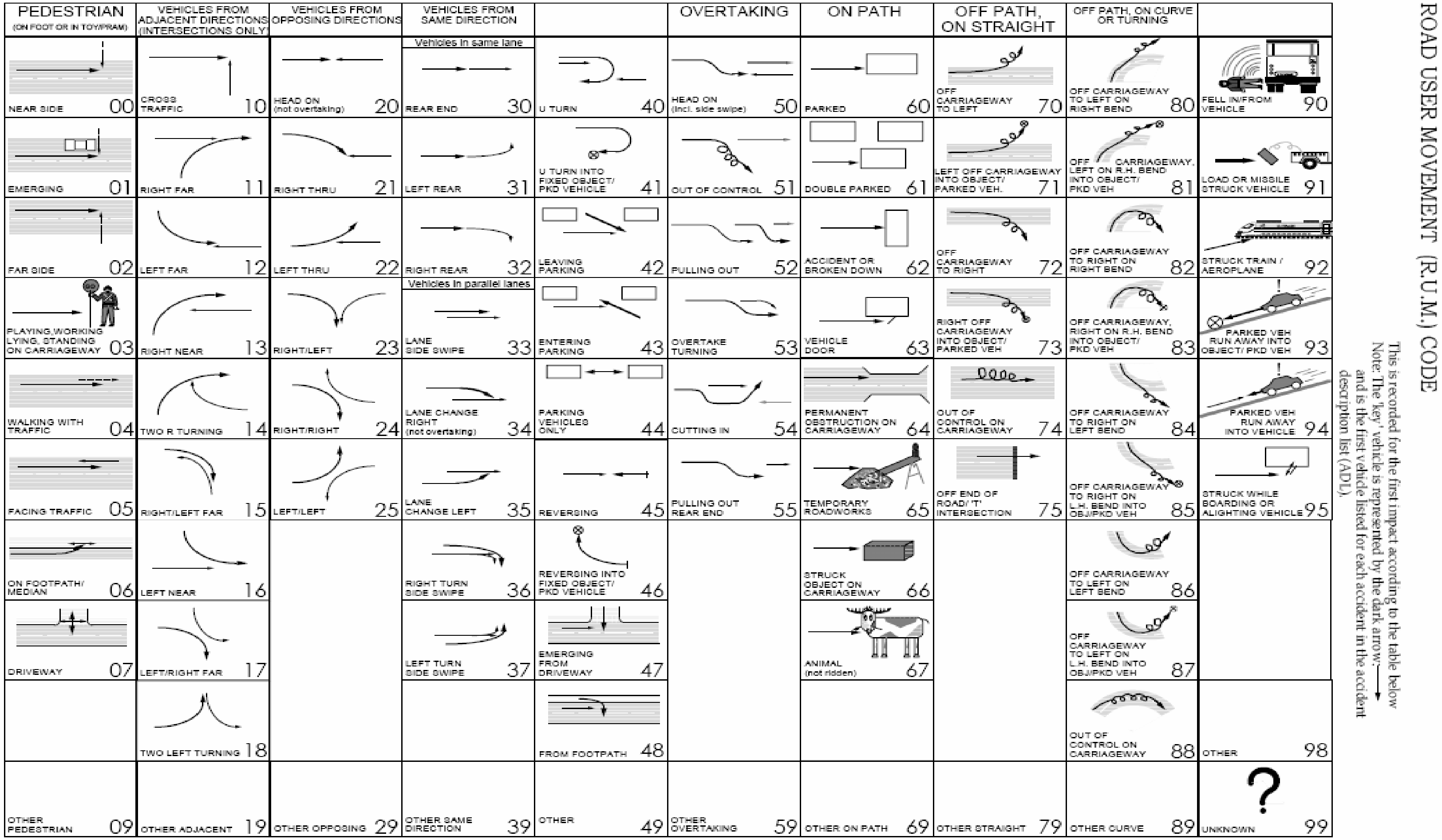
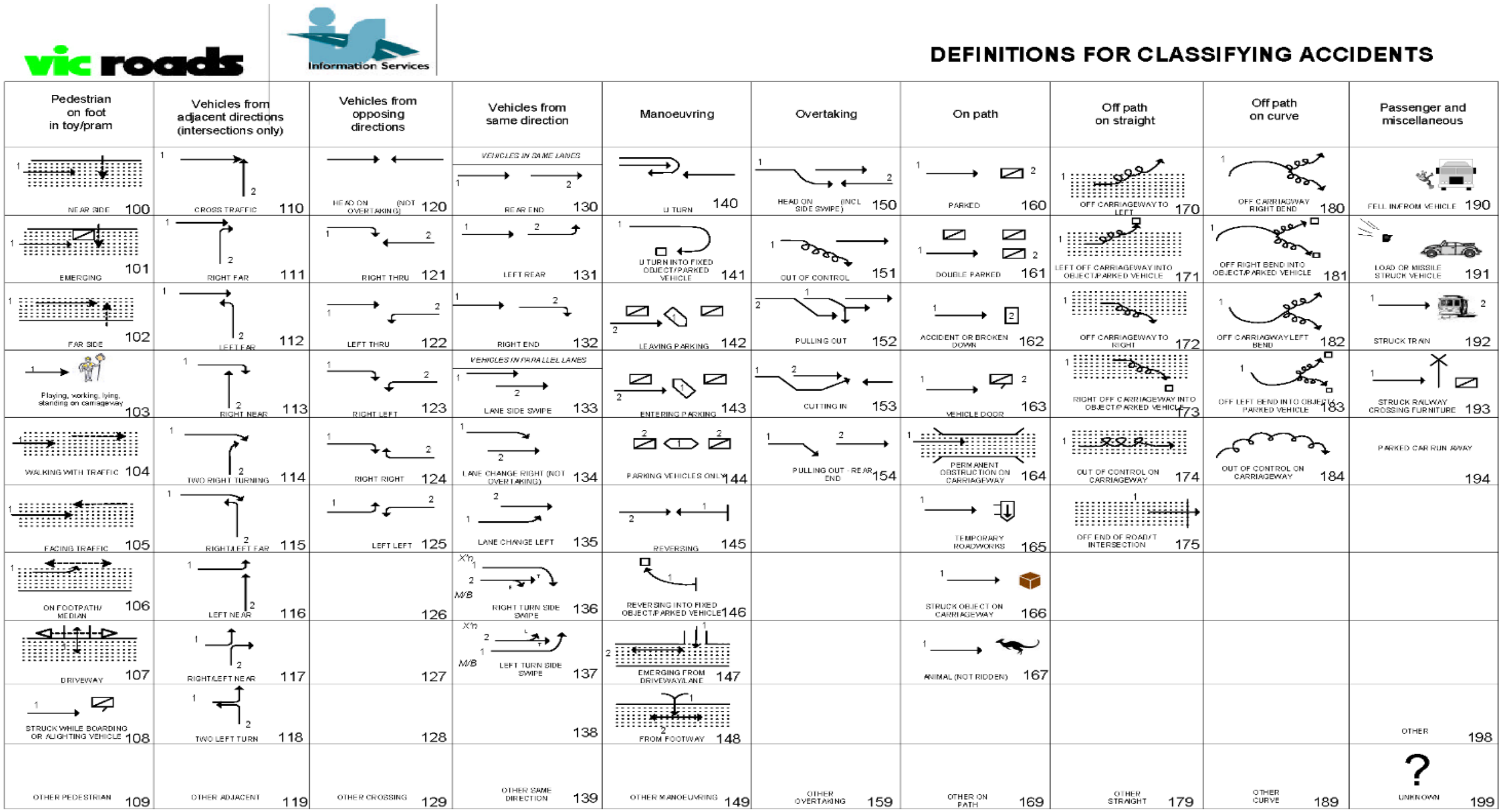


Figure A 2: VicRoads



1. DEFINITION FOR CLASSIFYING ACCIDENTS (DCA) SHOULD BE DETERMINED BY FIRST SELECTING A COLUMN USING THE TEXT ABOVE EACH COLUMN AND THEN BY DIAGRAMATIC SUB-DIVIVISION
2. THE SUB-DIVISION CHOSEN SHOULD BE DESCRIBE THE GENERAL MOVEMENT OF VEHICLES INVOLVED IN THE INITIAL EVENT. IT DOES NOT ASSIGN A CAUSE TO THE ACCIDENT
3. SUPPLEMENTARY CODES HAVE BEEN DEFINED FOR MOST SUB-DIVISION. THESE CODES GIVE FURTHER DETAIL OF THE INITIAL EVENT.
4. THE NUMBER 1, 2 INDENTIFY INDIVIDUAL VEHICLES INVOLVED WHEN THE DCA IS LINKED WITH OTHER VEHICLE/DRIVER INFORMATION.
5. THESE CODES WERE USED FOR 1987 ACCIDENTS AND REPLACE THE ROAD MOVEMENT (RUM) CODE.

Figure A 3: Department of Transport and Main Roads Queensland

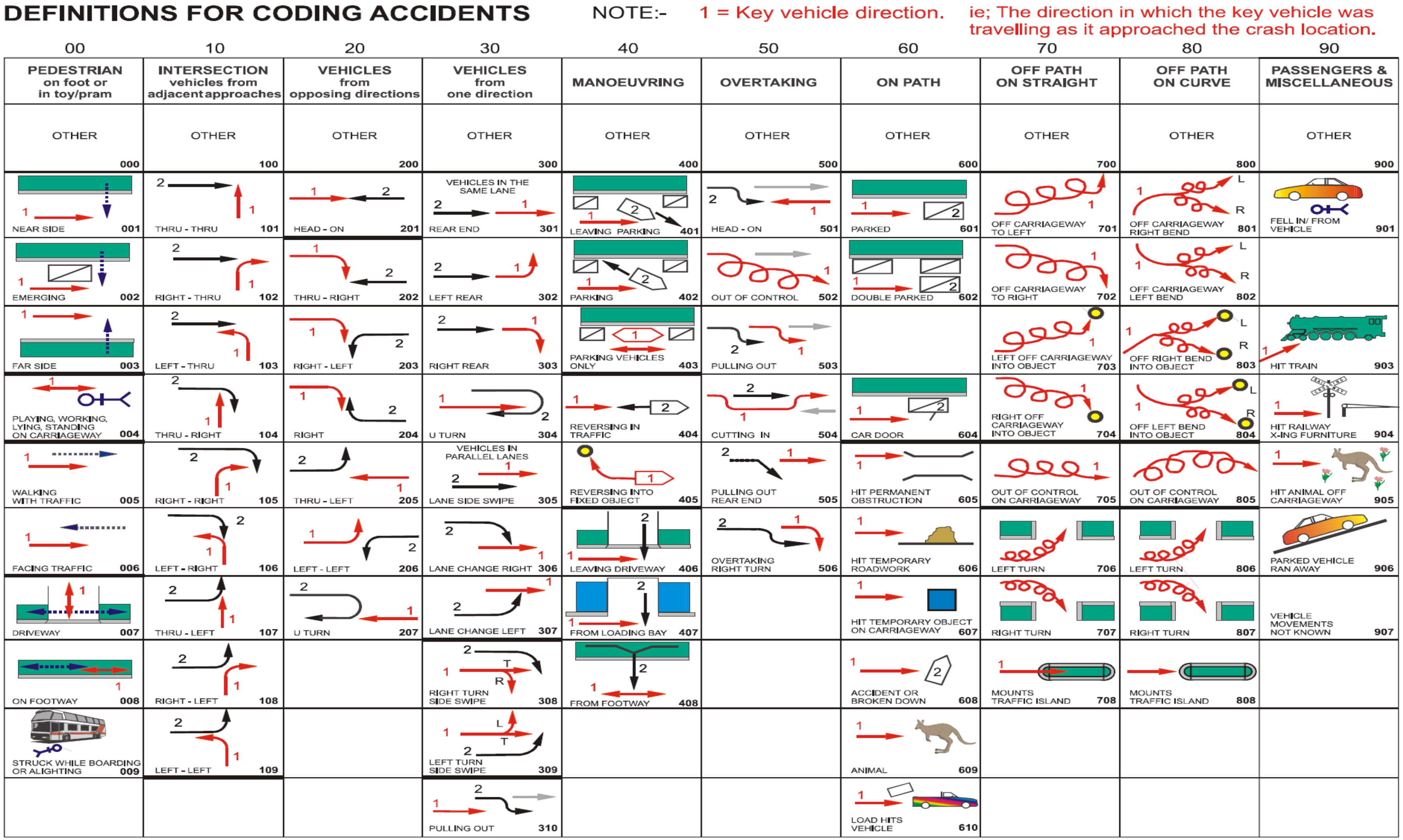


Figure A 4: Main Roads Western Australia

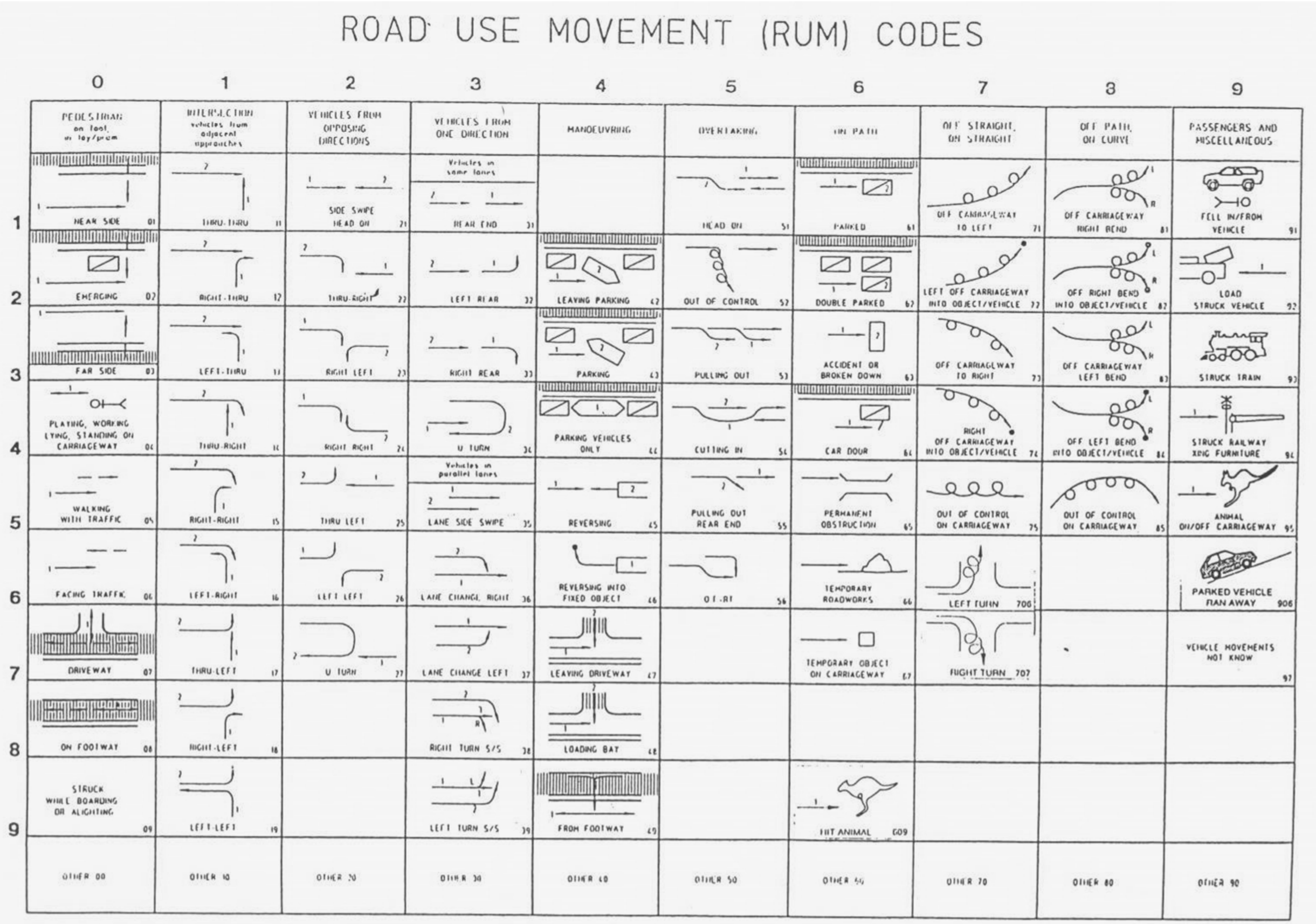


Figure A 5: Department of Planning, Transport and Infrastructure, South Australia (Pre 2013)

Crash Types

CODE	DESCRIPTION
01	Rear End
02	Hit Fixed Object
03	Side Swipe
04	Right Angle
05	Head On
06	Hit Pedestrian
07	Roll Over
08	Right Turn
09	Hit Parked Vehicle
10	Hit Animal
11	Hit Object on Road
12	Left Road - Out of Control
13	Other
14	Unknown

Directions of Travel

CODE	DESCRIPTION
1	North
2	North East
3	East
4	South East
5	South
6	South West
7	West
8	North West
N	N/A
X	Unknown

Unit Movements

CODE	DESCRIPTION
01	Right Turn
02	Left Tturn
03	U Turn
04	Swerving
05	Reversing
06	Stopped on Carriageway
07	Straight Ahead
08	Entering Private Driveway
09	Leaving Private Driveway
10	Parked
11	Parking - Angle
12	Parking - Parallel
13	Unparking - Angle
14	Unparking - Parallel
15	Overtaking - on Right
16	Overtaking - on Left
17	Other
51	Walking on Footpath
52	On Pedestrian Crossing
53	Within 30 m of Pedestrian Crossing
54	Alighted from Parked Vehicle
55	Walked from between Parked Vehicles
56	Walking on Road
57	Walking on Road - Against the Traffic
58	Pushing or Working on Vehicle
59	Playing on Roadway
60	Crossing without Control
61	Other (e.g. Police on Traffic Control)
62	Crossing with Traffic Signals
NA	N/A

Figure A 6: Department of Planning, Transport and Infrastructure, South Australia (from January 2013)

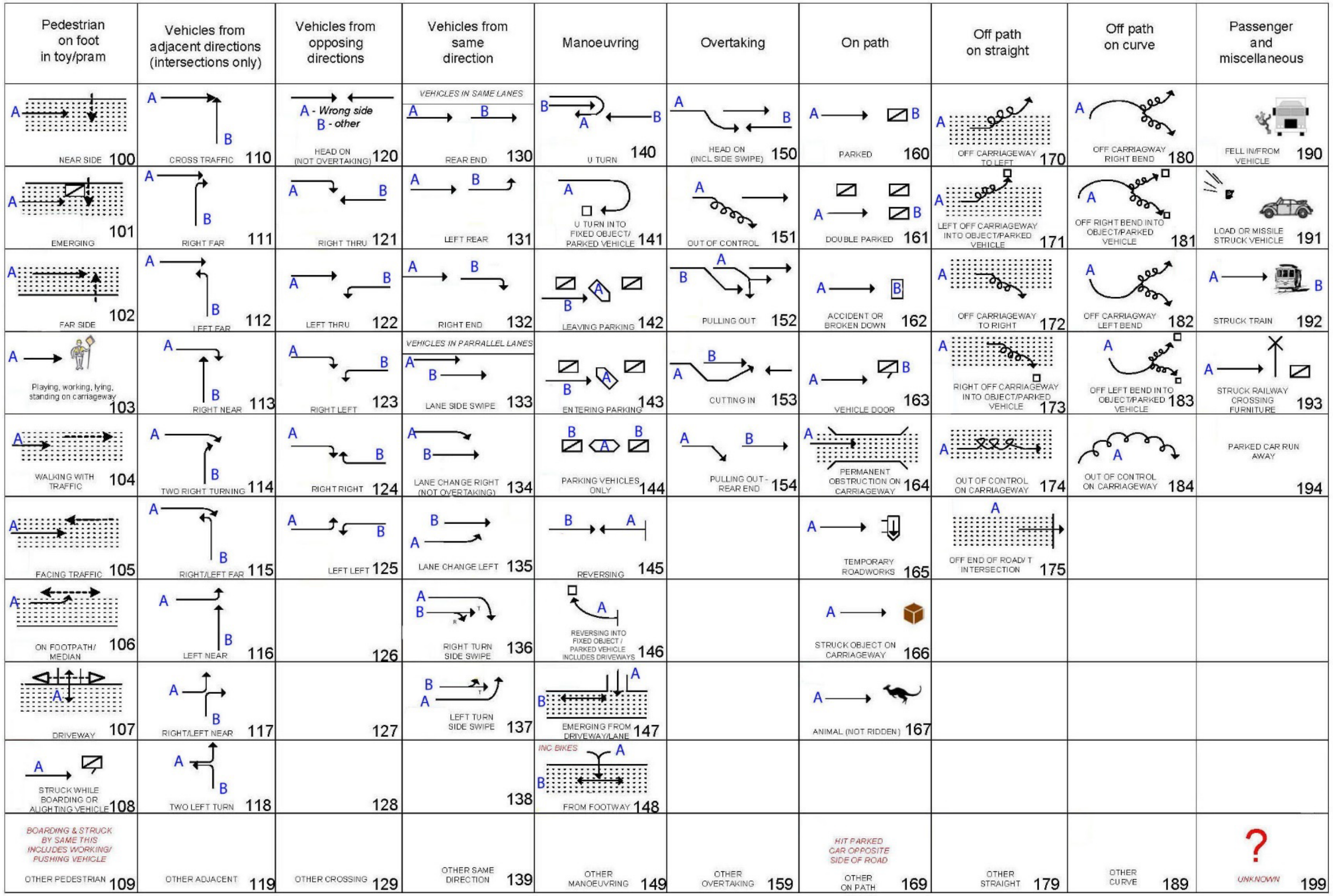
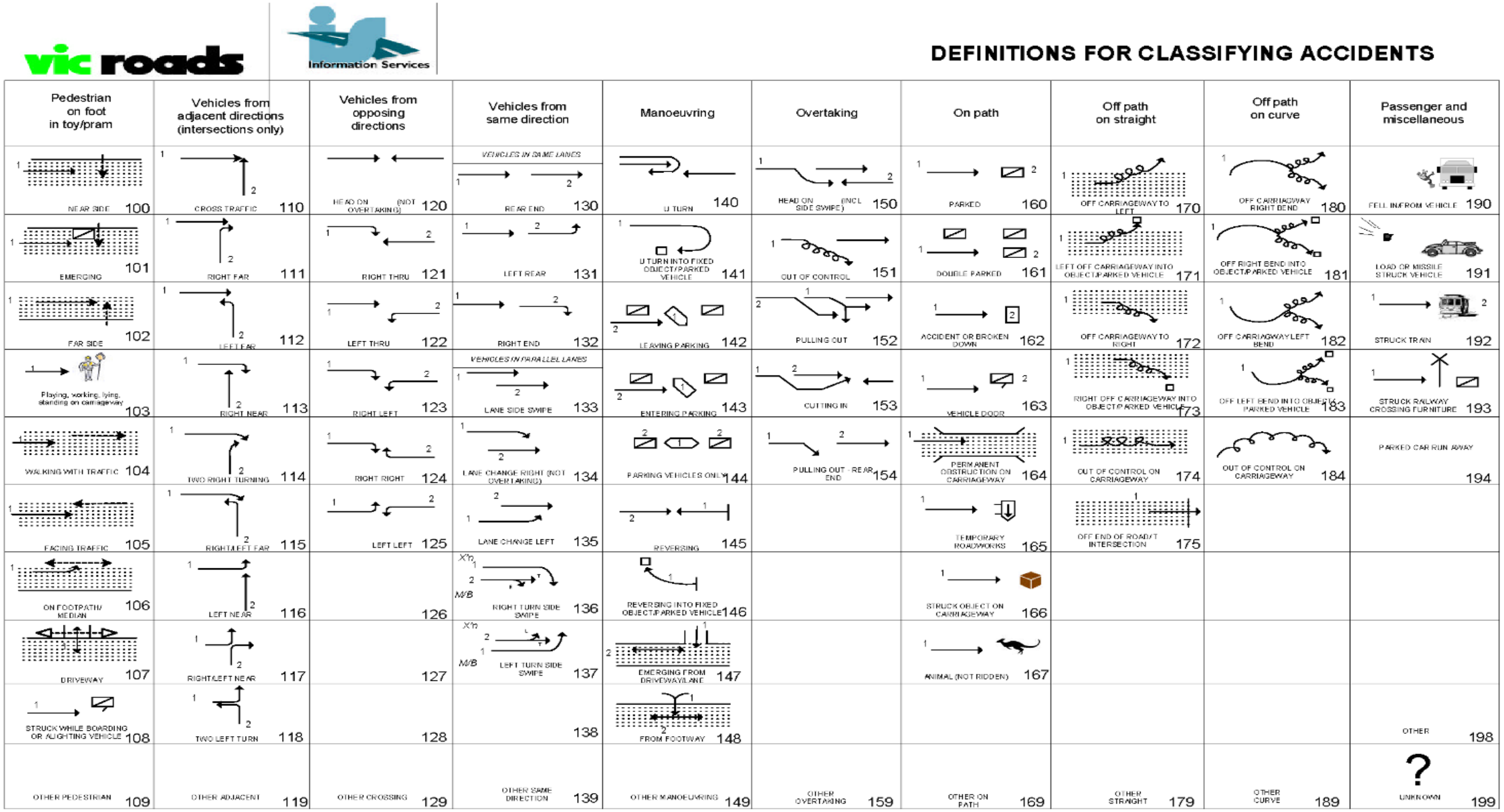


