Towards Safe System Infrastructure: A Compendium of Current Knowledge

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Abstract

This report provides a compendium of knowledge on Safe System treatments and identifies real world experience in the practical application of solutions that can mitigate crash severity.

The Safe System is internationally regarded as the best practice approach to road safety. Although Australia and New Zealand have been early adopters of the approach since 2004, there has generally been a lack of clarity amongst practitioners on how best to integrate the approach into their daily activities.

Assessment frameworks and tools are also now emerging that allow the alignment with Safe System be better quantified. A hierarchy of treatments is described that provide practitioners with a basic understanding of the types of practices that should now be applied on a trajectory towards a Safe System. Primary treatments are capable of virtually eliminating death and injury and certain supporting treatments can transform the network a step closer to reducing the overall harm being caused.

Keywords

Road safety, Safe System, harm minimisation, error tolerant roads, road design, traffic management, transport planning, urban planning

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About Austroads

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

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

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

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- Roads and Maritime Services New South Wales
- Roads Corporation Victoria
- Queensland Department of Transport and Main Roads
- Main Roads Western Australia
- Department of Planning, Transport and Infrastructure South Australia
- Department of State Growth Tasmania
- Department of Infrastructure, Planning and Logistics Northern Territory
- Transport Canberra and City Services Directorate, Australian Capital Territory
- Australian Government Department of Infrastructure, Regional Development and Cities
- Australian Local Government Association
- New Zealand Transport Agency.

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Summary

The Safe System approach is regarded as international best practice in road safety and provides an outcome whereby death and serious injury are virtually eliminated amongst users of the road system. Safe System is the management and design of the road system such that impact energy on the human body is firstly avoided or secondly managed at tolerable levels by manipulating speed, mass and crash angles to reduce crash injury severity.

The purpose of this report is to create a compendium of present Safe System knowledge and research in regards to planning, designing and managing roads and roadsides. It will provide a useful resource document that highlights the suite of well performing Safe System treatments developed to date.

The Safe System model is described in several publications and it is common for individuals to be able to identify key components and the underlying core principles. However, what is not well understood is that the Safe System entails a harm reduction approach to safety. That is, planning, road design and traffic management needs to also consider how to reduce the severity of crashes when they occur. Why is this a better response than conventional approaches? Primarily, the understanding of what lies behind road user error is evolving but it is evident that many of the situations people are placed in when using the road system invite certain errors to be made. We now understand that many of these errors cannot be easily eliminated. Furthermore, system designers and managers have a responsibility to not only mitigate for predictable errors but also protect those innocently caught up in crashes. The appropriate response to dealing with this issue is to ensure that the road network is forgiving of error and does not allow people to inadvertently cause harm.

Speed is at the heart of a Safe System and aspirational design speeds include: 30 km/h (car vs pedestrian/cyclist), 50 km/h (car vs car side impact at 90 degrees) and 70 km/h (car vs car head-on). With intersections, harm is mostly associated with red light running and unprotected right turns. Design options are to manage speeds to survivable levels and reduce impact angles. If 90 degree cross road geometry cannot be changed, further safety treatments such as speed plateaus on approaches can compensate for the non-favourable configuration. Where the intersecting approach geometry can be modified, designs that achieve lower speeds and impact angles will reduce the harm. The roundabout is a design that follows these principles but other innovative intersection designs are emerging. Signalised intersections should no longer be regarded as a primary treatment and compensating treatments are required to improve crash survivability.

With high speed lane departures on rural roads, 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 centre barrier has virtually eliminated death from head-on collisions and lane departures to the right. These configurations outperform unprotected corridors that utilise the clear zone / hazard protection approach.

Vulnerable road users require a low speed environment to interact with traffic. If this cannot be achieved then segregation must be used. There is guidance available regarding Safe System bicycle infrastructure design for Australia inspired by European practices. It is still not clear how motorcycles and heavy vehicles can be catered for in the Safe System. Infrastructure solutions must be combined with speed management and vehicle technology to achieve safer outcomes. Vehicle technologies have the potential to significantly reduce death and injury on the road network especially in relation to road departure and intersection crashes. Accelerating the deployment of these technologies in the fleet can lead to faster reductions in trauma.