Figure A 7: Department of State Growth, Tasmania – applies Victorian codes



1. DEFINITION FOR CLASSIFYING ACCIDENTS (DCA) SHOULD BE DETERMINED BY FIRST SELECTING A COLUMN USING THE TEXT ABOVE EACH COLUMN AND THEN BY DIAGRAMATIC SUB-DIVIVISION
2. THE SUB-DIVISION CHOSEN SHOULD BE DESCRIBE THE GENERAL MOVEMENT OF VEHICLES INVOLVED IN THE INITIAL EVENT. IT DOES NOT ASSIGN A CAUSE TO THE ACCIDENT
3. SUPPLEMENTARY CODES HAVE BEEN DEFINED FOR MOST SUB-DIVISION. THESE CODES GIVE FURTHER DETAIL OF THE INITIAL EVENT.
4. THE NUMBER 1, 2 INDENTIFY INDIVIDUAL VEHICLES INVOLVED WHEN THE DCA IS LINKED WITH OTHER VEHICLE/DRIVER INFORMATION.
5. THESE CODES WERE USED FOR 1987 ACCIDENTS AND REPLACE THE ROAD MOVEMENT (RUM) CODE.

Figure A 8: Department of Transport, Northern Territory

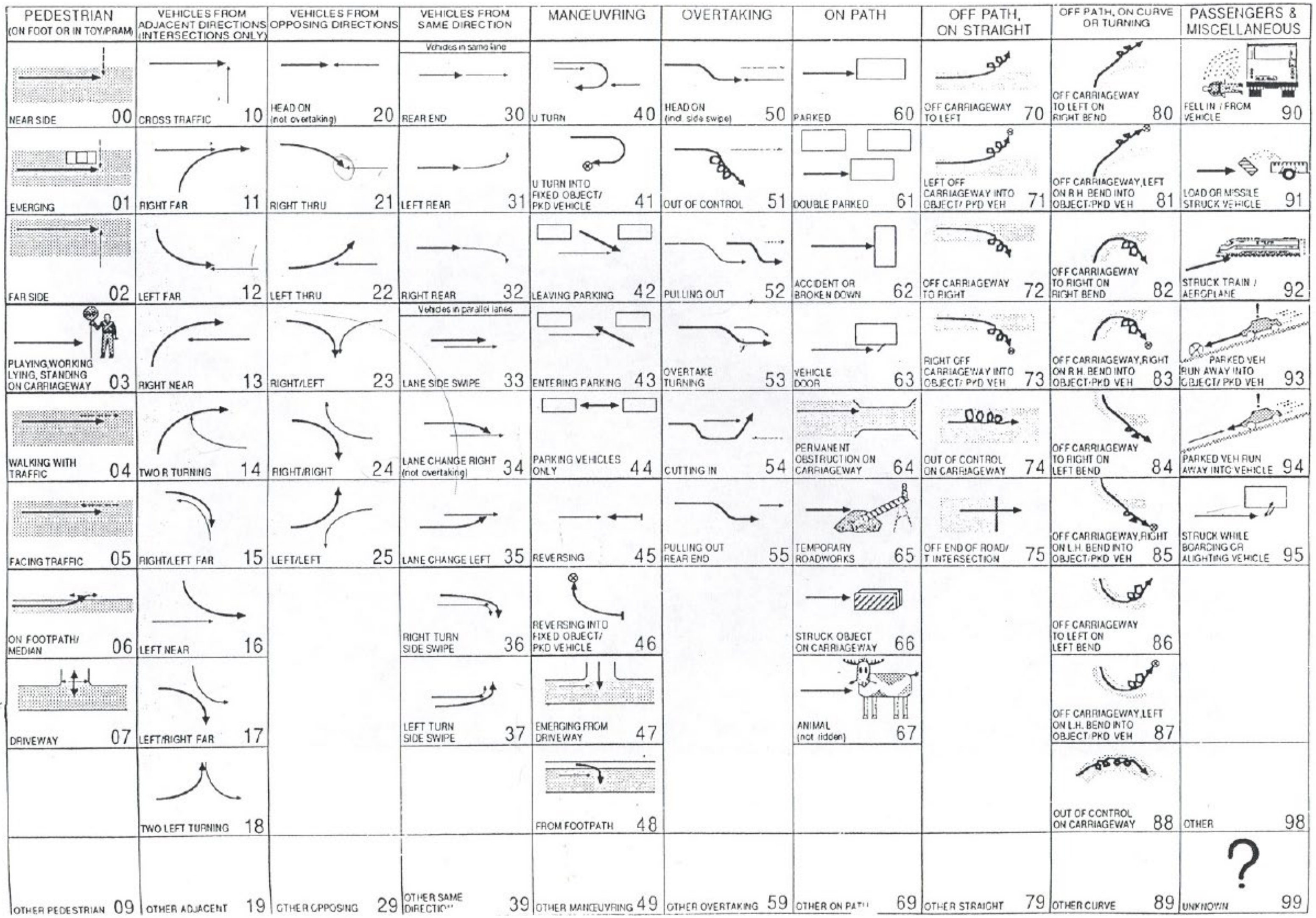


Table A 1: Territory and Municipal Services Directorate, Australian Capital Territory

00	10	20	30	40	50	60	70	80	90
Pedestrian	**Intersection**	**Vehicles from opposing directions**	**Vehicles from one direction**	**Manoeuvring**	**Overtaking**	**On path**	**Off path, on straight**	**Off path, on curve**	**Passengers and miscellaneous**
Other **00**	Other **10**	Other **20**	Other **30**	Other **40**	Other **50**	Other **60**	Other **70**	Other **80**	Other **90**
Near Side **001**	Thru-Thru **101**	Head-on **201**	Rear End **301**	Leaving Parking **401**	Head-on **501**	Parked **601**	Off Carriageway to Left **701**	Off Carriageway Right Bend **801**	Fell In/From Moving Vehicle **901**
Emerging **002**	Right-Thru **102**	Thru-Right **202**	Left-Rear **302**	Parking **402**	Out of Control **502**	Double Parked **602**	Off Carriageway to Right **702**	Off Carriageway Left Bend **802**	**902**
Far Side **003**	Left-Thru **103**	Right-Left **203**	Right-Rear **303**	Parking vehicles Only **403**	Pulling Out **503**	Accident Or Broken Down **603**	Left Off Carriageway into Object **703**	Off Right Bend into Object **803**	Hit Train **903**
Playing, Working Standing On Carriageway **004**	Thru-Right **104**	Right-Right **204**	U-Turn **304**	Reversing in Traffic **404**	Cutting In **504**	Car door **604**	Right off Carriageway into Object **704**	Off left Bend into Object **804**	Hit Railway Crossing Furniture **904**
Walking with traffic **005**	Right-Turn **105**	Thru-Left **205**	Vehicles in parallel lanes Lane side swipe **305**	Reversing into fixed Object **405**	Pulling out Rear End **505**	Hit Permanent Obstruction **605**	Out of Control On Carriageway **705**	Out of Control on Carriageway **805**	Hit Animal Off Carriageway **905**
Facing traffic **006**	Left-Right **106**	Left-Left **206**	Lane change Right **306**	Leaving driveway **406**	Overtaking Right Turn **506**	Hit Roadworks **606**	Left turn **706**	**806**	Parked Vehicle Ran Away **906**

00	10	20	30	40	50	60	70	80	90
Pedestrian	**Intersection**	**Vehicles from opposing directions**	**Vehicles from one direction**	**Manoeuvring**	**Overtaking**	**On path**	**Off path, on straight**	**Off path, on curve**	**Passengers and miscellaneous**
Driveway **007**	Thru-Left **107**	U-Turn **207**	Lane change Left **307**	From loading bay **407**	**507**	Hit Temporary Object on Carriageway **607**	Right turn **707**	**807**	Vehicle Movements Unknown **907**
On footway **008**	Right-Left **108**	**208**	Right turn s/s **308**	From footway **408**	**508**	**608**	Mounts Traffic Island **708**	Mounts Traffic Island **808**	**908**
Struck while boarding Or Alighting **009**	Left-Left **109**	**209**	Left turn s/s **309**	**409**	**509**	Hit Animal **609**	**709**	**809**	**909**
			Pulling out **310**						

Appendix B Example Blank Factor Matrix Form

DCA code (dominant crash type first[1]	Key direction (to)	Number of crashes each year						Direction of other vehicle				Type of road users							Surface		Light condition				Other factors (list items)			
							Total	To north	To east	To south	To west	Car or similar	Van, light truck	Truck	Bus	Motorcycle	Bicycle	Pedestrian	Dry	Wet	Dawn	Daylight	Dusk	Dark				
Totals																												

[1] Based on DCAs from Appendix A

The last columns of this blank form can be used for a variety of factors that might influence safety at the location being assessed, including issues such as time-of-day, severity, alignment, grade, speed etc.

Fill in one line per DCA code/key direction combination. Insert numbers of crashes in each cell, except: insert numbers of involved vehicles/pedestrians in ‘Type of road users’.

Appendix C Examples

This appendix includes a number of examples illustrating some of the key concepts in this guide. The examples provided are as follows:

- Practical Example 1: Investigation of High Crash Locations
- Practical Example 2: Chance Variation
- Practical Example 3: Writing a Preliminary Report
- Practical Example 4: Applying Crash Modification Factors
- Practical Example 5: Road Safety Audit of a Remedial Treatment
- Practical Example 6: Selecting the Countermeasures
- Practical Example 7: Economic Appraisal
- Practical Example 8: Monitoring.

C.1 Practical Example 1: Investigation of High Crash Locations

C.1.1 Example 1A

At a T-intersection in a semi-rural environment (Figure C 1) there have been 10 recorded crashes in three years. Four involve vehicles turning right out of the side road colliding with vehicles on their right.

Figure C 1: T-intersection (example 1A)

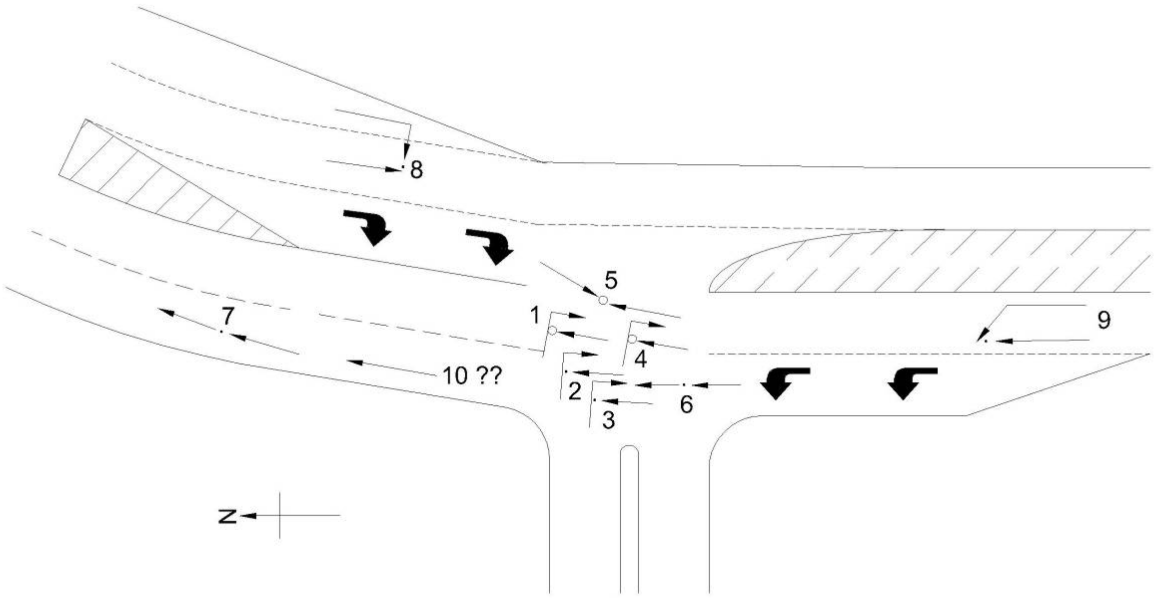
From the crash data (Table C 1) and collision diagram (Figure C 2) it is evident that the four DCA 104 crashes are the only clustering of crash types. This type of collision involves a vehicle turning right, from the east, being struck by a northbound vehicle. The analysis also revealed that most (90%) of the crashes involved a northbound vehicle, while half had occurred when the road was wet. Other common factors are not apparent.

Table C 1: Crash data (example 1A)

Crash number	Date: day - month	Date: year	Day of week	Time of day	Severity	Light condition	Road condition	DCA Code	Object 1	Object 2	Direction 1	Direction 2 (&3)
1	10–06	2004	Fri	17:10	Fatal	Dusk	Dry	104	Car	Light Truck	E	N
2	29–09	2004	Thu	10:15	Serious injury	Day	Dry	104	Heavy Truck	Car	E	N
3	20–04	2005	Thu	09:15	Serious injury	Day	Wet	104	Car	Car	E	N
4	08–12	2006	Sat	07:00	Minor injury	Day	Wet	104	Heavy Truck	Car	E	N
5	28–07	2004	Thu	08:52	Minor injury	Day	Wet	201	Car	Car	S	N
6	15–05	2005	Mon	16:40	Minor injury	Day	Dry	301	Car	Car	N	N
7	17–07	2006	Tue	17:10	Minor injury	Dusk	Dry	301	Car	Car	N	N
8	17–09	2006	Mon	05:45	Minor injury	Dawn	Wet	306	Car	Car	S	S
9	17–02	2005	Fri	20:00	Non-injury	Dark	Wet	307	Car	Car	N	N
10	13–10	2006	Sat	16:45	Non-injury	Day	Dry	400	Car	Car	N	N

Note: In this example, DCAs from Queensland have been used.

Figure C 2: Collision diagram (example 1A)



From the site inspection it is evident that sight distance out of the side road is adequate. Vehicles in the left turn lane do not block the side road drivers' view to vehicles in the through northbound lane. The intersection geometry is poorly defined and there is no clear give way position. A large number of northbound drivers use the left turn only lane as a through lane, because the layout of the lane lining encourages it and there are two northbound lanes north of the intersection.

The site inspection also found that the road surface was poor, particularly for the southern leg of the intersection.

Assessment: It is likely that drivers in the side road are moving out into the intersection, expecting any vehicles in the northbound left lane to be turning left. When a vehicle in the left lane continues north, a crash occurs.

The relatively high number of crashes that occurred when the road was wet (50%) suggests that the road surface requires investigation, particularly on the southern leg of the intersection.

Treatment: As mentioned earlier, and common to all proposed treatment considerations, speed management through lower limits (with enforcement) or traffic calming or other engineering treatments or applied technology, should be considered and is consistent with the Safe System approach. In this example, from an engineering perspective it is important to ensure that northbound vehicles travel at speeds that will enable them to avoid or minimise the severity of a collision should it occur. As identified in *Guide to Road Safety Part 3: Safe Speed* (Austroads 2021b), side impact speeds of over around 50 km/h produce a chance of a fatal and serious injury outcome.

Ensure the northbound left turn lane is used only by left turners. This requires physical alteration to lines and islands: it cannot be achieved by instruction signs. Bring the Give Way line out to near the through lane; protect it by extending the kerbed island in the side road; delineate the island (e.g. with hazard markers) so it is visible to northbound traffic, day and night. A Give Way line and sign should be installed to make the holding position obvious (note: the treatment is different from Practical example 1B, despite the same crash type, because the causes were assessed to be different).

Ensure that the road surface is free of any irregularities and that the skid resistance is improved.

C.1.2 **Example 1B**

At a T-intersection in a semi-rural environment (Figure C 3) there have been 13 recorded crashes in three years. Five involve vehicles turning right out of the side road colliding with vehicles on their right. Six are rear end crashes on the side road and two are right turns colliding with oncoming traffic on the main road.

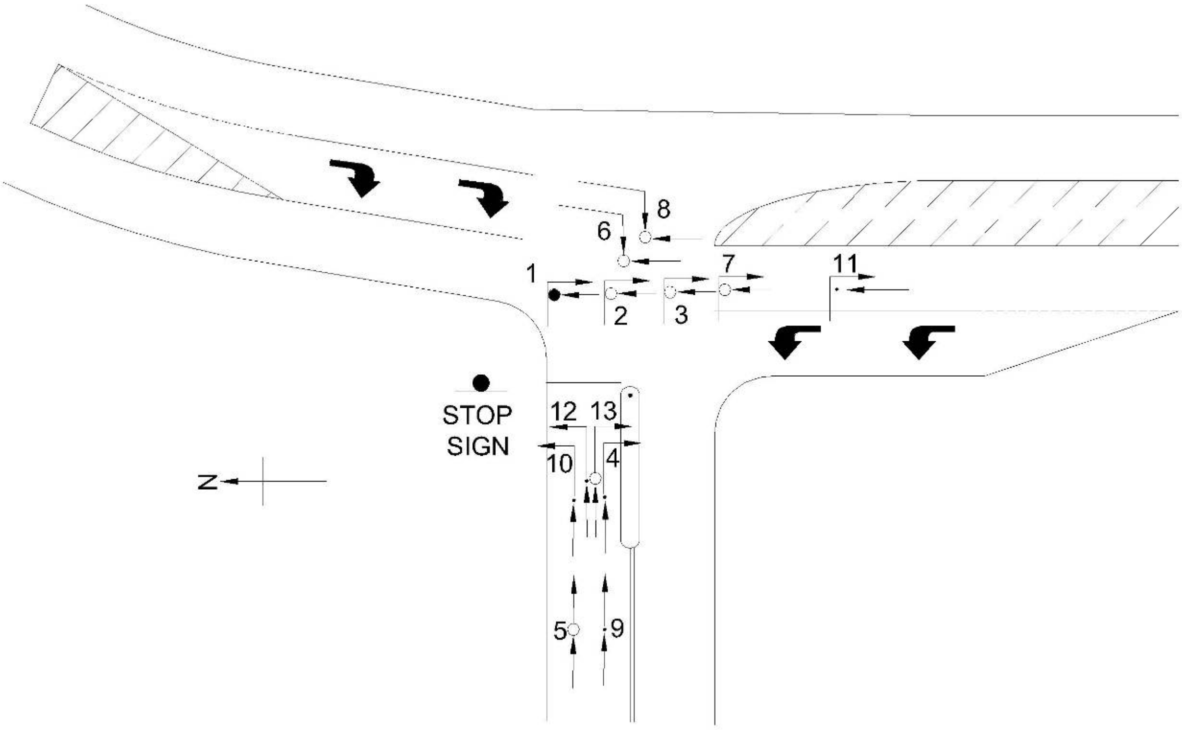
Figure C 3: T-intersection (example 1B)

From the crash data (Table C 2) and collision diagram (Figure C 4) it is evident that there are three distinct crash types with a clustering of crashes, namely rear-end (DCA 301, 2 and 3), through right (DCA 104) and right-turn-against (DCA 202). All of the rear-end crashes involved eastbound vehicles, while half occurred on wet roads. More than half (i.e. seven of thirteen) crashes involved a northbound vehicle. Both DCA 202 crashes involved a northbound vehicle and had occurred during the afternoon, when northbound flows were heavy.

Table C 2: Crash data (example 1B)

Crash number	Date: day - month	Date: year	Day of week	Time of day	Severity	Light condition	Road condition	DCA Code	Object 1	Object 2	Direction 1	Direction 2 (&3)
1	29-Jul	2007	Sun	16:43	Fatal	Day	Dry	104	Van	Car	N	E
2	20-May	2007	Sun	10:30	Serious injury	Day	Dry	104	Car	Car	N	E
3	4-Aug	2007	Sat	12:15	Serious injury	Day	Dry	104	Car	Car	N	E
4	12-Jul	2005	Tue	12:45	Minor injury	Day	Wet	303	Car	Car	E	E
5	1-Mar	2005	Tue	16:00	Minor injury	Day	Dry	301	Car	Car	E	E
6	22-Apr	2007	Sun	17:20	Minor injury	Dark	Dry	202	Car & trailer	Car	S	N
7	17-Jul	2007	Tue	11:45	Minor injury	Day	Dry	104	Truck	Car	N	E
8	12-Sep	2007	Wed	13:45	Minor injury	Day	Dry	202	Car	Car	S	N
9	12-Sep	2006	Wed	08:30	Non-injury	Day	Wet	301	Car	Car	E	E
10	21-Jan	2005	Fri	18:00	Non-injury	Day	Dry	302	Car	Car	E	E
11	23-Nov	2007	Fri	06:10	Non-injury	Day	Dry	104	Car	Car	N	E
12	11-Jul	2005	Mon	17:30	Non-injury	Dusk	Dry	302	Van	Car	E	E
13	12-Sep	2006	Wed	08:35	Non-injury	Day	Dry	303	Car	Car	E	E

Figure C 4: Collision diagram (example 1B)



From the site inspection it is evident that visibility out of the side road to the south is blocked by vehicles in the left turn lane, due to the curve in the main road. On the side road, there is a long crest approaching the intersection, preceded by a left curve: the intersection may be a surprise, despite the presence of a 'Stop Sign Ahead' warning sign.

Assessment: Vehicles in the curved northbound left turn lane are hiding through-vehicles from the view of side road drivers. On the side road, the intersection or a queue of traffic may be unexpected; the road surface is adequate. Right turners into the side road may be having difficulty finding gaps in the heavy oncoming traffic flow.

Treatment: As indicated in the previous example, speed management options should be considered as a means of lowering vehicle approach speeds to the intersection. Reducing vehicle speeds will be expected to reduce the crash risk and the severity of any crashes that do occur at the site.

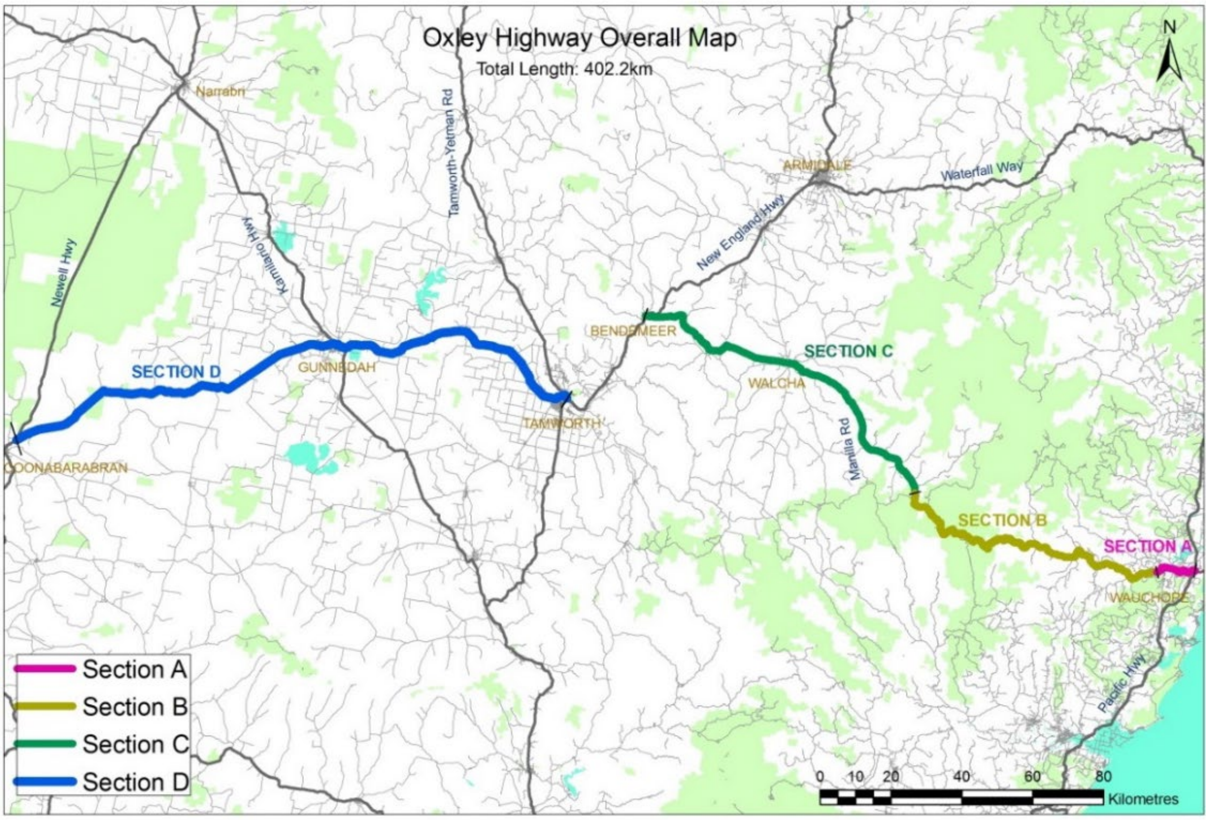
Straighten the left turn lane and taper it away from the through lane, to give side road drivers a clear view of northbound through traffic (note: the treatment is different from Practical example 1a for the same crash type because the causes were assessed to be different). On the side road, replace the 'Stop Sign Ahead' warning sign with a pair of W2-3 T intersection signs at the curve; raise the height of the hazard board opposite the intersection; replace the STOP sign with a large Give Way sign (visibility warrant for Stop sign not met). DCA 202 crashes can only be resolved by increasing gaps (e.g. by adding a second northbound through lane).

C.1.3 **Example 1C**

The Oxley highway in central NSW is over 500 km long and crosses variable terrain ranging from urban roads to rural and remote. During a 5 year period there have been 318 casualty crashes comprising 14 fatalities and 395 injuries.

The Centre for Road Safety (CRS) assessed the Oxley highway in various sections rather than specific sites in order to identify effective road safety countermeasures. The highway was divided into four homogeneous sections that range from 12.7 to 178.9 km and are generally defined by the nature of the road and its environment as indicated in Figure C 5.

Figure C 5: Oxley Highway split in four sections



Source: Eveleigh, Abeysekera & Tang (2014).

A road safety route review was undertaken as an initial stage of the project. This approach focuses on a single corridor, and includes analysis of crashes, and a physical review of the entire highway by a multidisciplinary road safety team that includes expertise in engineering, road design, behavioural science/psychology, statistics, and policing. The review process focuses on analysis of crash locations, and is not a review against standards.

The objectives of the route review were to examine the circumstances of fatal crashes and casualty crash clusters, the general road conditions, the facilities (including intersection treatments, safety barriers, signage, and line markings), the appropriateness of speed zones and priorities for rehabilitation and/or maintenance programs.

Further information on perceived risk locations were gathered through community consultation.

The Australian National Risk Assessment Model (ANRAM) was used to assess the likely benefit of treatment options. This tool combines information on existing crash locations and quantitative information about the likely safety impacts of existing infrastructure.

Based on the route safety review, the community consultation and the ANRAM results, CRS developed several program options, and assessed the cost-effectiveness of each. Each option included a range of engineering treatments. From ANRAM, a benefit cost ratio and a reduction of fatalities and serious injuries (FSI) was able to be estimated for each option.

Further information regarding this study can be found in Eveleigh, Abeysekera and Tang (2014).

C.1.4 **Example 1D**

This hypothetical example illustrates some of the key steps for treating crash locations along a route.

During the examination of crash data across a road agency's network, several high crash risk road corridors were identified. One of these was a rural route, connecting two towns. The total length was 13.2 km, and over a three year period there were 31 crashes, two thirds of which resulted in either fatal or serious injury outcomes. The crashes resulted in 38 casualties of which three were fatal and 22 were serious. This resulted in an average of 0.96 casualties per km per year. The severe crash rate was 0.56 per km per year.

Data was analysed, with a crash matrix developed for the route as a whole, and for individual road segments. A collision diagram was also developed.

Analysis showed that most of the crashes occurred at curves, and involved vehicles running off the road. Although there were several clusters of crashes at curves, many were scattered at isolated locations along the route. There were also several crashes at intersections, and a cluster of crashes at the eastern end of the route where the road entered a semi-urban area on the approach to a town. These crashes related to turning movements at intersections, and rear-end crashes at these same locations.

A route inspection was undertaken on the route. This occurred both during the day and at night given there were a number of casualties during dark conditions. The inspection identified poor delineation at various points throughout the route, and inconsistent advance warning at curves. There was also a lack of adequately sealed shoulders throughout the route. Curves with a crash history generally displayed one or more of these deficiencies, although it was also noted that there were other curves with similar features which had not yet experienced crashes.

It was observed that there was also poor sight distance at one of the intersections, and a lack of turning facilities at another.

There was increased development at the eastern end of the route, although the current speed limit remained at 100 km/h which did not match the level of abutting roadside activity.

It was recommended that:

- Curves be assessed in a consistent manner to improve delineation, including advanced warning signs, guide posts and chevron alignment markers. This included recommendations for locations that had experienced crashes, as well as those that were substandard, but where no crashes had yet occurred.
- Shoulders be widened at critical locations, including through curves.
- Roadside barriers be installed at one severe curve where roadside hazards were present.
- Sight distance improvements were recommended at one intersection, with the stop line being brought forward, and vegetation cleared. At another intersection, a left turn deceleration lane was recommended along with an indented right turn lane.
- Due to the increased level of development at the eastern end of the route, the speed limit be lowered from 100 to 80 km/h.

Initial scoping work was conducted, and the costs and benefits calculated for the project. The BCR exceeded 1 meaning that the project delivered more benefits than costs. The Net Present Value (NPV) was also calculated to help prioritise this project amongst others being investigated by the road agency.

C.2 Practical Example 2: Chance Variation

The crash history at a site for the past six years is 3, 1, 2, 1, 3 and 5 crashes per year. At the end of the sixth year there has been concern that a hazardous situation has developed, which has caused the apparently high number of crashes in that year.

How likely is it that this result may have occurred by chance?

In the previous five years the crash numbers were 3, 1, 2, 1 and 3. So at the start of the sixth year what range of crash numbers could be expected? The observed rate of occurrence is 2.0 crashes per year (i.e. [3+1+2+1+3] ÷ 5 years). The lowest number to that time has been 1 and the highest has been 3.

From Appendix F (Figure F 1), it can be seen that with c/n = 2.0 and n = 5, the expected range of crashes (the 'true underlying rate' of crashes) per year is from 0.9 to 3.7 (i.e. from 1 to 4). The occurrence of 5 crashes in the sixth year is outside this range.

Also from Appendix F (Figure F 2), it can be seen that with c/n = 2.0 and n = 5, the 'critical change in the mean' is 1.6. i.e., any number of crashes 1.6 above (or below) the observed mean of 2.0 would be regarded as not occurring by chance. The occurrence of 5 crashes in the sixth year is thus very unlikely to be the result of chance.

It is thus appropriate to add the site to the list for investigation.

Also, it is important to check if there is a common pattern in the crashes, both in previous years and in the most recent year. Is there a new crash type occurring? Is there a common feature (direction of approach, type of road user, etc.)? Check if there has been any change to circumstances at the site. Has this contributed to the increase?

C.3 Practical Example 3: Writing a Preliminary Report

This example has been adopted from an example report provided by Opus International Consultants, Tauranga, and Transit New Zealand (now the New Zealand Transport Agency).

A preliminary report has been prepared, to provide a crash location investigation team with information before its site inspection. Each team member receives a copy. The site is a crossroad intersection where the Highlands Highway intersects with Green Road and Black Road.

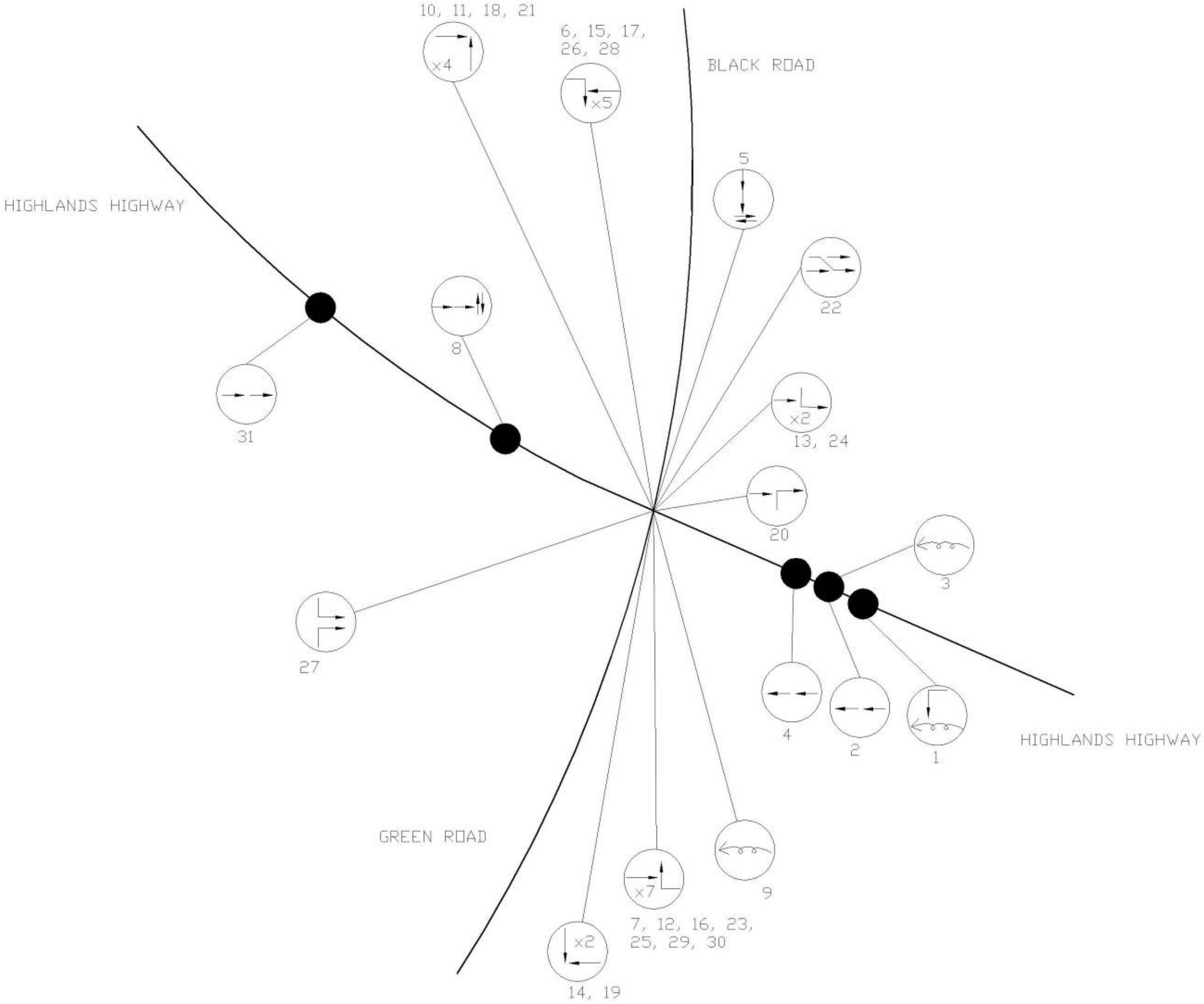
Several sites will be inspected and the report starts with a list of all the sites and a summary of the study procedures. For Highlands Highway/Green Road, the report contains a summary table which has space for the investigation team to provide comment under the headings of Discussion, Problem and Solution. It also includes a complete listing of all crashes for five years (not shown here), some graphical analyses of the crash data (crash severity not shown here), the collision diagram and a factor matrix (not shown here).

Table C 3: Example report

Site no.	1
LTSA no	548376
Location	Highlands Highway/Green Road Intersection
Description and history	This intersection was nominated to be reviewed in the study location Schedule (after analysis of the crash monitoring data) and the Council. The closest State Highway traffic count in this area is between Victoria Road and Auckland Corner which gives an AADT of 9 619 vpd with 19% HCV and 9.5% growth. The TDC traffic counts (Jan/Feb 2008) of the individual legs are: • Highlands Highway East 16 012 • Highlands Highway West 17 068 • Green Road 2 541 • Black Road 2 240 The surrounding land has since undergone extensive subdivision development on the eastern leg and the University is still in the process of expansion of its campus on the western leg. The prevailing speed limit is 80 km/h. Cross intersection: Give Way sign control Intersection was reconstructed in 2004.
Crash record	Refer attached collision diagram. This site had 31 crashes in the five year period, 2003–2007. 50% of the crashes occurred between 3 pm and 6 pm. The majority of the crashes are intersection type, i.e.: • Crossing (vehicle I turning) 40% • Crossing (no turns) 20%, • Rear-End 17%.
Discussion	The University has recently undertaken its own study.
Problem	Busy crossroads during peak periods with a large number of conflicting movements. High speed on through road.

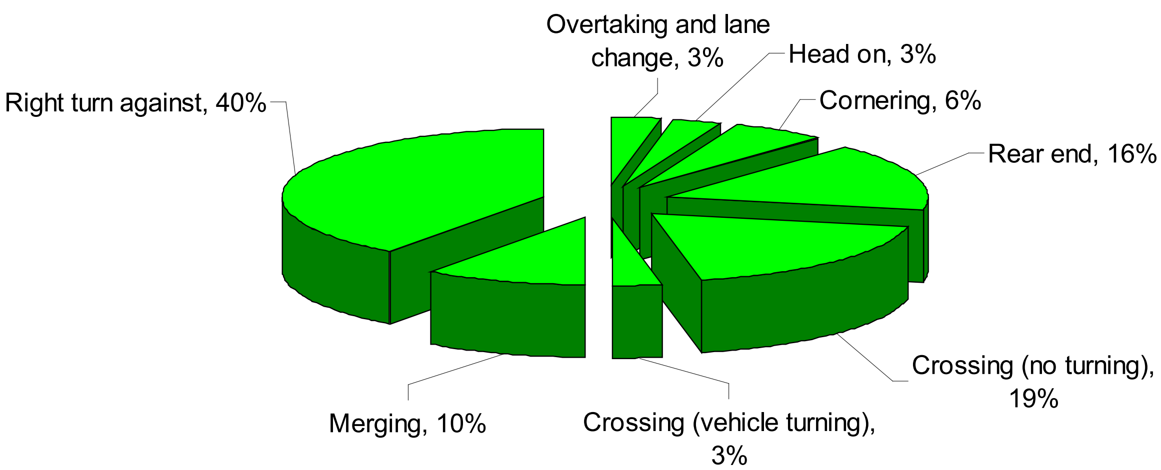
A collision diagram for the site is shown in Figure C 6. This shows the direction and location of each crash and the number and nature of each crash type.

Figure C 6: Collision diagram



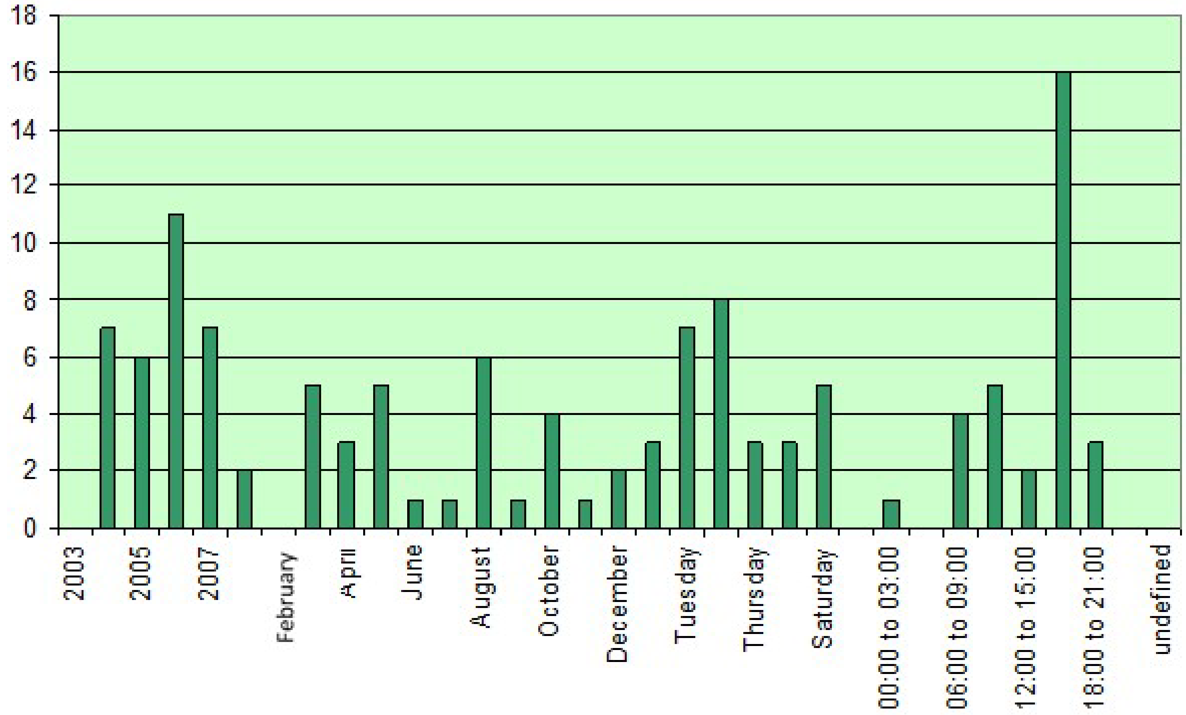
The movement category pie chart (Figure C 7) summarises the crashes by crash type. The team can see that right turn against makes up 40% of crashes, crossing (no turning) is 19% and rear end is 16%.

Figure C 7: Movement category pie chart



Crash distribution by year, month, day and time as shown in Figure C 8 can reveal trends. The yearly figures allow the team to see that crashes have been occurring since the intersection's reconstruction. The monthly figures show nothing unusual. The daily figures suggest a further examination of crash type by day may be worthwhile. The hourly figures show the worst problem is in the afternoon peak. Which crashes are occurring then?

Figure C 8: Crash distributions – year, month, day and time



Assessment: The investigation team used this information together with the site inspection, to consider the causes of the crashes. A common centreline was considered to be a key factor for the right turn against crashes: right turners could not see oncoming through traffic because their view was blocked by oncoming right turners. The solution would be to remark the right turn lanes 'head to head'. But this would not reduce the right angle and rear end crashes. Speeds are high, there is a tight curve just south of the intersection and traffic volumes are now too high for safe gaps in the major flows. It was recommended that a roundabout be installed here and at another crash problem site 700 m to the west on the Highlands Highway. In the interim, large crash hazard warning signs were installed.