Tools and frameworks are now emerging that allow the Safe System to be quantified. The intersection design tool X-KEMM-X can now provide feedback on the injury potential of an intersection design. The Safe System Evaluation Framework provides a means for assessing alignment with the Safe System. Importantly, a treatment hierarchy has evolved that guides practitioners through treatments that best align with harm reduction. Further Safe System solutions will need to evolve and will require innovation, risk assessment and most importantly continue to look for opportunities to improve and develop practices to reduce or eliminate harm when the inevitable road user error and consequent crash occurs.

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1. Introduction

Virtually all of us have grown up with death and injury as a seemingly inevitable consequence of the operation of road networks. With a growing awareness and understanding of safety issues, much progress has been made in past decades to reduce death and injury on the roads. Whilst there has been a strong focus on vehicle design and the performance of the road users themselves, improvements in traffic planning, management and infrastructure design have also contributed significantly towards overall improvements in safety. While the situation in Australia and New Zealand continues to improve over time, there is now a significant body of knowledge, theory and real world examples that demonstrate how the rate of improvement can be increased substantially.

Leading road safety countries have been pursuing a paradigm shift in the way the road safety problem is regarded since the 1990s. Commonly referred to as the “Safe System” approach, the shift represents a significant change in the way in which the road safety problem is perceived and therefore managed and a significant cultural shift is required before this approach becomes normalised practice. A Safe System forces everyone to look at road safety from a public health perspective, that is, injury is avoidable and responsibility lies with system planners designers and operators in addition to the road users. The philosophy of the approach is grounded on the moral and ethical imperative that no-one should be killed or injured when using the road system. It should be unacceptable that the victims of road trauma are blamed for the outcomes of road user errors and it needs to be acknowledged that the way in which the system has been set up and is operated may also contribute to crashes. A Safe System therefore expects that roads be planned, designed and operated to be forgiving of inevitable human errors so that severe injury outcomes are unlikely to occur.

1.1 Purpose of this report and intended audience

In recent years there has been much good research and improved understanding into improved roads and roadsides in the Safe System. While there are several reports and documents available that describe the Safe System, translating this knowledge into changes in practice on how we plan, design and manage roads is sometimes a complex and lengthy process. Furthermore, it is not easy for the practitioner or those who are involved with road safety to keep up to date on current thinking and developments regarding Safe System implementation given the diversity of documentation in circulation given the rapid evolution of knowledge and understanding in recent years.

The purpose of this report is therefore to create a compendium of present Safe System knowledge and research in regards to planning, designing and managing roads and roadsides. It brings together the principles, theory and rationale behind the Safe System along with established examples of real world implementations. The document summarises and highlights the state of knowledge of speed management, median treatments, roadsides design and management (clear zones versus barriers), intersection issues, vulnerable road user issues, motorcycle and heavy vehicle safety. The ongoing development of assessment tools is also discussed.

The guide is of most relevance to “road practitioners” associated with road safety management (policy/people and infrastructure/environment), planning, traffic management, network management, road design, asset management, project management (construction) and funding. This will predominantly represent people working within Federal departments, state road agencies, local government authorities and consultants. The guide will also be of general interest to people associated with other broader areas of the road transport system including those responsible for insurance, enforcement, education, media, communications, public relations and those in treasury.

It is important to note that this is not a "how to" guide. Our understanding of the Safe System is constantly evolving and requires thinking about new ways to approach road safety with a harm minimisation objective. In discussing Vision Zero (another commonly used term often used interchangeably with the Safe System) Kim, Muennig et al. (2017) succinctly describe the situation as follows:

> *"Vision Zero does not have a step-by-step manual on how to apply its philosophy and design principles; rather, it gives suggestions to system designers and safety planners on different methods they could utilize to attain a safer road system. While there is no one right way to implement Vision Zero, some common road design elements have emerged in different Vision Zero programs."*

While this report offers a starting point, there are still considerable gaps in knowledge, and innovation, trials and experiments are required to allow suitable solutions to be identified and refined, preferably as part of a coordinated effort amongst jurisdictions. Information in this report will be sufficient to enable practitioners to pursue innovative solutions armed with a clearer understanding of Safe System principles and a knowledge base of practices that have proven to be effective. This is a crucial step as it is necessary to gain the confidence to break from some conventional approaches and demonstrate that better safety outcomes are possible. This confidence needs to be established not only amongst the community, politicians and senior decision makers but also with road practitioners in general.