C.4 Practical Example 4: Applying Crash Modification Factors

It is important to use expert judgement when applying CMFs, including those in Appendix E. When implementing a change to a traffic control to reduce one crash type, do not assume this will also reduce other crash types. In some cases a measure that reduces one type of crash may result in more crashes of another type.

C.4.1 Example 4A

There is clustering of several crash types at a signalised crossroad. One type is the DCA corresponding with a through-right collision. It is decided to fully control the right turn involved in these crashes by installing a red arrow. The 'remodel signals' treatment lists a CMF of 0.6 for these crashes (see Appendix E). But what about the CMF for other crash types with this treatment?

The intersection also has a DCA corresponding with through-through collisions, but if the only improvement is the new right turn red arrow, there will be no reduction in these crashes because the right turn red arrow will not affect them. Only if other works are undertaken to target these crashes, can the 0.7 CMF for crashes where signals have been remodelled be applied.

C.4.2 **Example 4B**

Consider the installation of a roundabout in a local street such as that shown in Figure C 9 as a countermeasure to intersection crashes. The only crash type is through-through collisions.

Appendix F indicates the 'roundabout' treatment has a CMF for these crashes of 0.3. But what about the changes to other crash types for this treatment? Only apply the percentage increases to crashes of the relevant types already reported. In this case there are none. But be realistic and use engineering judgement: are there high cyclist numbers, which would make cyclist crashes likely with a roundabout? Might rear-end crashes start to occur? How might they be avoided? To minimise the risk of new types of crashes, have the new design road safety audited.

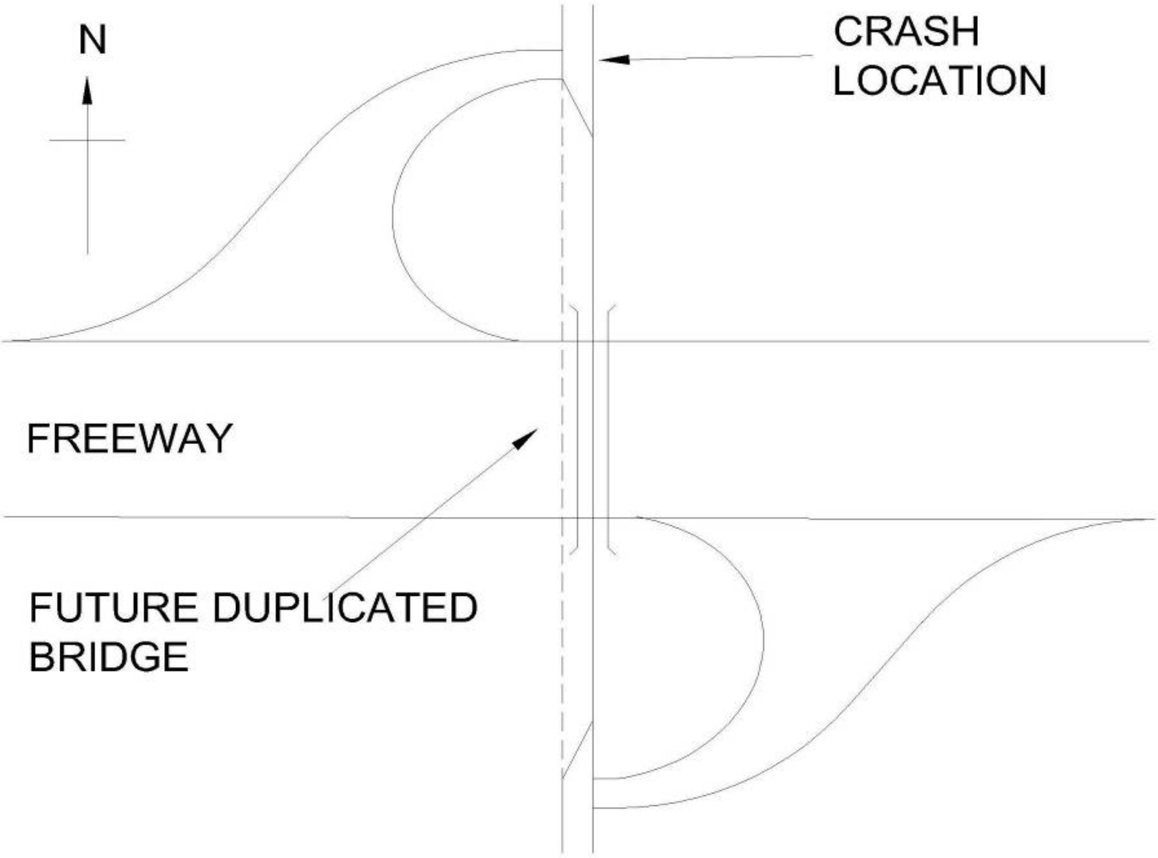
Figure C 9: Example of a roundabout installed within a local street

C.5 **Practical Example 5: Road Safety Audit of a Remedial Treatment**

This example illustrates the need to road safety audit the design for a crash remedial treatment, to ensure that new crash problems are not created when existing problems are solved.

A freeway interchange was built at an arterial road and the ramp terminal intersections were controlled by Give Way signs. As traffic increased, there was an increase in DCA 104 crashes at the northern intersection (right turns from the exit ramp colliding with a vehicle on their right). Part of the problem was the offset freeway bridge and the space left for a duplicate bridge to the west of the initial one. Figure C 10 shows an indicative diagram of the location.

Figure C 10: Interchange used in practical example 5



Both intersections at the interchange were signalised in 2005. As the abridged factor matrix (Table C 4) shows, the DCA 104 crashes ceased, but right-turn into-oncoming-traffic crashes started occurring, as well as rear-end crashes.

Table C 4: Abridged factor matrix

DCA code 1	Key direction (to)	Number of crashes each year							Direction of other vehicle				Surface		Light condition			
		2002	2003	2004	2005	2006	2007	Total	To north	To east	To south	To west	Dry	Wet	Dawn	Daylight	Dusk	Dark
102	E				1			1						1				1
103	E		1					1			1			1		1		
104	E	1	1	1	4			7	7		1		5	2		6		1
202	S					5	4	9	9				7	2	3	2		4
301	S					2		2			2		2			1	1	
301	W					1		1					1			1		
706	E					1		1					1					1
Totals		1	2	1	5	9	4	22	16	–	4	1	16	6	3	11	1	7

1 *Dominant crash type first - based on DCAs from Figure A 2*

From the crash data and the factor matrix it is evident that DCA 104 crashes are no longer a problem. Since the signals were installed, DCA 202 crashes have become a problem. Rear-end crashes have also increased. This may be a particular problem or could be typical of signalised sites.

The site inspection showed that drivers turning right onto the freeway are permitted to ‘filter’ turn after the green arrow signal ends. However they are positioned directly facing oncoming traffic, where it is very difficult to judge approach speeds as there is no lateral movement (Figure C 11). This task is harder in poor light. Also, only the front vehicle is visible. It appears that right turners are misjudging speeds and picking a gap which is too short.

Figure C 11: Looking south from where right turners wait to turn

Treatment: *Fully control the right turns with a red arrow signal.*

C.6 Practical Example 6: Selecting the Countermeasures

At an urban local street crossroad there have been 14 casualty crashes in five years. All are right angle crashes. The intersection is controlled by a Give Way sign on the north and south approaches.

From the crash data (Table C 5) and collision diagram (Figure C 12) it is evident that two-thirds of the crashes involve southbound traffic (north approach). Half the crashes involve southbound vehicles striking westbound vehicles. One-third of the crashes are in daylight.

Figure C 12: Collision diagram for practical example 6

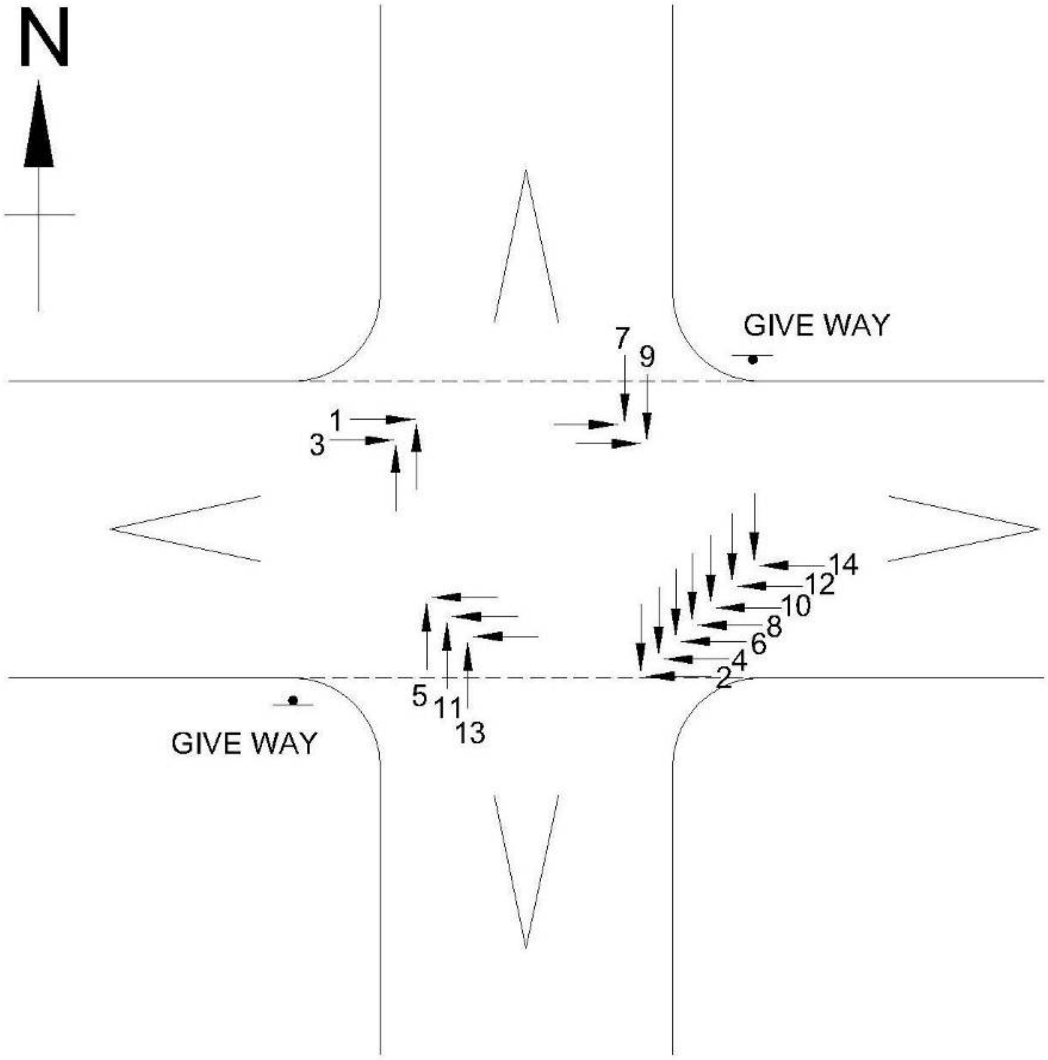
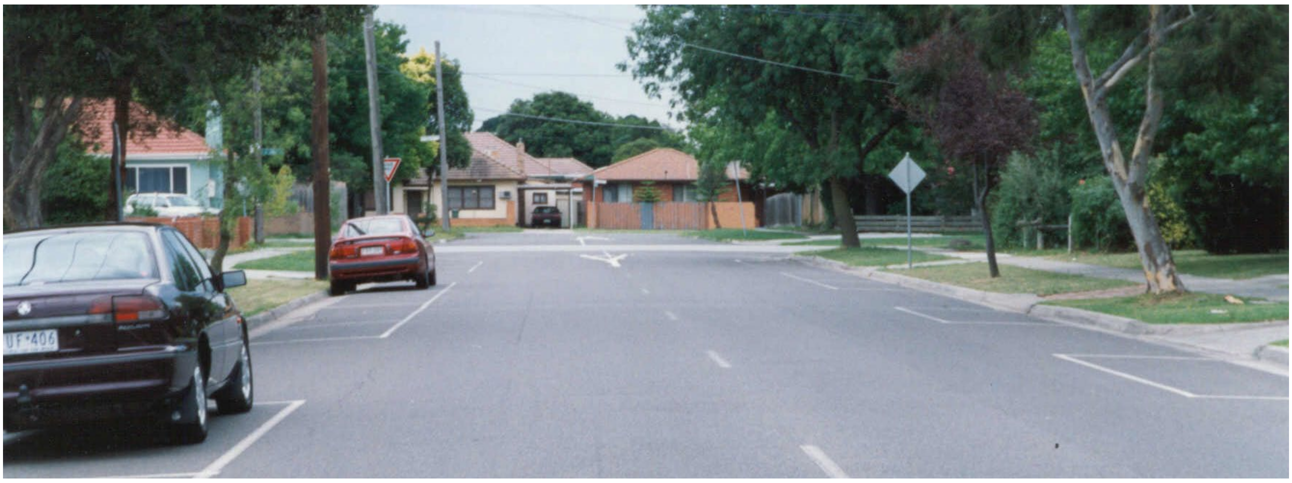


Table C 5: Crash data for practical example 6

Crash number	Date: day - month	Date: year	Day of week	Time of day	Severity	Light condition	Road condition	DCA Code	Object 1	Object 2	Object 3	Direction 1	Direction 2 (&3)
1	13-Jul	2004	Tue	17:00	Minor Injury	Dusk	Wet	101	Car	Car		N	E
2	4-Sep	2004	Sat	18:55	Minor Injury	Dark	Wet	101	Car	Car		S	W
3	19-Dec	2004	Sun	15:30	Serious Injury	Day	Dry	101	Car	Truck		N	E
4	8-Jun	2004	Wed	19:00	Minor Injury	Dark	Dry	101	Car	Car		S	W
5	3-Jul	2005	Sun	13:45	Serious Injury	Day	Dry	101	Car	Car	Car	N	W,E
6	7-Nov	2005	Mon	21:45	Minor Injury	Dark	Dry	101	Car	Car		S	W
7	30-Dec	2005	Fri	19:00	Minor Injury	Day	Dry	101	Car	Car		S	E
8	27-Feb	2006	Mon	12:20	Minor Injury	Day	Dry	101	Car	Truck	Car	S	W,N
9	3-May	2006	Wed	18:00	Minor Injury	Dark	Dry	101	Car	Car		S	E
10	24-Jul	2006	Mon	20:00	Serious Injury	Dark	Dry	101	Car	Car		S	W
11	18-Apr	2007	Wed	18:45	Minor Injury	Dark	Dry	101	Car	Car	Car	N	W ,E
12	21-May	2007	Mon	16:10	Serious Injury	Day	Dry	101	Car	Car		S	W
13	14-Jun	2007	Thu	17:35	Serious Injury	Dark	Wet	101	Van	Car		N	W
14	20-Aug	2007	Mon	18:55	Minor Injury	Dark	Dry	101	Car	Car		S	W

From the site inspection (Figure C 13) it is evident that on the north approach, the drivers' attention is drawn through this intersection to the T-intersection beyond. Both Give Way signs are partly obscured: on the north by a pole and on the south by tree foliage. Non-standard centre of road markings on all four approaches look like roundabout splitter islands. The Give Way lines are worn.

Figure C 13: Intersection used in practical example 6



Assessment: The crashes with vehicles on the second half of the major road suggest some drivers may think this is a roundabout, misled by the highly visible centre markings. On the north approach there is a low level, fully mountable roundabout at the previous intersection. However the markings are only two years old. Alternatively, some drivers may have their attention drawn beyond the intersection by the T-intersection to the south. Direction 2 being west may be because most traffic on the major road approaches from the east.

Treatment: Immediate – install larger Give Way signs in more prominent positions, duplicate them on the right side of the road, change markings to standard centreline and holding line, install a Give Way Sign Ahead sign on both minor approaches. In the near future works program include a roundabout or on both minor approaches build a left kerb outstand and angled centre island (which sits across drivers' line of sight along the road) and install a pair of Give Way signs on these new features (decide which after an economic appraisal of both options).

C.7 Practical Example 7: Economic Appraisal

C.7.1 Example 7A: (based on Ogden 1996)

Consider the installation of a roundabout in a local street discussed in Appendix C 4. Assume there is data on crashes, including crash type or DCA code and that the crash costs by crash-type are as shown in Table 6.4. The following parameters apply:

- capital cost: $240 000
- change in vehicle operating cost: assumed zero
- current crash rate: average of one adjacent approaches crash per year
- assumed effect of roundabout on crashes: 70% reduction
- appraisal period: 20 years
- discount rate: 4% per annum.

The appraisal

It is first assumed that there will be no change in the traffic flow through the intersection over the appraisal period. If this were not so, there would be a need to make some assumptions about what the likely future annual crash rate would be in the do nothing case (i.e. if the crash problem was not treated). However as it is in a local street it could be reasonably assumed that if there is a history of one adjacent-approaches crash every year this will continue in the future in the do nothing case.

Therefore, in the 'do nothing' case, there is an annual crash cost of $93 440 for intersection crashes (Table 5.4). The roundabout is expected to eliminate 70% of these crashes (Appendix E). It is assumed that there will be no other effects of the roundabout, i.e. that it will not introduce crash types which are not there at present. If this were not the case, there would be a need to estimate the additional effects. Therefore the annual benefit of the roundabout is expected to be $65 400.

Using a discount rate of 4% per annum, it is calculated (or obtained from discount tables) that the present worth of an annual sum of $1 per year over 20 years is $13.59. Therefore, multiplying the annual benefit value above by 13.59, the net present benefit of the project is $888 800.

As the installation cost of the roundabout is $240 000, the NPV is $648 800 (i.e. $888 800 – $240 000) and the BCR is 3.7 (i.e. $888 800 ÷ $240 000).

Sensitivity testing

Assume range of crash reductions between 50% and 80%. In this case, keeping all other assumptions the same, the annual benefit of the roundabout project is between $46 700 (at 50% reduction in crashes) and $74 800 (at 80%) per year and the net present benefit of the project is $634 700 (low estimate) to $1 016 500 (high estimate). As the installation cost of the roundabout is $240 000, the NPV is in the range of $394 700 to $776 500 and the BCR is in the range 2.6 (i.e. $634 700 ÷ $240 000) to 4.2 (i.e. $1 016 500 ÷ $240 000).

C.7.2 **Example 7B (based on Andreassen 1992a, p.5)**

This example refers to the post-installation evaluation of a traffic signal installation program. New traffic signals were installed at 41 intersections. Figure C 14 shows an example of a traffic signal installed as a countermeasure to intersection crashes.

Figure C 14: Example of a recent traffic signal installation

Crash data were analysed for two years before and two years after the installation at each site. The only significant changes in crash types were a reduction of adjacent-approaches crashes (DCA code 101 in Figure 3.1 and Table 6.4) from 6.54 per site per year to 1.88, and an increase in right-turn-into oncoming-vehicle crashes (DCA 202) from 0.71 per site per year to 1.82. To evaluate the program the following assumptions are made:

- capital cost: $170 000 per intersection
- operating cost: $10 000 per intersection per year
- appraisal period: 10 years
- discount rate: 7% per annum.

The appraisal

It is assumed that the same level of crashes would occur each year for the next five years if the signals were not installed and that the crash rate experienced over two years would continue unchanged over five years.

Based on Table 6.4, the average cost of a crash type 101 is $93 440 and that for crash type 202 is $92 482. The annual benefit of the program per intersection is:

the improved difference in annual crash frequency for intersection crashes (6.54 – 1.88) multiplied by the average cost per intersection crash ($93 440)

minus

the worsened difference in annual crash frequency for right turn into oncoming vehicle crashes (1.82 – 0.71) multiplied by the average cost per DCA 202 crash ($92 482)

= $332 775 (per intersection per year).

The net annual benefit is less than this, as there is an annual operating cost of $10 000. It is $322 775. Using a discount rate of 7% per annum, it is calculated (or obtained from discount tables) that the present worth of an annual sum of $1 per year over 10 years is $7.02.

Therefore, multiplying the net annual benefit ($322 775) by 7.02, the net present benefit of the signalisation project is $2 265 883.

As the installation cost of the signals at each site was $170 000, the NPV is $2 095 883 ($2 265 883 – $170 000) and the BCR is 13.3 (i.e. $2 265 883 ÷ $170 000).

Note that the benefit has been taken as the net annual return from the investment (i.e. safety benefits minus operating costs) and the cost as the initial investment (installation cost). If the costs had been defined as the outlay by the road agency, as is sometimes done, this would have included the annual signal operating cost of $10 000. In this case the benefit would be $2 336 083 (7.02 x $332 775) and the costs would be $240 200 ($170 000 + (7.02 x $10 000)). This would give an NPV of $2 095 883 and a BCR of 9.7 (i.e. $2 336 083 ÷ $240 200).

Note that the NPV is identical whichever way costs and benefits are defined, whereas the BCR will change. This is the reason for the cautions given in Section 6.3.

C.8 Practical Example 8: Monitoring

A narrow, two lane wooden bridge in poor condition was replaced with a wider bridge. As part of the project the road was reconstructed a short distance in each direction. The south approach is straight, but the construction on the north end finished half way around a curve, signed at a 25 km/h advisory speed. The curve and speed warning was retained after the bridge was replaced. Figure C 15 shows an image of the reconstructed bridge.

Figure C 15: Looking north to the reconstructed bridge and curve

At the curve just north of the bridge, the number of crashes in three years went from none before the works, to 12 afterwards, as shown in the abridged factor matrix (Table C 6).

Table C 6: Abridged factor matrix

DCA code [1]	Key direction (to)	Number of crashes each year					Total this combination of DCA and key direction	Direction of other vehicle				Surface		Light condition			
		2002	2003	2004	2005	2006		To north	To east	To south	To west	Dry	Wet	Dawn	Daylight	Dusk	Dark
603	N					1	1	1				1			1		
607	N			1			1					1			1		
803 Off curve	N			1	2	6	9					7	2		2	1	6
804 Off curve	S					1	1						1				1
Totals				2	2	8	12	1				9	3		4	1	7

1 *Dominant crash type first - based on DCAs from Figure 5.1*

From the crash data and the factor matrix it is evident that drivers were failing to safely negotiate the curve after the bridge and running off the road. The crash data shows five of the DCA 803 crashes were on Saturday nights.