It should be noted that this compendium does not imply that historical approaches did not attempt to improve safety or constantly evolve. Indeed there are many successes that can be highlighted that have saved many lives and injuries over the decades. The document highlights differences between the new ways of thinking under the Safe System and many established conventional methods.

1.2 Adoption of the Safe System

The Safe System was endorsed in Australia in 2003 by the Australian Transport Council and adopted by Austroads in 2006. The approach is now integral to road safety strategies in jurisdictions in Australia and New Zealand as outlined in Table 1.1.

Table 1.1: Road safety strategies underpinned by the Safe System approach for jurisdictions in Australia and New Zealand

Jurisdiction	Supporting document/policy
Australia	National Road Safety Strategy, 2001-2010 (ATC 2000) National Road Safety Strategy, 2011-2020 (ATC 2011) Guide to Road Safety, first edition (Austroads 2006) Guide to Road Safety, current edition (Austroads 2013)
New Zealand	Safer Journeys: New Zealands Road Safety Strategy 2010-2020 (MoT 2010)
Local Government	e.g. Mornington Peninsula Dravesafe 2008-2018 (Mornington Peninsula Shire)
NSW	NSW Road Safety Strategy 2012-2021 (Transport for NSW 2012)
Qld	Safer Roads Safer Queensland: Road Safety Strategy 2015-2021 (TMR 2015)
Vic	Towards Zero Road Safety Strategy and Action Plan 2016-2020 (Victoria State Government 2016)
SA	Towards Zero Together - South Australia's Road Safety Strategy 2020 (DPTI 2011)
WA	Towards Zero – Road Safety Strategy for WA 2008-2020 (Office of Road Safety 2009)
Tas	Towards Zero - Tasmanian Road Safety Strategy 2017-2026 (Department of State Growth 2016)
ACT	ACT Road Safety Strategy 2011-2020 (ACT 2016)
NT	Towards Zero Discussion Paper (Northern Territory Government 2017)

While providing background information on the Safe System and its theories and principles, this report does not seek to make a case for the validity of the approach. The focus is now on how to operationalise a harm minimisation approach to tackle the future burden of death and injury through use of the road system and create a Safe System of road transport.

1.3 What is a Safe System?

The Safe System philosophy brings a public health type focus on road safety where efforts should primarily be made to address the harm that is being done. At the centre of this is human fallibility and the fact that errors at present can lead to unintentional death and injury. Movement should not be at the expense of human wellbeing.

An example of a visual representation of a Safe System is shown in Figure 2.1 adapted from the Queensland road safety strategy (TMR 2016). There are numerous similar depictions of Safe System models in various strategy and road safety documents.

Figure 1.1: Portrayal of the Safe System

Source: Adapted from Safer Roads, Safer Queensland: Queensland's Road Safety Strategy 2015–21 http://roadsafety.gov.au/nrss/safe-system.aspx

There are four key principles that form the basis of the Safe System philosophy (ITF, 2016):

1. People make mistakes that can lead to road crashes
2. The human body has a limited physical ability to tolerate crash forces before harm occurs
3. A shared responsibility exists amongst those who plan, design, build, manage and use roads and vehicles and provide post-crash care to prevent crashes resulting in serious injury or death
4. All parts of the system must be strengthened to multiply their effects; and if one part fails, road users are still protected.

While we should be expecting compliance and the cooperation of road users, we should also be open to the idea that solutions to these problems may lie outside the enforcement and legislative domain and adopting an alternative intersection design for example might eliminate or mitigate the problem altogether.

A topic of ongoing debate relates to perceptions in relation to “error” and the extent to which non-compliant and risk taking behaviour should also be accommodated. Many Safe System approaches have been published indicating an expectation of “alert and compliant road users”. The rationale then becomes that no one should be killed or injured while legally using the road system. This aligns more closely with a historical view of road safety and excludes other possibilities under the “system” approach. For example, certain road designs may eliminate the possibility of non-compliant behaviour (eg illegal overtaking because a centreline barrier is in place). In addition, there is a need to protect innocent parties from the inevitable actions of others; to date our key response to the burden of trauma caused by red light running over several decades has been to put safety cameras in place at selected sites in the network. However, red light running behaviour is a known phenomenon at signalised intersections and should be expected as part of network operation. Additionally, our understanding of errors should not be limited to an assumption of deliberate and risky actions - there are many circumstances in which a road user might unintentionally run a red light.

A Safe System is usually considered in terms of key interacting “pillars”:

- Safe roads and roadsides
- Safe Speeds
- Safe Vehicles
- Safe Road Users.

A fifth pillar, post-crash response, was introduced by the United Nations in 2010 (WHO 2011) but is not yet reflected in many portrayals of the Safe System. It is noted however that post-crash response is also included as part of the current NSW and SA state road safety strategies but only as a supporting activity.

Each of these pillars is inter-related and problems in one area may be compensated for with solutions in other areas. A true systems approach would involve the optimisation in planning, design and operation across all pillars however in practice this can be difficult. Vehicle design is predominantly an offshore activity within the private sector whereas planning, road design and operation is predominantly the domain of government. Despite this, there are opportunities to ensure that there is synergy between the two. For example, intersection geometry could be established that maximised the occupant protection offered by current vehicle design. Road user performance can also contribute via training, enforcement and education. However, no matter how well this is done, errors will continue to occur.

Key inputs to the system commonly include:

- using data, research and evaluation to understand crashes and risks
- developing road rules and enforcement strategies to encourage compliance and manage non-compliance with the road rules
- managing access to the road through licensing drivers and riders and registering vehicles
- providing education and information
- being open to and seeking innovation
- developing standards for safe vehicles, roads, equipment and operation
- good planning, management and coordination.

1.4 The transition to a Safe System

A common first response by road practitioners to the Safe System philosophy is an overwhelming sense that it is impossible to eliminate death and injury from the road system. Whilst it is unlikely that absolute elimination is possible over the entire system, substantial gains and even virtual elimination is possible in components of the system over varying timeframes.

Due to the complexity of the road system and its interacting components, a Safe System may take several decades to accomplish. While this report is focussed on certain aspects of the road infrastructure pillar, it is important to note that infrastructure alone cannot be expected to achieve Safe System outcomes and contributions from the other pillars will still be required. Speed management can be used to achieve rapid and significant outcomes; vehicle safety, whilst effective, may take several years to have influence due to the time it takes to turn-over the fleet. Automated technologies show massive potential and deployment can be faster than infrastructure change alone; behavioural measures can also be effective but it is difficult to optimise outcomes.

To add some further context to this discussion, the amount of state road network rebuilt each year in NSW is approximately 2% of the overall state network; in Queensland this is approximately 0.5% (pers comm.Peter Ellis and David Bobbermen). Even through transformational road upgrade projects, it is evident that it will take a very long time to bring enough of the road network up to a Safe System standard at current levels of funding commitment. The implementation of Safe System infrastructure can also create a capital and recurrent impact on budgets. Therefore expectations regarding infrastructure transformation must be based on long term cumulative outcomes unless the business model changes. Even then, it is unlikely that Safe System compliant roads will be affordable in all parts of the network and the other pillars will need to compensate for this, especially on low to medium volume rural roads.

This also highlights the importance of ensuring that future problems are not being created when new road infrastructure is being built. An important evolution will be the adoption of default safety starting points in terms of crash consequence. A good example of this is the adoption of roundabouts (or Safe System equivalents) as a default intersection type in WA (MRWA 2015). Roundabouts deliver near Safe System outcomes for vehicle occupants and should be the starting point for any road project considerations. This does not mean that roundabouts must be used in all circumstances and context is important, however they should at least be considered first due to their superior harm reduction potential over other intersection types.