From the site inspection it is evident that the curve now has a change of radius half way. Near the bridge it is faster than 25 km/h, then it tightens to 25 km/h. The slower section has no edgelines. Approaching from the south the curve looks faster.

Assessment: This example illustrates how improving the approach to a substandard curve has lessened drivers' expectation that the road ahead is of poor alignment. The improved bridge alignment encourages higher speed into the tight curves whereas previously the bridge acted as a traffic calming device. There is nothing to suggest the curve tightens and so the 25 km/h advisory speed sign loses its credibility. If the design had been road safety audited, the potential problems could have been avoided. In the absence of an audit, this illustrates the importance of monitoring the effects of projects, especially on adjacent sections of road.

Treatment: Short term: improve the warning and delineation for the curves, including prominent warning that it tightens after the curve starts. Extend the guard fence. Consider lighting the curve. Longer term: reconstruct the whole curve and nearby sections so that they have a consistent design speed and consistent markings and delineation.

Appendix D Detailed Case Study

In Appendix D, a case study is used to illustrate how to apply each of the steps in the investigation and treatment process, as described in Sections 4 to 7. While it is based on a real example, some circumstances and data have been altered for the purposes of presentation.

D.1 Step-by-step Process in the Investigation and Treatment Process

D.1.1 Background

A fatal head-on crash occurs on a curve on an urban arterial road in mid-2007 (on High Street between the Golf Club intersection and Craig Street (Figure D 1). A southbound car crossed the centreline. As part of the investigation of the fatal crash, state crash records are examined. They show that on this section of road, for the previous 10-years, only two other crashes have been reported, both run-off-the-road southbound. There are common factors in the three crashes:

- all involved loss of control
- all left their lane on a curve
- all problem movements were southbound.

There have been only three crashes in 10-years. Is this really a problem location or is it just typical of urban crash patterns and nothing more than random events, albeit with a severe consequence in the latest crash? It is decided to conduct a fuller investigation.

D.1.2 Deciding which road sections and intersections are to be included

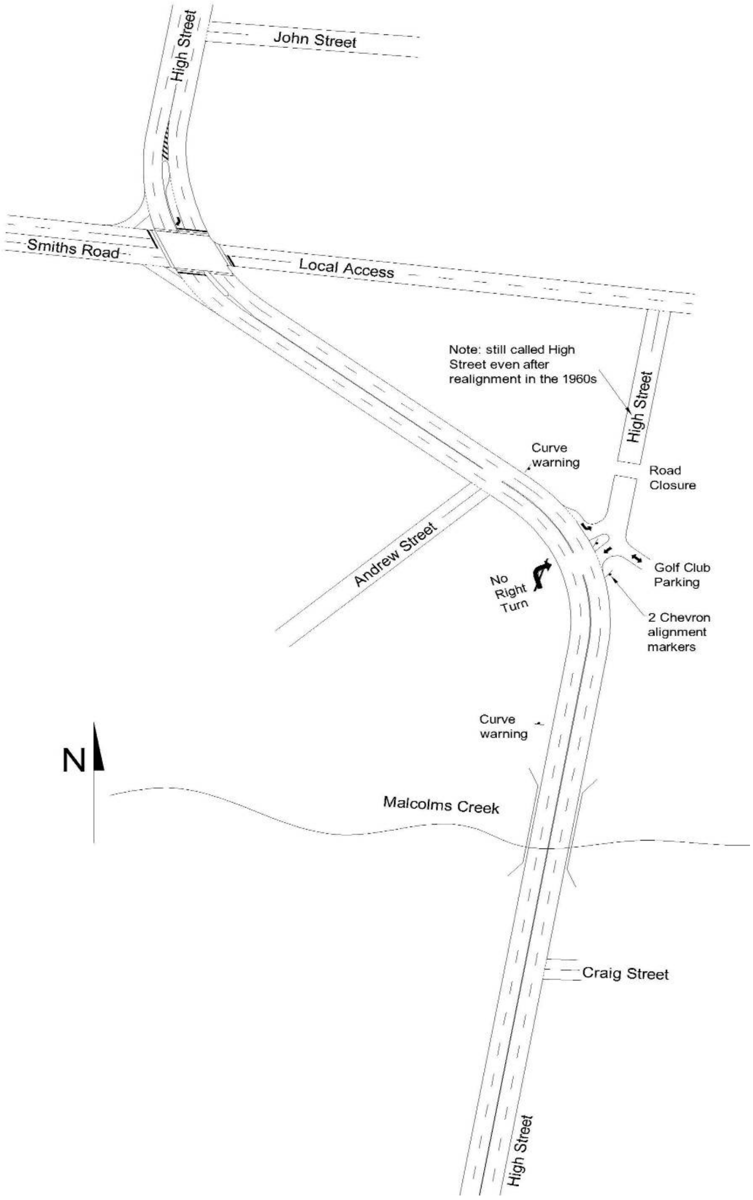
In the state crash records, the road section in which the fatal crash occurred is 200 m long, between two adjacent intersections. But it is only one part of a longer curve. The curves were built in the late 1960s to realign High Street and make it continuous. It is decided to look at the complete reverse curve and approaches. This includes an arterial road intersection within the reverse curve (Figure D 1).

As soon as the crash information is collected for the complete section of road, it is discovered that there have been over 40 crashes in the previous five years, including 12 out-of-control and eight head-on. It is locally termed a ‘blackspot’, hidden by the segregation of crash records into individual road lengths and intersections. This shows the importance of looking at whole lengths which have consistent characteristics. It is decided the crash investigation will examine the whole length.

D.1.3 Deciding on the time period

Traffic signals were installed at the intersection to the north in the late 1980s. This road and other similar arterial roads were marked into four traffic lanes in the early 1990s. In the late 1990s the southern curve was treated with longitudinal grooving. Within the past three years a nearby local street has been closed and a left turn deceleration lane installed into it, as part of a golf club expansion. However, at least three years’ crash data are required, so those recent changes will need to be kept in mind, but should not restrict the time period. It is decided to look at the previous five years’ data, a period in which there were no other changes.

Figure D 1: Case study site plan (not to scale)



D.2 Obtaining all the Relevant Information

The relevant information includes the crash data from the state crash records and the traffic volumes. Anecdotal information from residents can be helpful, although judgement is required before it is used as a basis for decisions (or, equally, dismissed as not relevant). Information about the physical features of the road will be critical in the assessment.

The traffic volumes are:

- High Street: 24 000 vpd
- Smiths Road: 13 000 vpd.

There are no recent turning counts at the arterial road intersection. The current speed limit is 70 km/h. The crash information in the state crash records is set out in Table D 1 and Table D 2). It is grouped by intersection and road section, using the numbers in the route plan as shown in Figure D 2.

Table D 1: Case study crashes at intersections

Crash number	Road location	Date: day – month	Date: year	Day of week	Time of day	Severity	Light condition	Road condition	DCA code (crash-type)	Object 1	Object 2	Direction 1	Direction 2
1	i1	22–02	2003	Sun	19:20	NI5	Dusk	Dry	703	Car	Hydrant	N	
2	i1	23–11	2004	Tue	14:45	NI5	Day	Dry	202	Car	Car	N	S
3	i1	12–09	2005	Mon	17:40	MT3	Day	Wet	201	Car	Car	N	S
4	i2	13–02	2003	Thu	08:30	INT4	Day	Wet	302	Car	Car	E	E
5	i2	11–03	2003	Tue	08:20	MT3	Day	Dry	302	Car	Car	N	N
6	i2	11–08	2003	Mon	08:20	INT4	Day	Dry	302	Minibus	Car	NW	NW
7	i2	30–10	2004	Sat	01:30	NI5	Dark	Dry	301	Car	Car	S	S
8	i2	16–05	2004	Sun	10:45	MT3	Day	Dry	202	Car	Car	S	N
9	i2	15–06	2004	Tue	15:30	MT3	Day	Dry	308	Car	B/cyc	E	E
10	i2	02–08	2004	Mon	18:15	INT4	Dark	Wet	705	M/cyc		SE	
11	i2	15–03	2005	Tue	16:30	NI5	Day	Wet	202	Car	Car	N	S
12	i2	30–09	2005	Fri	00:30	NI5	Dark	Dry	804	Car	Signals	S	
13	i2	01–05	2006	Mon	09:30	NI5	Day	Dry	302	Truck	Car	E	E
14	i2	19–12	2006	Tue	06:30	NI5	Day	Dry	303	Car	Car	N	N
15	i2	21–04	2006	Fri	13:50	INT4	Day	Dry	202	Car	Car	SW	N
16	i2	30–08	2006	Wed	00:35	INT4	Dark	Dry	804	Car	Signals	S	
17	i2	22–10	2007	Mon	17:50	MT3	Dusk	Dry	705	M/cyc		E	
18	i2	01–12	2007	Sat	23:50	HA2	Dark	Wet	803	Car	Signals	N	
19	i3	12–Jun	2006	Mon	20:30	NI5	Dark	Wet	703	Car	Post	N	
20	i3	27–Apr	2007	Fri	05:15	K1	Dark	Wet	703	Car	Tree	SE	

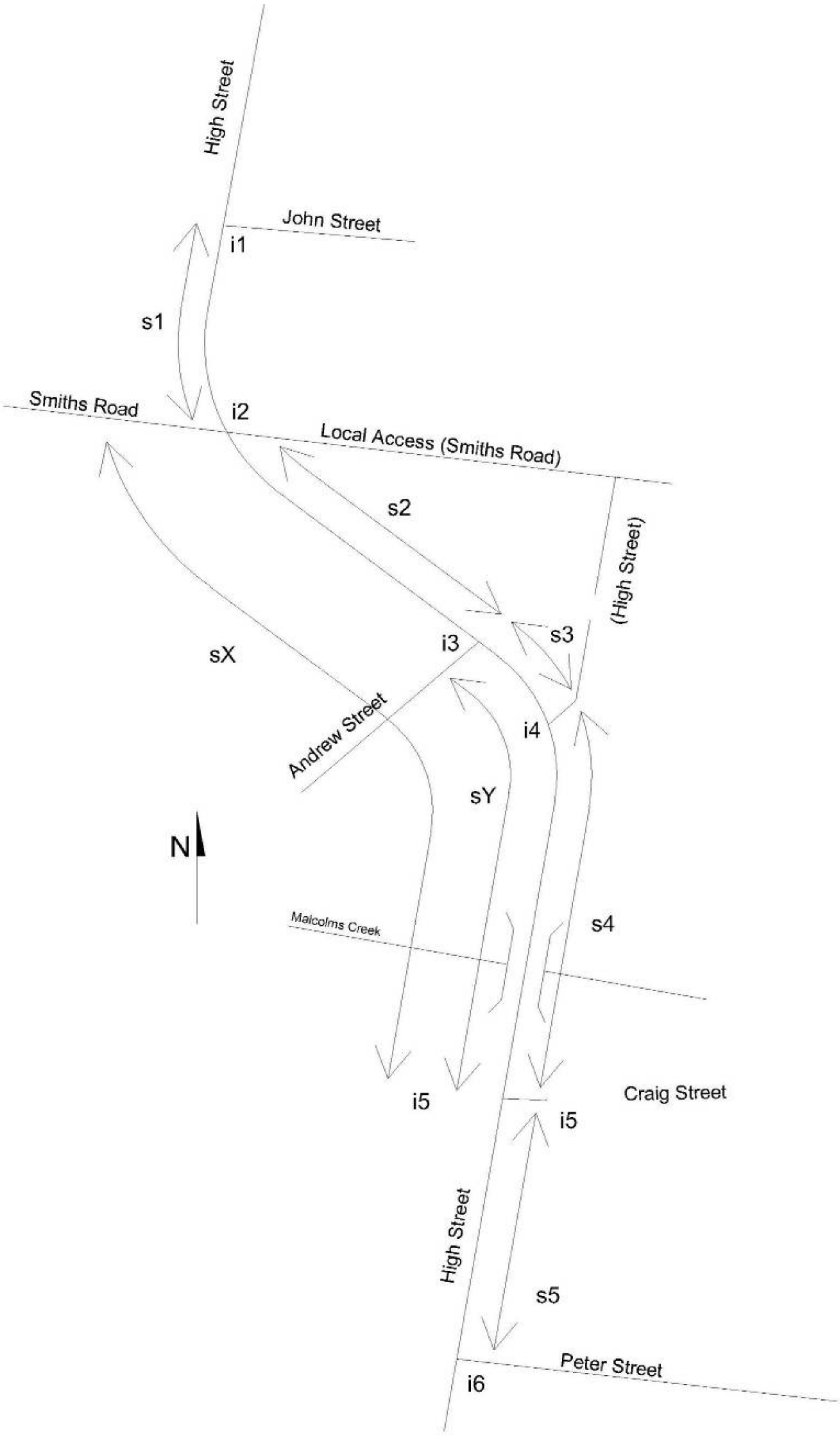
Table D 2: Case study crashes between intersections

Crash number	Road location	Date: day – month	Date: year	Day of week	Time of day	Severity	Light condition	Road condition	DCA code (crash-type)	Object 1	Object 2	Object 3	Direction 1	Direction 2 (&3)
21	s1	15–01	2004	Thu	08:00	NI5	Day	Dry	703	Car	Sign		N	
22	s1	03–09	2004	Fri	11:30	MT3	Day	Dry	003	Bus	Ped		S	
23	s1	02–11	2004	Tue	07:00	INT4	Day	Wet	603	Car	Car		N	N
24	s1	17–04	2005	Sun	13:10	NI5	Day	Dry	307	Car	Car		N	N
25	s1	14–01	2005	Fri	22:45	HA2	Dark	Wet	201	Car	Car		N	S
26	s1	18–06	2005	Tue	14:20	HA2	Day	Wet	703	Car	Car	Fence	N	S
27	s1	22–03	2006	Tue	14:20	HA2	Day	Wet	603	Car	Car	Ped	N	N
28	s2	30–03	2002	Sat	13:00	NI5	Day	Wet	201	Car	Car		N	E
29	s2	23–08	2003	Sat	07:15	NI5	Day	Wet	703	Car			S	
30	s2	21–10	2003	Tue	19:40	HA2	Dark	Dry	201	Car	Car		NE	S
31	s2	07–02	2004	Sat	11:30	NI5	Day	Dry	406	Car	Car		N	W
32	s2	25–06	2004	Fri	01:00	HA2	Dark	Wet	804	Car	Tree		N	
33	s2	05–10	2004	Tue	18:00	NI5	Dusk	Wet	307	Unknown	Car	Pole	S	S
34	s2	28–05	2006	Sat	05:15	HA2	Dark	Wet	201	M/cyc	nk		N	S
35	sX	27–10	2004	Wed	17:30	NI5	Day	Wet	301	Car	Car		S	S
36	sX	15–03	2005	Tue	20:30	NI5	Dark	Dry	201	Car	Car	Car	S	N,S
37	s3	28–02	2003	Fri	09:30	INT4	Day	Wet	201	Truck	Car	Car	S	N,S
38	s4	03–10	2003	Fri	01:20	NI5	Dark	Wet	801	Car			SE	
39	s4	04–12	2005	Sun	18:10	HA2	Day	Dry	803	Car	Car	Gdrail	S	N
40	sY	09–06	2004	Wed	13:30	NT5	Day	Wet	201	Car	Car	Car	SE	N,S
41	s5	02–02	2005	Wed	10:45	NI5	Day	Wet	202	Car	Car		nk	nk
42	s5	08–06	2005	Wed	16:20	HA2	Day	Dry	003	Car	Ped		S	
43	s5	25–04	2006	Mon	22:30	INT4	Dark	Dry	303	Car	Car		S	S

Notes:

- *Road location: see the plan; i = intersection, s = between intersections*
- *DCA code: see Figure 3.1*
- *Object: (vehicle, person or object) number relates to direction number; nk = not known*
- *Direction: the direction the vehicle or person was travelling in when the collision occurred (and before making any turn involved in the collision).*

Figure D 2: Case study route plan showing road section and intersection numbers



D.2.1 Data discrepancies

The information in Table D 1 and Table D 2 is a direct tabulation of the state crash record information. Note that some of the information requires interpretation:

- Direction 1 and 2 are the direction the vehicle was travelling in. Some directions are recorded as SE (south-east) while others are S (south). By looking at the plan of the road, common-sense shows these are the same direction. However, crash number 15 has a direction SW. This appears to be wrongly recorded at the site (i.e. it is the direction after a turn was commenced, rather than before). It should be coded S.
- For one crash, the direction of travel is not known. This crash cannot be included in the collision diagram unless the original police report form is obtained (and even then it may not be possible).
- Crashes no. 35, 36 and 40 were coded not using adjacent intersection names. To determine the location, the original police report form needs to be examined.
- The plan of the road shows that there are two intersections of Smiths Road with High Street, as the old bypassed road has not had a change of name. There is also an intersection of High Street with High Street. In these circumstances, care is needed in interpreting the state crash records (e.g. look at chainage information, type of intersection control, type of crash, or obtain the police report form).

D.3 Constructing a Factor Matrix and Identifying Common Factors and Clustering of Crashes

An examination of the factor matrix applicable to the case study (Table D 3) shows that:

- A high number of off-travel-path crashes (DCA 701-5 and 801-5) occurred on a wet road.
- An unusually high number of northbound loss-of-control crashes (DCA 701-5 and 801-5) occurred on Sunday.

During construction of the factor matrix it became apparent that:

- DCA 201 (head-on) crashes principally occurred on a dry road at night or on a wet road in daylight.

D.4 Drawing a Collision Diagram and Identifying Clusters of Crash types at Locations

The collision diagram (Figure D 3) which does not show all the road features, as a separate plan (Figure D 1) has been prepared showing intersection controls, lane lines, islands, etc. and this would be included with any crash investigation report. An examination of Figure D 3 shows that:

- Off-travel-path crashes (DCA 701–705 and 801–805) and head-on crashes (DCA 201) predominate around the southern curve, principally for southbound vehicles.
- North of the signalised intersection (i.e. the northern curve) northbound vehicles are going off their travel path (DCA 701–705 and 801–805) or crossing the centreline (DCA 201).
- At the signalised intersection, there is no significant clustering by crash types, although there are some crash types which have more than one crash: off-travel-path (DCA 701–705 and 801–805), right-turn-into-oncoming-traffic (DCA 202) and rear-end-into-left-turn (DCA 302) on two approaches.
- Looking at crashes involving travel along High Street, 18 out of 34 crashes north of the creek bridge occurred in wet weather.

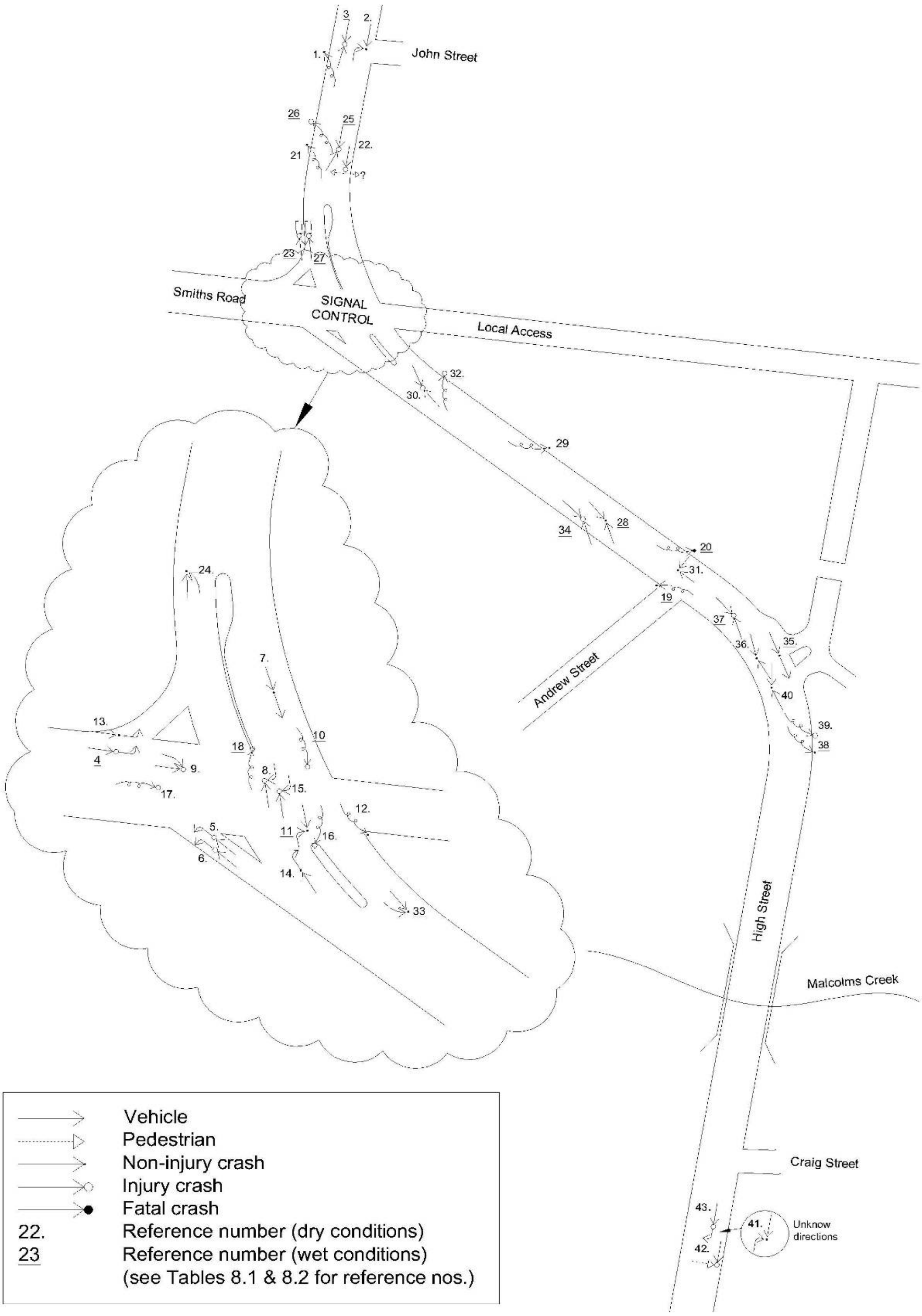
Table D 3: Case study – factor matrix

DCA code[1]	Key direction (to)	Number of crashes each year						Direction of other vehicle				Type of road users							Surface		Light condition				Day of week*			
		2002	2003	2004	2005	2006	Total	To north	To east	To south	To west	Car or similar	Van, light truck	Truck	Bus	Motorcycle	Bicycle	Pedestrian	Dry	Wet	Dawn	Daylight	Dusk	Dark	Weekday	Saturday	Sunday	Most common day
201	N	1	1	1	1	1	5		1	4		8				1			1	4		2		3	4	1		-
201	S		1	1	1		3	3				8		1					1	2		2		1	2		1	-
701 –5 and 801 –5	N	1		2	2	1	6			1		7							2	4		2	1	3	1		5	SUN
701 –5 and 801 –5	S		3	1	2	1	7	1				7				1			3	4		2		5	5	2		-
202	N		1		1		2	2				4							2			2			1		1	-
302	N	2					2	2				3			1				2			2			2			-
302	E	1			1		2		2			3		1					1	1		2			2			-
603	N			1		1	2	2				4								2		2			2			-
Totals		5	6	6	8	4	29	10	3	5		44		2	1	2			12	17		16	1	12	19	3	7	

[1] Dominant crash type first – based on DCAs from Figure 3.1

Note: A copy of an example blank factor matrix form can be found in Appendix B. The last columns of this blank form can be used for a variety of factors that might influence safety at the location being assessed, including issues such as time of day, day of week, severity etc. In this case, day of week was selected as a relevant factor, but for other situations, different variables may be more appropriate.

Figure D 3: Case study collision diagram



D.5 Summarising the Factors Identified from the Crash Listings, Factor Matrix and Collision Diagram

D.5.1 Intersections

John Street

Of the three crashes, one was in the wet. The other two involve northbound vehicles.

Smiths Road

There were 15 crashes recorded. Factors include:

- nine crashes in the daytime
- eleven crashes in dry conditions
- six involved southbound vehicles in the first instance, five northbound and four eastbound
- five were off-travel-path, three involved right-turn-into-oncoming-traffic (mix of directions), four were rear-end-left-turn (two at each of the slip lanes).

The predominant factors were southbound traffic, left turn slip lanes and loss of control.

Andrew Street

There were two crashes, both in the dark and in wet conditions. Both were off-travel-path type, rather than involving intersection conflicts, so they have been included in consideration of the reverse curve section between Smiths Road and Craig Street (see below).

D.5.2 Road sections

John Street to Smiths Road

There have been seven crashes. Common factors include:

- six crashes in the daytime
- five crashes in wet conditions
- six involved northbound vehicles in the first instance
- one head-on, one side-swipe, one pedestrian, two off-travel-path and two struck a stopped vehicle (crash or broken down) mid-block.

The predominant factors are northbound traffic, wet road surface, parking and not keeping in one lane.

Smiths Road to Craig Street

There have been 15 crashes. Common factors include:

- seven crashes in the daytime, seven in the dark and one at dusk
- eleven crashes in wet conditions
- nine involved southbound vehicles in the first instance and six northbound
- six involved loss of control and off-the-carriageway and six were head-on. There were only three other crashes: a side-swipe, a rear-end and a driveway crash.

The predominant factors are wet conditions, head-on crashes and vehicles leaving the carriageway.

Craig Street to Peter Street

There have been three crashes. Common factors include:

- two crashes in the daytime
- two crashes in dry conditions
- two involved southbound vehicles in the first instance (the third one is unknown).

There is no common crash pattern; the predominant factor is southbound vehicles.

D.5.3 **Summary of factors**

Common factors include:

- A high number of off-path crashes (DCA 701–5 and 801–5) occurred on a wet road.
- An unusually high number of northbound off-travel-path crashes (DCA 701–5 and 801–5) occurred on Sunday.
- DCA 201 (head-on) crashes principally occurred on a dry road at night or on a wet road in daylight.
- Off-path crashes (DCA 701–705 and 801–805) and head-on crashes (DCA 201) predominate around the southern curve, principally for southbound vehicles.
- North of the signalised intersection (i.e. the northern curve) northbound vehicles are losing control or running off the carriageway (DCA 701–705 and 801–805) or crossing the centreline (DCA 201).
- At the signalised intersection, there is no significant clustering of crash types, although there are some crash types which have more than one crash: off travel path (DCA 701–705 and 801–805), right turn into oncoming traffic (DCA 202) and rear end into left turn (DCA 302) on two approaches.
- 18 out of 34 crashes involving travel along High Street north of the creek bridge occurred in wet weather.

Armed with this summary (in a preliminary report), the crash listing, the factor matrix and the collision diagram, the crash investigation team can now inspect the site. An example of a preliminary report for a different site (produced prior to a site inspection) can be found in Appendix C.3

D.6 **Inspecting the Site**

An inspection of the case study site in daylight and at night-time resulted in the following observations:

D.6.1 **Observations from driving the site**

- There are two substandard curves, with inadequate warning and delineation.
- Trees obscure sections of the curving alignment in both directions. Trees obscure traffic signals and warning signs southbound as shown in Figure D 4.

Figure D 4: Vegetation obstructing signal on the southbound approach curve

- There is poor alignment of traffic lanes in both directions on the north curve.
  - Northbound, the alignment on the south approach to Smiths Road runs traffic in the left lane into the right lane on the departure side and runs traffic in the right lane into the median on the departure.
  - Southbound, the curve begins tight, slackens through Smiths Road, then tightens again. On the departure from Smiths Road, the left kerb at the end of the bus bay is aligned so that it protrudes into the left lane travel path: it is at the tight part of the curve and it has been struck often. The bus bay is partly on the left hand curve, so there is poor kerb definition around the curve.
- There is very poor visibility between traffic on the north approach and traffic activity within the eastern half of the Smiths Road intersection (e.g. signal displays, pedestrians on the road).
- The alignment through the south curve is uniform, but tight (advisory 50 km/h).
  - Northbound, the curve warning sign is small and too close to the curve. There is no delineation around the curve. The RRPMs on the centreline are not picked up by headlights due to the tight left curve and the orientation of the RRPMs.
  - Southbound, the single curve warning sign on the left is too close to the curve (and is the first curve warning southbound). Driver attention is focused on the tight curve and the warning sign may be missed. The outer kerb alignment is interrupted by the left turn deceleration lane into the closed section of High Street. There are two CAMs (chevron alignment markers) on the outside of the curve. They are too few, too small and they are too low down (lost in the foliage). The guardrail south of the curve is close to the kerb, making the left lane seem narrow.

D.6.2 Observations from inspecting the site on foot

The Smiths Road intersection and north curve

- Northbound, there is no warning of the curve and delineation consists of the lane line, RRPMs and kerbs. On the approach a (worn out) crossroad warning sign gives misleading information. The left turn lane into Smiths Road runs in a direct alignment off the left kerb. Staying on High Street requires a right curving movement.
- Southbound, there is no warning of the curve, the signals or the intersection. There is a severe visibility problem on the north approach. In the left lane in particular, there is insufficient sight distance to the east part of the intersection, because the road curves left and the properties on the left (east) side block the view. In addition, the street tree outside the second house from the corner petrol station obscures visibility to the signals. A pedestrian considering crossing High Street from the north-east corner of the intersection has only about 50 m (three seconds of travel) sight distance to any southbound traffic. This is grossly inadequate for safety. The wattles on the south-east corner block visibility to the first curve warning sign. They hang out over the road.
- Other pedestrian issues: there are no pram crossings across Smiths Road on the west side of the intersection; the pram crossing on the north-east corner (for crossing Smiths Road) is too far around the corner to expect left turning motorists to give way; on the south-west corner, the pram crossings do not line up for the shortest crossing distance over the slip lane, and a redundant pram crossing encourages pedestrians to cross Smiths Road to the west of the intersection.
- On the eastbound approach, a street tree completely blocks visibility to the primary signal lanterns.

The south curve

- There is no lane widening on the curve. The lane widths are minimum for a straight road, but inadequate for a curve (12.2 m between lips of channel, for four lanes). Larger vehicles are unable to stay within a single lane and the road is undivided.
- There is longitudinal grooving around the south curve.
- Northbound, the curve warning sign (too close to the curve) is the minimum size and its reflectorisation is poor. A large wattle in the parkland on the west side obscures the alignment of the road. A large gum tree beyond it also partly obscures the alignment.
- Southbound, many vehicles were observed cutting the curve and driving outside their lane as shown in Figure D 5. The two CAMs on the outside of the curve have Class II reflective sheeting instead of Class 1. They start too late and end too soon (they do not provide worthwhile curve delineation).
- There is W-beam guard fence on the outside (east side) of the curve, to restrain errant southbound vehicles. This guard fence is a hazard, for example, it has been struck several times (not repaired), starts too far around the curve, has no spacer blocks, and is too close to the kerb; its northern end treatment is rigid and is located part way around the curve where it can be struck by an errant vehicle; beside the end treatment there is an unprotected rigid wooden electricity pole; the south end treatment is rigid.

Figure D 5: Inadequate lane width for southbound traffic on the south curve

Other observations

- There are rigid electricity poles close to the carriageway on the splitter island on the south-west corner of Smiths Road (on the outside of the curve, northbound) and on the east side of the road, just north of the south curve.
- There is no separate right turn lane for traffic from the south at Smiths Road, despite this being the only entry from the south to the golf club car parking. It is on a curve and is likely to increase the risk of rear-end crashes. The northbound slip lane enters Smiths Road at an angle of 40º, which encourages speed.
- The eastbound slip lane in Smiths Road has its Give Way sign too high and the repeater sign on the left is too far around (after the petrol station driveway). The holding line position results in a conflict between left turners and any northbound vehicle in High Street which is travelling into the petrol station.
- Some sections of High Street appear to have a polished surface.

D.6.3 **Observed driver behaviour**

- Southbound through the south curve, trucks and buses could not keep within the lane width. Numerous smaller vehicles were observed cutting the curve and not keeping in their lanes.
- Northbound through the signalised intersection, some drivers in the left lane drifted across into the right lane, due to the poor alignment of the lane markings.
- In the left turn slip lane from south to west, some drivers used excessive speed and had to brake quickly when a conflicting car appeared.

D.6.4 Confirm speed limit

The appropriateness of the prevailing speed limit needs to be considered (refer to *Guide to Road Safety Part 3: Safe Speed* (Austroads 2021b) and local guidance). If required, a full assessment should be undertaken to determine the appropriate speed limit.

D.6.5 Discussion

Some of the observed safety deficiencies at the site appear not to be a contributing cause in any of the reported crashes. For example:

- There is very poor visibility north up High Street for a pedestrian standing on the north-east corner at Smiths Road.
- A street tree on the west approach in Smiths Road blocks visibility to the primary signal lanterns.

For the crash investigator, how should these other safety hazards be dealt with? The answer is that this requires road safety engineering judgement. If the problem really is potentially serious (as the above two examples are), then it should be included in the list of problems and remedial treatments. Bear in mind that this may be the only time that safety problems at this location are thoroughly investigated. And it may well be that low cost, yet effective, treatments can be included (e.g. signs or removal of a tree). They could be included in the report as other safety problems warranting treatment.

D.7 Selecting the Countermeasures

The reported crashes typically provide the best information about the main problems to be solved. The site inspection provided insights into possible causes of some crashes. Another aspect of the problem is user behaviour issues noted on-site. Some of this behaviour (e.g. crossing the centreline on curves) is likely to be a factor in reported crashes (e.g. head-on crashes). The task now is to deal with those physical features of the road which are leading to crashes or to potentially unsafe behaviour. Firstly, it is apparent that there is no pattern to the three crashes south of Craig Street and these will not be considered further here.

D.7.1 Loss of control and head-on crashes

The reverse curves are substandard and vary in safe driving speed. One factor in the high number of loss of control crashes and head-on crashes is that people are driving too fast for the conditions or are misjudging the alignment. The south curve is tighter than the north curve. Possible solutions include:

- provide warning which is large enough and early enough
- install duplicate reverse curve signs on both approaches and repeater curve signs half way
- review the speed limit
- delineate both curves using chevron alignment markers (CAMs) (one curve has substandard CAMs)
- improve lane lining and delineation of lines (RRPMs)
- align RRPMs so headlights pick them up in time.

Of the 34 mid-block crashes, 18 occurred in wet weather, suggesting that the skid resistance of the road surface required investigation, possibly testing. Eight of the 13 loss-of-control crashes occurred at night. The lighting appeared adequate and the pattern of lanterns was not misleading. It is recommended that reliance be placed on warning and delineation improvements (outlined above).

The lanes are only 3.05 m wide (adequate on a straight urban road), but are not widened on the curves. Large vehicles are unable to stay in their lane. If drivers make errors, there is no room for correction within a lane. Over most of the length the road is undivided and vehicles cross the centreline. Widen the lanes on the curves and physically separate opposing traffic.

Through Smiths Road (the north curve), there is poor alignment in both directions. Realign the lane lines and edgelines (include RRPMs) in both directions, to provide smooth alignments.

Trees block visibility to signs (southbound) and the general alignment (both directions) for the south curve. Remove or prune trees regularly to restore adequate visibility.

D.7.2 **Fixed object crashes**

Cars have run into parked vehicles, northbound, north of Smiths Road. Install permanent no stopping restrictions on the west side, north from Smiths Road.

Trees and poles on the east side, south of Smiths Road have been hit in three crashes. The trees block visibility to the alignment and signs. Two poles are very close to the roadway. Remove the trees and relocate the poles back from the kerb.

Two vehicles have struck the guard fence, on the east side at the south curve. The inspection showed the guard fence to have several hazardous aspects and was not shielding an electricity pole where it started. It was too close to the narrow lanes. Reconstruct the guard fence to current standards and shield the pole (note that this particular pole has not been struck, but hit-pole crashes have occurred through this section).

Signals have been struck at the Smiths Road intersection. Countermeasures (above) to improve the road surface, delineation and lane alignment should address this problem.

D.7.3 **Other intersection crashes**

On the north approach to Smiths Road, there has only been one rear-end crash and one out-of-control-on-carriageway crash, but the site inspection identified a severe visibility obstruction to the traffic signals and pedestrians, caused by trees in the properties on the east side and by a street tree. Remove one street tree before the curve and two between there and the signals. Take steps to widen the road reservation to achieve adequate visibility (possible medium term project).

The four rear-end left-turn crashes at the two left-turn slip lanes are likely to be caused by the alignment which permits high speed turns and results in last minute braking. Reshape the slip lanes to a 70–90º intersection angle with the road they enter.

The two right-turn-into-oncoming-traffic crashes on the north approach may have involved visibility being blocked by an oncoming right turner (there is no oncoming right-turn lane). On the south approach there was a rear-end right-turn crash. Construct a separate right-turn lane on the south approach.

D.7.4 **Other issues**

The site inspection identified other matters which need to be addressed, especially where they have a high potential for injury crashes or they are cheap to solve.

On the west approach in Smiths Road, a street tree close to the intersection blocks the primary signal lanterns. Remove the tree.

Access to the golf club is difficult from the south and requires vehicles to U-turn at the signals where there is no separate right turn lane. Include alternatives in the design.

In the next section a design will be prepared, incorporating the countermeasures proposed here.

D.8 Designing a Safe Remedial Treatment

The individual countermeasures need to be incorporated into a safe remedial treatment. They should not cause any new problems in the way they are added to the existing layout.

In this case, two options will be developed, because the option of widening the road to provide physical separation of opposing traffic and wider lanes is relatively expensive (Figure D 7). Thus, an option involving works generally within existing kerbs has been developed as a short-term option which can be implemented quicker, but which will have an impact on road capacity (Figure D 6).

In the lower cost option, the separation of traffic has been achieved by reducing northbound traffic to one lane. This could be done in both directions, but there can be increased crash costs with merging traffic to one lane on an urban road with residential driveways. The designers considered it difficult to find a safe location for a southbound merge.

Both options include a northbound right turn lane to the golf club and clubhouse. As soon as the designs commenced it became obvious that this access was a real problem. The previous road closure in old High Street (to protect local residents from clubhouse traffic) severely limits options for low cost safe access to the clubhouse. This emphasises the importance of taking a broad road safety view of proposals like road closures and developments adjacent to arterial roads – and of having the proposals road safety audited.

Both options retain the traffic signals at Smiths Road. An alternative could be a roundabout, involving road widening on the south-west corner. The need for pedestrian signals would need to be investigated in association with a roundabout.

Both options ban right turns into Andrew Street. Although there have been no reported crashes involving this turn, the designers consider the risk may increase. Safer alternative access is available via Smiths Road.

The new preliminary designs will need to be road safety audited, to ensure they are safe and do not introduce any new safety problems.

Figure D 6: Lower cost case study treatment option (drawing not to scale)

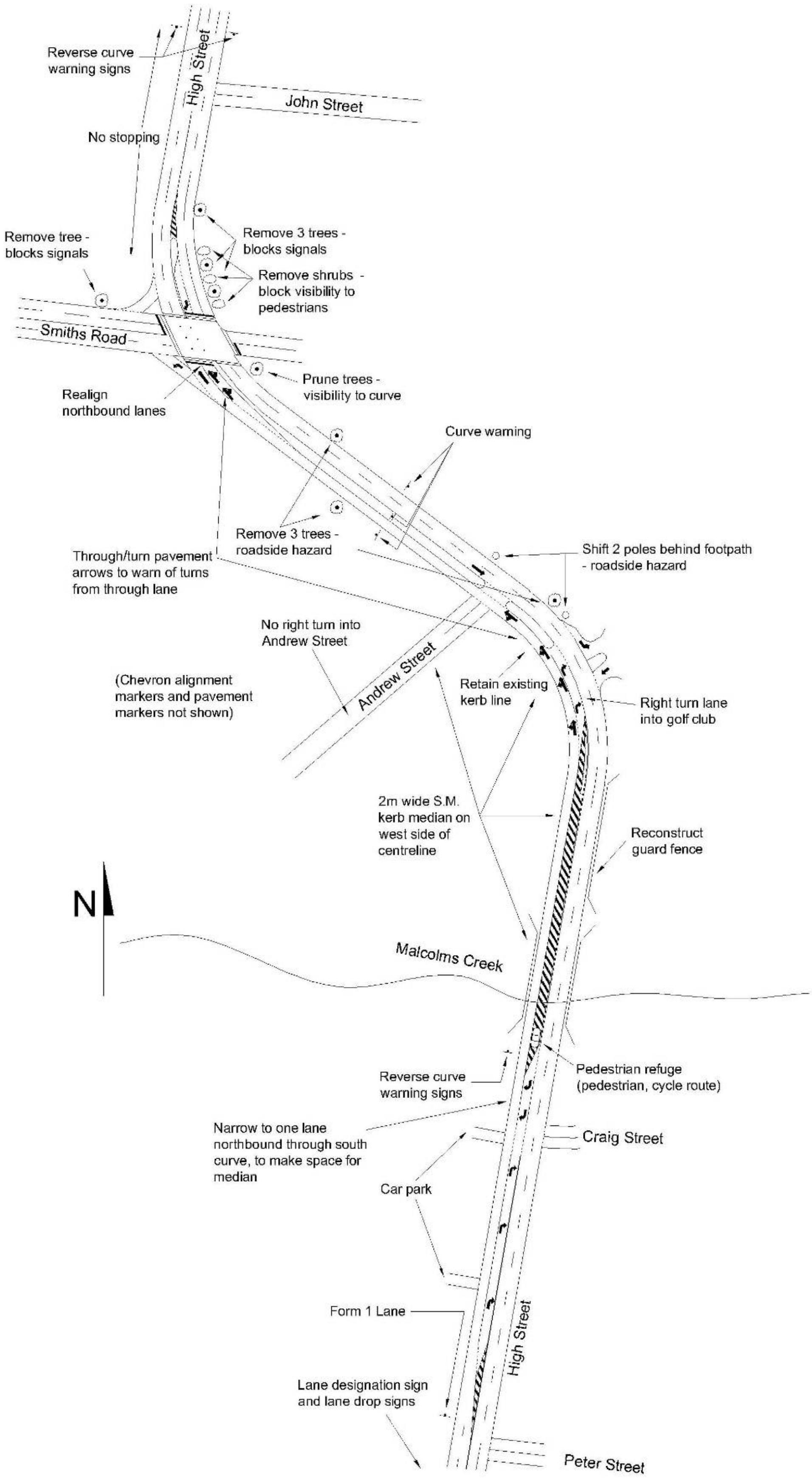
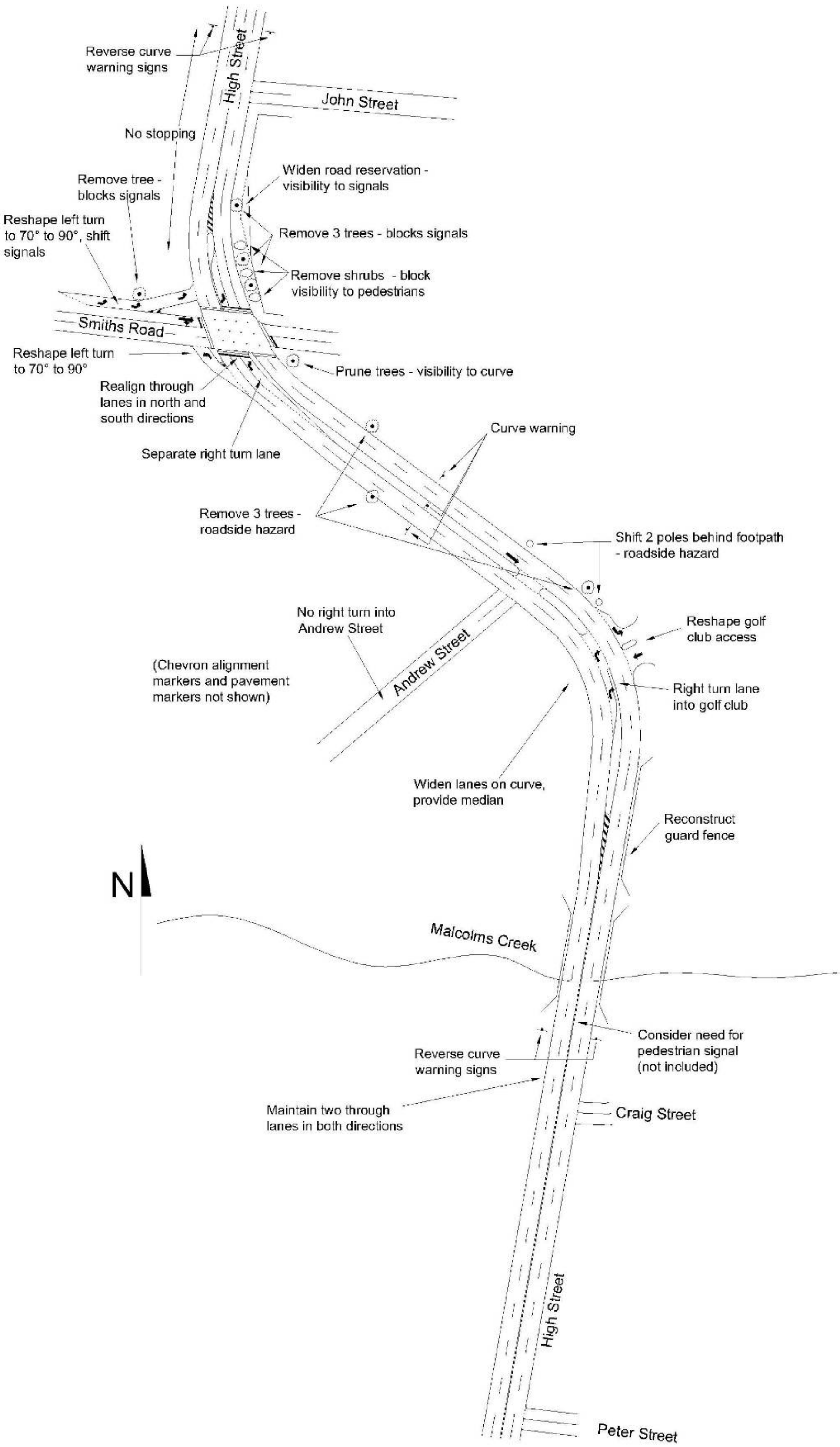


Figure D 7: Higher cost case study treatment option (drawing not to scale)



D.9 Economic Appraisal

The options in Figure D 6 and Figure D 7 involve the implementation costs shown in Table D 4, estimated by the road agency's designers. Note that these costs are provided for the purpose of this case study only. Estimated costs of treatments should be obtained from the relevant jurisdiction.