As we understand more about Safe System implementation, a hierarchy of treatments that are capable of achieving the best harm reduction outcomes currently possible begins to become apparent (see Section 6 and 7). Practitioners need to be aware of these hierarchies and why treatments are well aligned with Safe System principles. If the treatments with the most harm reduction potential are considered first, there is a good chance that the transition towards Safe System outcomes will be maximised. Unless this approach is adopted, there will continue to be the potential for road projects to proceed without making the most of opportunities for a transition towards Safe System outcomes. At worst, a project might still proceed with no movement towards Safe System outcomes. In this light it is clear that safety outcomes need to be managed: there should not be an assumption that because a road is new and built to the standards that it is necessarily as safe as it can be. It should also be noted that this approach is equally applicable to all urban and rural situations from major highways to low volume roads.

This also highlights the importance of an integrated approach towards achieving Safe System transformation of the road network across all areas of activity including funding analysis, network planning, traffic management and road design. The hierarchy of treatments needs to be considered as early as possible in planning and evaluation processes to maximise the outcomes. The ability to pursue Safe System outcomes will be severely constrained if the task is just left to road designers or safety managers when key decisions have already been committed to.

Another evolution towards Safe System implementation has been changes in the way that the business cases for safer road programs are being made. It has been common for programs to be considered in terms of the percentage reduction in fatalities or serious injuries (FSI) and business cases made around Benefit Cost Ratio (BCR), Investment Rate of Return (IRR) and Net Present Value (NPV). Whilst informative and correlated with FSIs, these measures are based on metrics that attempt to place an economic value on loss of life and health; when this is done safety trade-offs are made which is in direct opposition to the ethical ideology of the Safe System. Therefore, other metrics are evolving. These include the average cost per FSI saved, average FSI saved per annum per $100 m invested, residual FSI per annum/km and percent residual problem of the original. Some of these newer metrics have been a feature of road safety treatment prioritisation in Victoria and NSW in recent years (Transport for NSW 2017). A benefit of this type of approach is the ability to upgrade entire corridors for better safety outcomes when compared to the collective treatment of discrete sites along the corridor. Another useful outcome is that a more holistic approach can better avoid situations where there are differing safety standards along the corridor (e.g. having many 3 star sections on a 5 star road corridor). There is also evidence emerging that integrating alignment with Safe System (with treatments already aligned with the Safe System) during the planning phases is relatively cost neutral and adds significant reduction in harm (see Section 9.2).

The most significant variation from past practices is that practitioners now need to firstly consider the harm minimisation aspects as an outcome to their activity. There needs to be an assumption that a crash will occur and attention paid to ways in which crash consequence can be mitigated considering the interactions across all pillars. For infrastructure, treatments with the most potential to minimise harm should be considered first. In many cases this will mean innovation and doing things differently whilst applying the principles of sound engineering judgement and expertise. The result should be a risk management approach that utilises available resources in a practical way with an outcomes focus on harm minimisation.

1.5 Legal liability issues

The type of innovation required to pursue Safe System principles is often perceived by practitioners and managers as a corporate risk thus limiting the potential for non-standard engineering treatments to be installed on the road network. This may lead to a ‘do-nothing’ approach unless a standards-compliant treatment is feasible. However, ‘doing-nothing’ ultimately leaves the identified hazard untreated and thus continuing to pose a safety risk to road users.

Some road agencies are exploring this issue further and many legal commentaries consistently point to the fact that doing something to manage risk for road users is better than doing nothing at all. That is, using innovative treatments is a realistic option which does not compromise the level of legal vulnerability carried by a road authority and should be used to encourage innovation rather than used as a deterrent. A common proviso is that documentation must justify the reasonable decisions made when selecting and implementing crash mitigation options.

In New Zealand, supplementary guidance in the form of a Technical Memorandum (TM-2503) was released in 2012 to provide a focus for designing dual carriageway roads with a Safe System approach on Roads of National Significance (subsequently revised in 2013). The document places an emphasis on ‘engineering logic’ rather than ‘definitive justification’ for road safety and highlights that an engineer’s knowledge, skills and experience may justify the use of viable non-standard treatments. Similar documents are currently under development by VicRoads in response to their Safe System Road Infrastructure Program (SSRIP).