Table D 4: Implementation costs for the case study options (A$)

Item	Cost option (lower cost) $	Cost option (higher cost) $
Curve warning signs (8). Reverse curve on approaches and single curve in between	2 500	2 500
Chevron alignment markers (CAMs) (14) – both directions on both curves	3 500	3 500
Replace/realign RRPMs	1 500	1 500
Re-surface the road to restore appropriate level of skid resistance	150 000	150 000
Physically separate opposing traffic with a kerbed median	90 000	150 000
Widen the lanes on the south curve	–	350 000
Realign the lane lines and edgelines at Smiths Rd (with RRPMs) in north or both directions, to provide smooth alignments	1 000 (to north)	1 500 (both ways)
Tree removal: 3 south of John Street; 1 west approach in Smiths Rd.; 3 south of Smiths Rd.; prune 4 others	5 000	5 000
No Stopping restrictions on the west side, north from Smiths Road	500	500
Relocate two poles back from the kerb, east side between the curves	25 000	25 000
Reconstruct the guard fence	35 000	35 000
Widen the road reservation to achieve adequate visibility, east side north of Smiths Rd	–	120 000
Reshape the two slip lanes to 70–90 degree intersection angle with the road they enter	–	40 000
Construct a separate right turn lane on the south approach to Smiths Rd; realign lanes	–	55 000
Total	**314 000**	**939 500**

The expected crash reductions for the two options in Figure D 6 and Figure D 7 are set out in Table D 5. It should be noted that:

- The case study site is in Queensland, so that the values in Table 6.4 apply.
- The crash costs in Table 6.4 already include factoring for severity; thus, the severity is not separately considered at this stage; it is just the number of crashes for the different crash types.
- The crashes south of Craig Street are not included, as the scheme is not likely to address the causes of those crashes.
- It is assumed that a DCA 603 crash has the same costs as a DCA 601 crash in Table 6.4.
- It is expected that the northbound merge in Option 1 (Figure D 6) will result in an increase in crashes at that location, though of a lower severity than those occurring on the curves.

Table D 5: Annual crash reduction savings for the case study options (A$)

Crash type (see Table 5.4)	$ Cost/ crash (metro)	No. of crashes per year	Likely crash reduction (–) or increase (+)			
			Option 1 (lower cost)		Option 2 (higher cost)	
			%	$/year	%	$/year
001–003	164 600	0.2	–30	–9 900	–30	–9 900
703–704	116 200	1.2	–20	–27 900	–40	–55 800
705	84 400	0.4	–20	–6 750	–20	–6 750
801–802	102 700	0.2	–10	–2 050	–20	–4 100
803–804	137 600	1.0	–20	–27 500	–40	–55 000
201	178 300	1.6	–90	–256 750	–90	–256 750
202–206	77 300	0.8	–30	–18 550	–30	–18 550
301–303	38 800	1.4	–10	–5 450	–40	–21 750
305–307 • existing • new northbound merge	 60 600 60 600	 0.4 0.5 say	 –20 +100	 –4 850 +30 300	 –40 0	 –9 700 0
308–309	54 200	0.2	0	0	0	0
407	54 900	0.2	–20	–2 200	–20	–2 200
601 (603)	55 000	0.4	–50	–11 000	–50	–11 000
Total				–342 600		–451 500

With the construction costs and crash reduction benefits estimated, an economic appraisal can be made. The objectives in this appraisal are to:

- decide whether the proposed treatment options are beneficial (benefits are greater than costs)
- establish the value of the benefits
- decide which one of the options gives the greater benefits.

It has been assumed that the traffic volumes remain the same over the appraisal period. The lower cost option involves a reduction in northbound traffic capacity. At this stage it has been calculated (by separate calculations not included here) that there will not be any significant delays (i.e. costs) associated with this capacity reduction. If congestion was to occur, an assessment of treatment options should take this into account.

Also note that these two options are not the only options. As the crash reduction benefits of the separate elements of each option can be estimated, some parts of the treatment could be deleted (or added) and the effect on crashes recalculated. However, this can only be done within a process whereby sound road safety engineering judgement is applied: taking elements of a treatment out without understanding their impact on the effectiveness of other elements, can lead to wasting money on an ineffective treatment. Note also that a roundabout could be considered, to replace the signalised intersection. Its impact on pedestrian movements and access to the golf club would need to be considered.

An appraisal period of five years has been selected, as one option involves a reduction in capacity which may render it an interim treatment. Table D 6 sets out the economic appraisal.

Table D 6: Economic appraisal of case study options (A$)

Item	Option 1	Option 2
Implementation cost (Build now = present worth of costs)	$314 000	$939 500
Benefits per year	$342 600	$451 500
Appraisal period for benefits	5 years	5 years
Present worth of benefits (4% discount rate) Present worth of benefits (7% discount rate)	$1 524 600 $1 404 700	$2 009 200 $1 851 200
BCR: benefit/cost ratio (4% discount rate) BCR: benefit/cost ratio (7% discount rate)	4.9 4.5	2.1 2.0
NPV: net present value (4% discount rate) NPV: net present value (7% discount rate)	$1 210 600 $1 090 700	$1 069 700 $911 700

This appraisal shows both options would be beneficial. Both options have very similar NPVs. The lower cost option has higher BCRs. Assuming that the northbound roadway has adequate capacity, the lower cost option is regarded as having the greater benefit. A recommendation would therefore be made to include Option 1 (Figure D 6) for funding consideration within a works program.

Appendix E Crash Modification Factors

Table E 1: Crash modification factors of various countermeasures for intersection crashes

Treatment type	Description and DCA code								
	Adjacent approach 101–109	Head-on 201	Opposing turns 202–206	Rear end 301-304	Lane change 305–307	Parallel lanes-turning 308, 309	Vehicle hits ped 001–003	Loss of control, L or R turns 706, 707	Hit parked/ parking vehicle 601, 401, 402
Roundabout	0.3			1.2			0.4		
New traffic signals (no turn arrows)	0.3		1.9				0.7		
New traffic signals (with turn arrows)	0.3		0.55				0.7		
Remodel signals	0.7		0.6				0.7		
Grade separation	0.0		0.5			0.8	0.3	0.5	
Improve sight lines	0.7		0.7				0.7	0.8	
Street closure (one leg of cross-intersection)	0.5		0.5				0.5	0.9	
Street closure (close stem of T)	0.0		0.0				0.5	0.0	
High skid resistance surfacing				0.6				0.9	
Stagger cross-intersection (right-left)	0.5		0.5	1.3	1.1				
Improve/reinforce priority (e.g. add a control sign)	0.7								
Prohibit right turns			0.5			0.5		0.5	
Ban left or U-turns			Note 1	0.5		0.5		0.5	
Improve lighting							0.7		
Traffic islands on approaches		0.8	0.8	0.8				0.9	0.9

Treatment type		Description and DCA code								
		Adjacent approach 101–109	**Head-on 201**	**Opposing turns 202–206**	**Rear end 301-304**	**Lane change 305–307**	**Parallel lanes-turning 308, 309**	**Vehicle hits ped 001–003**	**Loss of control, L or R turns 706, 707**	**Hit parked/ parking vehicle 601, 401, 402**
Indented right turn island				0.7	0.6				0.8	0.8
Painted turn lane				0.8	0.8					0.8
Ban parking adjacent to intersection		0.9			0.8	0.8		0.7		0.5
Extend median through intersection		0.0	0.0	0.0				0.5		
Reduce radius on left turn slip lane					0.5					
Protected left turn lane in crossing street					0.9					
Cost per casualty crash ($'000)	Metro	173	373	180	89	135	119	234	140	174
	Rural	367	660	303	208	339	267	410	293	297

Note 1: Costs are in 2014 dollars, and are based on research conducted by Dr David Andreassen for the Australian Transport Safety Bureau in 1996. Costs have been adjusted based on CPI.

Note 1: The treatment 'banning U turns' is a relevant treatment for crash type 207, with an estimated 50% reduction [costs for 207: $142K (metro) and $257K (Rural)]. Banning left turns is a relevant treatment for crash types 203, 205 and 206 with a 50% reduction.

Table E 2: Crash modification factors of various countermeasures for non-Intersection crashes

Treatment type	Description and DCA code					
	Head-on 201	Opposing turns 202–206	Rear end 301–304	Lane change 305–307	Vehicle hits pedestrian 001–003	Hit parked/ parking vehicle 601, 401, 402
Median on existing carriageway	0.1				0.5	
Pedestrian refuge					0.55	
Pedestrian (zebra) crossing					0.6	
Kerb blisters	0.9				0.9	0.5
Pedestrian overpass					0.15	
Pedestrian signals					0.3	
Pedestrian crossing lighting					0.4	
Improved route lighting					0.7	
Clearway, parking bans			0.8		0.7	0.5
Indented right turn island		0.7	0.6			
Painted turn lanes		0.8	0.8			
Roadside hazards – remove	Note 1					
Roadside hazards – guard fence						
Wire rope safety barrier – roadside						
Wire rope safety barrier – median	0.05					
High skid resistance surfacing			0.6			
Seal shoulders	0.6					
Advisory speed signs on curves	0.7					
Delineation						
Edgelines						
Audio-tactile edgelines						

Treatment type		Description and DCA code					
		Head-on **201**	**Opposing turns** **202–206**	**Rear end** **301–304**	**Lane change** **305–307**	**Vehicle hits pedestrian** **001–003**	**Hit parked/ parking vehicle** **601, 401, 402**
Reconstruct superelevation on curve		0.5					
Climbing/overtaking lanes		0.7 Note 2			1.1		
Signs (railway level crossing)							
Flashing lights (railway level crossing)							
Barriers or gates (railway level crossing)							
Bridge or overpass (railway level crossing)							
Frangible posts, poles							
Cost per casualty crash ($'000)	Metro	373	180	89	135	234	174
	Rural	660	303	208	339	410	297

Table E 3: Crash modification factors for various countermeasures for midblock crashes

Treatment type	Description and DCA code						
	On straight			On curve			Hit train 903
	Off road 701–702	Off road, hit object 703, 704	Loss of control, on road 705	Off road 801, 802	Off road, hit object 803, 804	Loss of control on road 805	
Median on existing carriageway							
Pedestrian refuge							
Pedestrian (zebra) crossing							
Kerb blisters							
Pedestrian overpass							
Pedestrian signals							
Pedestrian crossing lighting							
Improved route lighting							
Clearway, parking bans							
Indented right turn island							
Painted turn lanes							
Roadside hazards- remove	1.8	0.2		1.8	0.2		
Roadside hazards – guard fence	0.7	0.7	1.3	0.7	0.7	1.3	
Wire rope safety barrier – roadside	0.15	0.1		0.15	0.1		
Wire rope safety barrier – median							
High skid resistance surfacing	0.9	0.9	0.9	0.9	0.0	0.9	
Seal shoulders	0.6	0.6	0.6	0.6	0.6	0.6	
Advisory speed signs on curves				0.7	0.7	0.7	
Delineation	0.85	0.85	0.85	0.85	0.85	0.85	
Edgelines	0.7	0.7		0.7	0.7		

Treatment type		Description and DCA code						
		On straight			On curve			Hit train 903
		Off road 701–702	Off road, hit object 703, 704	Loss of control, on road 705	Off road 801, 802	Off road, hit object 803, 804	Loss of control on road 805	
Audio-tactile edgelines								
Reconstruct superelevation on curve					0.5	0.5	0.5	
Climbing/overtaking lanes								
Signs (railway level crossing)								0.85
Flashing lights (railway level crossing)								0.5
Barriers or gates (railway level crossing)								0.2
Bridge or overpass (railway level crossing)								0.0
Frangible posts, poles			Note 3			Note 3		
Cost per casualty crash ($'000)	Metro	133	272	140	210	323	149	628
	Rural	261	452	293	404	503	268	928

Note 1: For this treatment removing the objects which were hit after the vehicle left the carriageway is to reduce crashes that relate to hitting objects (i.e. crash types 703–704, 803–804) but the reduction in these crashes will be matched by an increase in crash types 701–702 and 801–802, as vehicles will continue to leave the carriageway but now will not be hitting objects (all else being equal). The net benefit will be a reduction in crash severity.

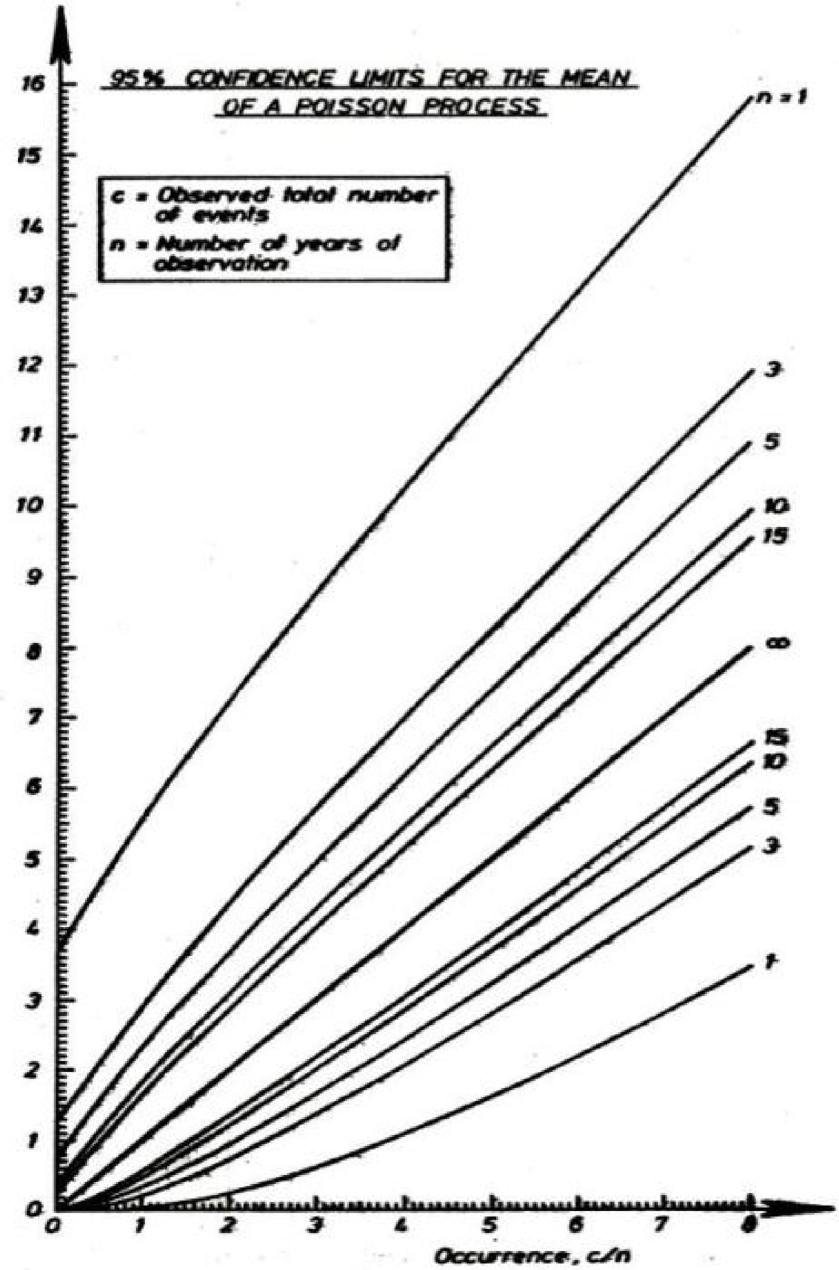
Note 2: For this treatment crash type 501 (head-on, overtaking) is also relevant (use DCA 201 cost).

Note 3: For this treatment, the number of off-road-hit-object crashes is not expected to change. However, the severity outcome of these crashes will be reduced.

Appendix F Confidence Limits and Changes in Critical Mean

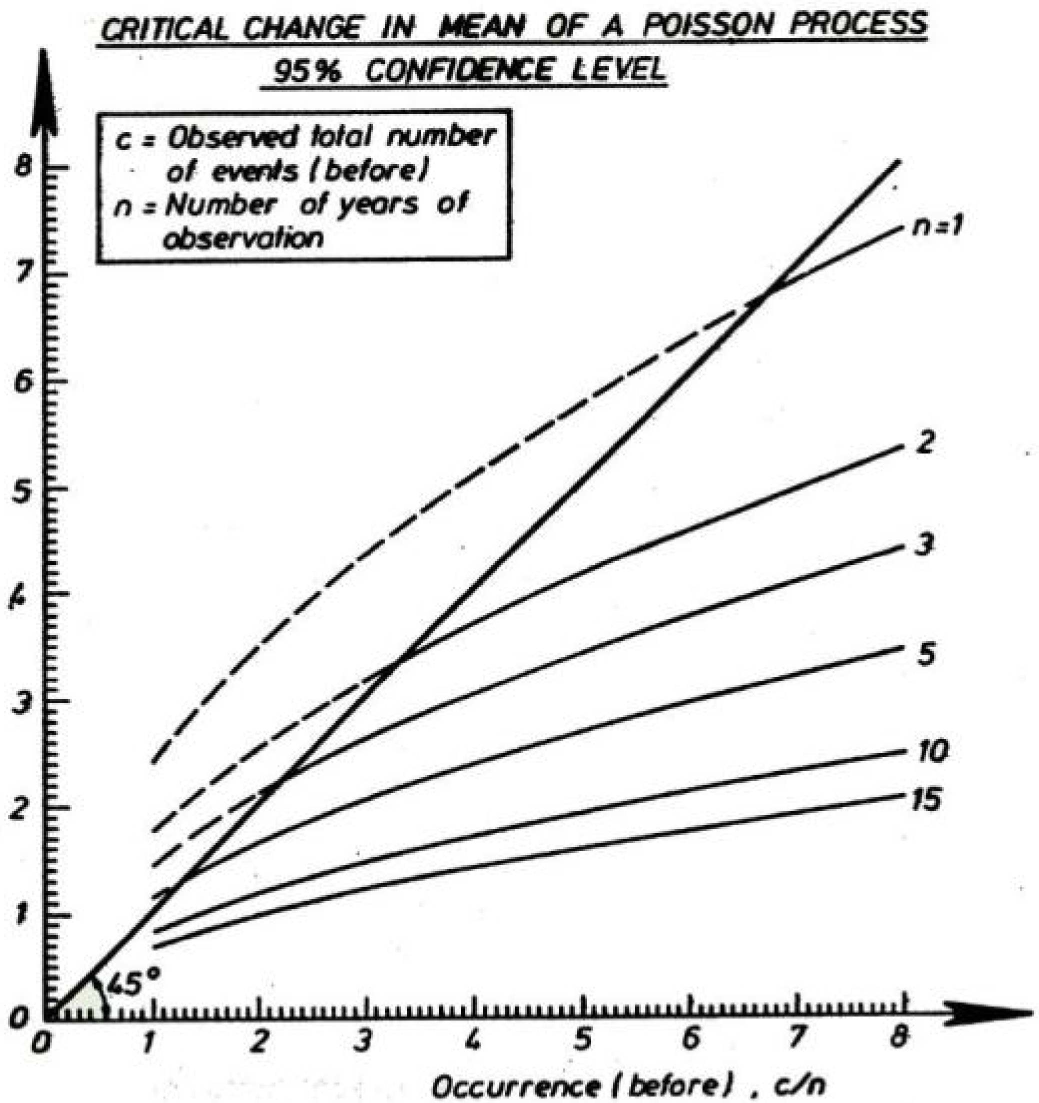
See Appendix C.2 for an illustration of how to use these graphs.