1.6 Gaps in knowledge

In our transition towards a Safe System, there is still much to be learnt about how to minimise the harm in components of the system and ultimately the system as a whole. While there is considerable understanding of how to achieve a Safe System for motor vehicle occupants and travel in urban areas, minimising the harm in other parts of the system and with different road users remains a challenge. For vulnerable road users, it is apparent that avoiding collisions altogether may need to be the principal way of achieving Safe System performance.

1.6.1 Vehicle technologies

There is much discussion about the potential use of autonomous vehicles on the road network in the future. While there is no doubt that this is a possibility under a multitude of possible scenarios, it is the driver assist technologies that are likely to yield the largest safety benefits over the next 20 years. However, even if new technologies were available tomorrow, the vehicle fleet takes a long time to turnover and in some jurisdictions this could take as long as 20 years. Despite this there is massive potential for vehicle technologies to contribute to reductions in trauma especially if their deployment and fleet penetration can be accelerated.

Infrastructure will continue to be an important contributor to a Safe System for many decades to come. What will become of increasing importance is the ability of the infrastructure to be compatible with vehicle capabilities to maximise the benefits from the most effective technologies (e.g. edgelines that are readable by cars). For large parts of the road network where large investment in infrastructure upgrades are unlikely, such as low volume roads, vehicle technologies may play a crucial role in preventing road departure crashes and intersection collisions and compensating for the many errors that may lead to severe crashes.

1.6.2 Rural roads

Most rural roads are not going to see the type of infrastructure investment that is applied to higher volume highways and arterials. The situation is even more pronounced when considering low volume roads in rural areas. In this case infrastructure treatments are likely to take a less substantive role when compared to the contribution of vehicle safety. Further innovation is required to identify low cost treatments suitable for these types of environments. Vehicle based speed management technologies may offer the most feasible solutions in the interim.

1.6.3 Pedestrians

There is a good understanding of risk of injury to pedestrians if struck by a passenger car. We understand that we should be aspiring to interaction speeds of no more than 30 km/h because at or below these speeds harm outcomes becomes substantially less likely. The inter-relationship between infrastructure and speed is therefore a critical consideration. The “Movement and Place” methodology, which places emphasis on the place value of roads rather than just their value as conduits for traffic movements, will become increasingly important in ensuring that there is an integrated and holistic approach towards achieving environments that are not hostile to pedestrians. Many jurisdictions are now re-considering their road networks in a Movement and Place context and the understanding of how safety can be improved particularly in urban areas is likely to improve as more schemes are implemented. Separation or treatments that support a very low speed environment for motor vehicles are currently the best means for achieving safety outcomes.

1.6.4 Cyclists

As road infrastructure has been optimised for motor vehicle use, the road network does not support safe cycling on most parts of the network. Even the leading countries with the highest participation rates are still striving for ways to minimise the harm that is occurring. There are good learnings from Europe regarding cycling infrastructure and some jurisdictions are beginning to trial these approaches. The full extent to which these are directly translatable to the Australian and New Zealand environment remains to be seen. However, they provide a sound basis for a risk management approach to cycling safety.

1.6.5 Motorcycles

Motorcycles provide one of the greatest challenges in achieving a Safe System. The vulnerability of the human body in combination with non-survivable operational speeds means that an effective infrastructure solution is difficult to achieve. While there have been some infrastructure treatments that improve safety for motorcyclists, such as barriers with underride protection, they generally fall well short of Safe System aspirations. Nonetheless, the harm minimisation philosophy should still apply and harm reduction should continue to be pursued at whatever extent is possible.

1.6.6 Heavy vehicles

The significant challenge posed by heavy vehicles is the fact they operate at the same speed as lighter motor vehicles yet have significantly higher mass, leading to respectively more severe outcomes to non-heavy vehicle road users when interactions occur. Even containment using crash barriers poses a problem as systems that can contain heavy vehicles are likely to be more aggressive for light vehicle occupants. Unless segregation can be achieved, the manipulation of speed and/or mass remain the main option at present to ensure Safe System outcomes. Vehicle based technologies may also begin to offer feasible solutions, with the added advantage that heavy vehicles have a faster fleet turnover when compared to light vehicles.