Figure F 1: 1–8 occurrences per year



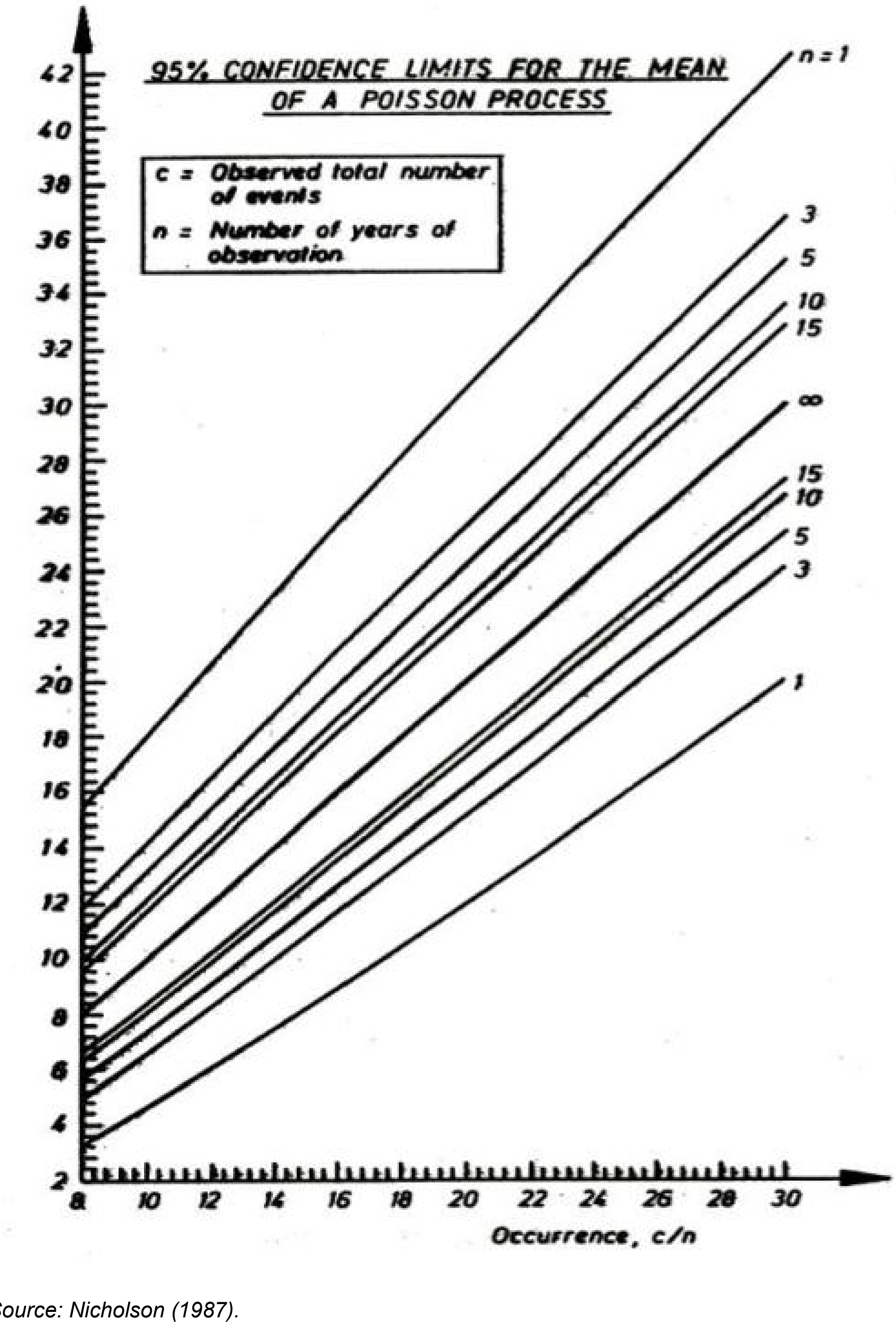
Source: Nicholson (1987).

Figure F 2: 1–8 occurrences per year



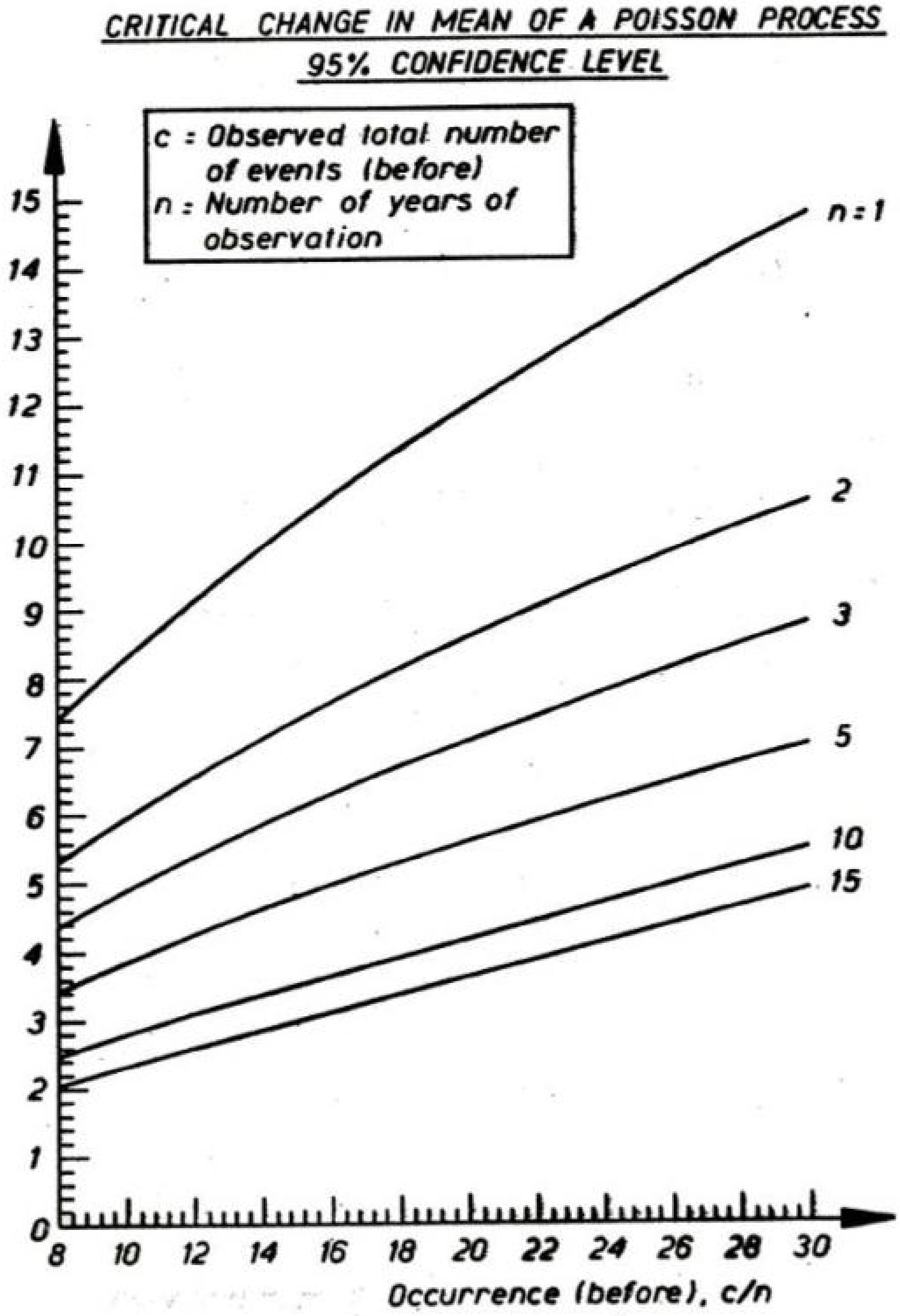
Source: Nicholson (1987).

Figure F 3: 8–30 occurrences per year (95% confidence level)



Source: Nicholson (1987).

Figure F 4: 8–30 occurrences per year (95% confidence level)



Source: Nicholson (1987).

Appendix G Monitoring Techniques and Allowing for Regression-to-the-mean

This appendix provides guidance on monitoring and evaluating safety improvement projects, and considering the effects of the regression-to-the-mean phenomenon with regard to crash rates.

G.1 Monitoring Techniques

G.1.1 Experimental design

Monitoring aims to measure what is actually happening now and, in an evaluation phase, comparing that with what is expected would happen if a treatment had not been introduced. There are several experimental design challenges in doing this, including the following:

- There may be changes in the road environment, such as a speed limit, traffic flow, abutting land uses, or traffic control (other than the safety-related change the effect of which is to be monitored). All of these are possible at a site over a three to five year time period, and virtually certain over an area or route. It is impossible to conduct a rigorous scientific study where every possible influence is controlled.
- Because crashes are rare and randomly occurring events, there will be fluctuations year by year which have nothing to do with the treatment being analysed. Data for short time periods (say one year) are therefore highly unreliable. These random year-by-year fluctuations, while not necessarily biasing the result of a monitoring exercise, introduce variability which must be accounted for in the statistical analysis. A particular problem is that of regression-to-the-mean (Appendix G.2).
- It is necessary to monitor all significant factors which could possibly affect the outcome, otherwise the outcome may be wrongly attributed to the treatment. If the variation in the treatment (e.g. a speed limit) varies systematically with another variable (e.g. design standard), it may not be possible to isolate the effects of one from the other. However, if only one is measured, it is likely that all of the change will be attributed to it.
- As a variation on the previous point, if the two variables which are systematically related are in fact both measured, then it will not be possible to reliably isolate their independent effects. This is particularly a problem if multiple linear regression techniques are used, since these require that the various independent variables are not correlated one with another.
- Statistical correlation does not necessarily imply logical correlation. For example, Haight (1981) quotes a case where the law giving pedestrians the right of way over vehicles was considerably strengthened in 1977 and the number of pedestrian deaths dropped from 365 in 1977 to 268 in 1983. However, the new law was not enforced and thus had no effect on behaviour, so the improvement in the pedestrian situation could not have been a result of the change in the law and must have been due to some other factor(s). This underlines the importance of establishing a true link between the treatment being monitored and the change in the performance measure.
- Seasonal factors must be taken into account. Some factors which may affect road safety vary in a systematic way throughout the day (e.g. natural light, street lighting) or throughout the year (rain, hours of daylight, perhaps traffic flow). The selection of factors such as control sites and before and after periods must take these variations into account. It would be incorrect to compare the summer (before) crash record with the winter (after) crash record if one was trying to assess the effect of skid-resistant pavements, for example.
- Crash reporting levels may change over time and there may be inconsistencies in the crash data which need to be considered. For example, the definitions attached to specific pieces of data (e.g. severity) may change over time, or the requirement to report crashes (e.g. property damage only crashes) may be changed. The analyst needs to be aware of these changes and correct for them, since they can severely impact upon the analysis, e.g. in before and after studies.

- There may be a long term trend in crash occurrence; changes over time in the number or rate of crashes at a site may merely reflect global trends. For this reason, it is usually necessary to use some form of control group and compare crashes at the test site with those at the control site (Section 7.2).

It is necessary to take these types of factors explicitly into account in the evaluation of the effect of a road safety treatment or program. There are four ways in which this can be done:

- controlled experimentation, in which all other factors are held constant except the factor whose effect is being investigated. This approach is rarely if ever applicable in road safety engineering because in the real world it is not possible to hold everything constant. It will not be discussed further
- before and after studies
- comparisons using control sites
- time trend comparisons. This approach is also rarely if ever applicable in road safety engineering and it will not be discussed further.

G.1.2 **Before and after studies**

This is the simplest method of monitoring and evaluation and involves comparison of the crash record at the location before and after the treatment. It is the least satisfactory method because it does not include control of extraneous factors such as those discussed above. For example, through the 1980s several countries experienced a very substantial reduction in total casualty crashes. If a treatment installed in the middle of the decade was evaluated using, say, 3–5 year before and after periods, it would quite possibly have shown a significant reduction in crashes in the after period compared with the before period. However, in reality, this may have merely reflected nationwide trends and had very little to do with the conditions at the site.

The method involves:

- determining in advance the relevant objectives (e.g. crash types intended to be affected) and the corresponding evaluation criteria (e.g. crash frequency, crash rate)
- monitoring the site or area to obtain numerical values of these criteria before the treatment and again after the treatment
- comparing the before and after results
- considering whether there are other plausible explanations for the changes, and correcting for them if possible.

It is usual in a before and after study to rely on pre-existing data for the before period. It would be very rare that implementation was delayed so that adequate before data for a location could be collected. This underlines the need for systematic, ongoing data collection, so that the effect of changes in the system can be monitored routinely.

It is important to distinguish crashes by type and perhaps by time of day (e.g. when considering a lighting scheme) or by weather conditions (e.g. when considering a skid resistant pavement treatment), etc. It is often helpful to prepare collision diagrams for the site or area before and after the treatment, as there may be new or relocated crash patterns evident. If sample surveys are undertaken (e.g. to obtain a measure of traffic flow or turning volumes), the observation period should ideally cover several days to gain a representative sample.

The statistical analysis of the data should be carefully undertaken, having regard to the accuracy of the data. It will often be helpful to consider more than just the change in crashes expressed, say, as annual average crash frequency of the particular crash type. It may also be useful to consider changes in the 85 percentile values, the variance, skew, etc.

Monitoring of the location should commence immediately after implementation (to detect any unexpected crash or operational problems). For before and after comparisons to be statistically valid, a reasonable period of time must elapse to enable a sufficiently large sample to be obtained (Ogden 1996, p.463). Three years is generally regarded as a reasonable period for trends to be established and a large enough data set to be obtained. Nicholson (1987) has recommended five years from the viewpoint of statistical confidence.

Using this simple before and after comparison without taking account of trends or external changes is not recommended as it is likely to lead to erroneous conclusions (Section 7.2).

G.1.3 **Comparisons using control sites**

This major drawback with the simple before and after approach can be overcome through the use of control sites. There are two variations of this method, the first using control groups which are randomly determined, and the second using selected comparison groups (Council et al. 1980).

Randomly determined control groups

This method involves a controlled experiment, whereby several candidate sites for a particular treatment are identified in advance. They are then randomly split into two groups. All sites in the first group are treated, while no sites in the second group are treated. The two groups do not have to be of equal size, but must satisfy sample size requirements (Ogden 1996, p.463). It is important to make the control and treatment groups equal on all factors (except the treatment).

This method has considerable power as an investigation tool but it is of limited validity for most applications faced by road safety engineers because there will rarely be the opportunity to conduct a controlled experiment of this nature.

Selected comparison groups (an enhanced before and after method)

This method is of more relevance in road safety engineering. It involves a before and after study as discussed in the previous section but the results for the before and after periods at the treated location are compared with the results at control sites. The process involves:

- determining in advance the relevant objectives (e.g. crash types intended to be affected) and the corresponding evaluation criteria (e.g. crash frequency, crash rate)
- identifying a control site or (preferably) a set of control sites where no remedial works have been or are intended to be introduced
- monitoring both the treated site and the control site(s) to obtain numerical values of these criteria before the treatment and again after the treatment
- comparing the before and after results at both the treated and control sites
- considering whether there are other plausible explanations for the changes, and correcting for them if possible.

Selection of the control sites is of key importance. Ideally they would be randomly selected. However, this is rarely possible unless a large number of control sites can be identified and a random selection made from these (Andreassen 1989, p.34). The control sites should satisfy the following criteria (Benekohal & Hashmi 1992; Council et al. 1980; Institution of Highways and Transportation 1990; Ward & Allsop 1982). These should:

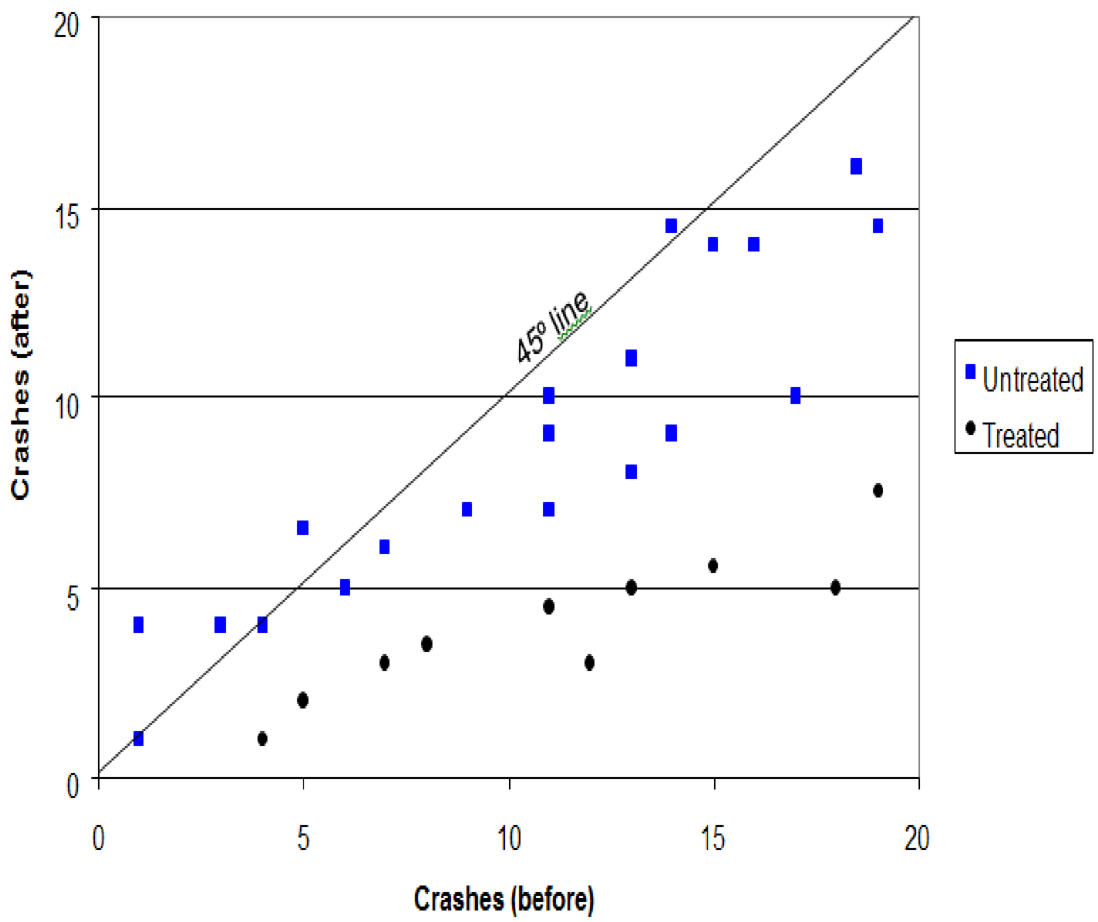
- be similar to the treated sites in general characteristics (e.g. network configuration, geometric standard, land use, socio-economic characteristics, enforcement practices, etc.)
- have the same or similar traffic flows

- not be affected by the treatment at the test site
- be geographically close (however, be aware that using adjacent or nearby sites as control sites leads to bias in the evaluation results (Maher 1987))
- not be treated in any way themselves for the period of the before and after study
- have crash records and other data (if applicable) which are consistent in both collection criteria and coding covering the period of the study.

The before and after periods for both the treated location and the control sites must be the same (although it is not necessary that the common before period be the same as the common after period).

In addition to the statistical analysis, a graphical presentation of treated and control sites (as shown in Figure G 1) can be helpful.

Figure G 1: Comparison of crash data at treated and control sites



Source: Adapted from County Surveyors' Society (1991).

If there was no change in the number of crashes (or whatever criterion might be used) between the before and after periods, all points would lie on a 45 degree line passing through the origin. The extent to which there is a change in crashes in the after period is indicated by the departure from the 45 degree line. If there is a noticeable tendency for points representing the treated locations to be well below the 45 degree line compared with the control sites, the treatments are having a positive effect.

G.2 Regression-to-the-mean

Over a period of years, if there are no changes in the physical or traffic characteristics at a site, crashes at that site per unit of time (e.g. annually) will tend to fluctuate (due to the random nature of crash occurrence) about a mean value. Because sites are commonly selected for treatment on the basis of their ranking in the numbers of crashes compared with all other sites, there is a high possibility that sites will be chosen when their crash count is higher than the long term average.

Wright and Boyle (1987) assert that regression-to-the-mean can overstate the beneficial effect of a treatment by 5 to 30%. To the extent that knowledge about the safety effects of treatments is built up from the results of these sorts of studies, there is (unless corrected for) a tendency to overstate the effectiveness of road and traffic engineering treatments. This is sometimes called ‘bias by selection’ (Hauer 1980). There is a responsibility for the analyst to separate the real gains from the treatment from the changes due to regression-to-the-mean.

The problem can be substantially minimised by increasing the number of years of data used in the site selection process (Nicholson 1987). However, this does not solve the problem entirely, nor is it always expedient to wait for several years before conducting an evaluation exercise.

To correct for regression-to-the-mean, the essence of the task is to attempt to estimate the true underlying crash rate. One approach is described below. It involves adjusting the data to correct for biases, using assumptions about the statistical distribution of crashes year by year (Abbess, Jarrett & Wright 1981).

Crash data must be assembled for all sites similar to the site under study, for the same time period. Then, using the full data base, the mean number of crashes *a* and the variance of crashes *var (a)* is calculated. The regression-to-the-mean effect, R (in per cent), is then given by Equation A1:

$$\mathrm{R} = \left[\frac{\mathrm{n}(\mathrm{S_o} + \mathrm{S})}{\mathrm{S}(\mathrm{n_o} + \mathrm{n})} - 1\right] \times 100 \qquad \text{A1}$$

where

S = the number of crashes observed at the site during a period of n years,

S_o = a^2 / (var(a) - a)

n_o = a / (var(a) - a)

S_o and n_o are the estimates of the parameters of the statistical distribution showing the underlying true crash rates, i.e. the probability distribution of the crash rate before any data become available. This assumes that a site with a given crash history should behave in the same way as the set of all similar sites with the same crash history.

Prolonging the before and after periods will decrease the regression-to-the-mean effect, but not remove it altogether (Nicholson 1988). On the other hand, these longer periods enlarge the influence of general trends in crashes on the results of a study (Elvik 1997).

G.2.1 A worked example of correction for regression-to-the-mean (from Ogden 1996, p 458)

Suppose there is a site where there have been 90 crashes over the previous five years (an average of 18 crashes per year). The site has been treated, and in the following period, it has shown an average of 14 crashes per year.

To correct for regression-to-the-mean, data is needed for sites which are, as far as possible, similar to the site under study. Data for these sites is used to estimate the parameters of the statistical distribution of crashes at the test site.

Suppose that over the previous five years, the number of crashes at the comparison sites had been 15, 15, 16, 17 and 19 crashes per year. This produces a mean (a) of 16.4 crashes per year and a variance var (a) of 2.80.

Thus, the values for entry in the above equations are:

- $n = 5$ (years)
- $S = 90$ (crashes)
- $S_o = –19.78$
- $n_o = –1.21$.

This gives a value for R of 0.09. That is, it would be expected that in the after period, crashes at the test site, even if nothing was done, would reduce by 9%, i.e. to 16.38 per year. It is this value of 16.38 which must then be compared with the actual after performance of 14 crashes per year to determine whether there has been a significant change in the crash frequency.

From Figure F 4 in Appendix F, it can be seen that with c/n = 16.38 and n = 5, the critical change in the mean is 5.0, i.e. any number of crashes up to five above or five below the observed mean of 16.38 would be regarded as not occurring by chance. The occurrence of 14 crashes (i.e. 2.38 fewer on average) per year after is thus very likely to be the result of chance, rather than due to the treatment.

Austroads' **Guide to Road Safety Part 2: Safe Roads** is designed to help practitioners minimise the risk of road crashes including run-off-road, intersection and head-on crashes and to implement countermeasures to achieve a safe road system.

Guide to Road Safety Part 2

Austroads

Austroads is the association of Australasian transport agencies.

austroads.com.au