1.6.7 New modes of travel

The Safe System approach also needs to be adaptive to, and somewhat responsible for new modes of transport. Even better, before they become established the conversation (or process) about how they can be integrated, or not, in a Safe System context is key.

1.7 Connection with other Austroads Guides and projects

1.7.1 Guide to Road Design and Guide to Road Safety Activities

To complement targeted research and mitigation strategies, Austroads has initiated a comprehensive overview of system-wide areas of research to provide guidance to jurisdictions in the complete life-cycle of mitigating treatments:

- Road Safety Task Force NRSS Action Plan support
- SSP6038 Key Interventions to Reduce Road Trauma – Forecasting Potential Gains for Jurisdictions
- SAG6050 Road Safety Summary by Jurisdiction (Online Survey Report)
- SRL6045 Registration and Licensing Summary by Jurisdiction (Online Survey Report)
- SSP2068 Road cross sections for Road Stereotypes supporting Network-wide Safety Plans and a Safe System
- SAG2090 Best Practice Program Development for Road Safety
- SAG2060 GRS Part 6 - Road Safety Audit Practice

- SRD6045 Inclusion of all recent Safe System Research Considerations into Road Design
- Adding Safe System content into the Guide to Traffic Management.

All of these projects will have Safe System philosophy and latest emerging evidence as an integral component of research, recommendations and jurisdictional guidance.

1.7.2 Safe System Assessment Framework

Published by Austroads in 2016, the Safe System Assessment Framework is a qualitative tool that provides a means for checking the Safe System alignment of a project or scheme. This alignment is considered through a scoring system between zero and 448; the closer to zero, the better the alignment with Safe System principles. The framework allows the user to assess aspects of road user exposure, crash likelihood and crash severity in considering the potential for harm to occur. The framework allows users to improve Safe System alignment by adopting treatments or schemes that reduce exposure, likelihood and severity in a compensatory way across key crash types including intersections, run-off road and vulnerable road users. The framework is not a compliance check but a way to identify where progress is and is not being made towards minimising the potential for harm to occur (see Section 9.2.1).

Safe System assessments are starting to be used by several road authorities at State and Local Government levels and early indications from the Victorian SSRIP program highlight that considerable safety benefits can be achieved when utilised early in the planning phase (see Section 9).

1.7.3 Safe System Intersection Design Tool

Austroads project SS2061 has formed the basis for quantifying the relationship between intersection design and injury severity outcomes. A software model is currently in development that will be made available to practitioners as a design assessment tool in 2018 (See Section 9.2.2).

1.7.4 Guide to Road Safety Audit

The road safety audit process started in the UK approximately 30 years ago and predates the Safe System. Whilst it has, and still does, serve well as a proactive tool to help prevent crashes and unsafe features being designed and built into roads, it has often been criticised for being little more than checks of compliance against design and construction standards and standing in the way of innovation. Austroads are currently reviewing the Guide to Road Safety Part 6, Road Safety Audit (2009) with a view to better incorporating Safe System thinking. This review will include whether or not the Austroads (2016e) Safe System Assessment Framework could be incorporated into the review process.

2. An Introduction to the Safe System

The Safe System approach is regarded as a best practice approach to road safety and has been adopted by leading road safety countries and recommended by several international organisations including the United Nations Road Safety Collaboration (WHO 2011), the Organisation for Economic Cooperation and Development (International Transport Forum 2016), and PIARC (2015). The Safe System underpins the current Australian National Road Safety Strategy (ATC 2011) and those of its constituent jurisdictions and the New Zealand "Safer Journeys" Road Safety Strategy (MoT 2013).

Further information on the Safe System approach can be found in numerous publications and it is recommended that the PIARC (2015) *Road Safety Manual* and the International Transport Forum (2016) *Zero Deaths and Serious Injuries* report also be consulted as a starting point. A list of resources at the end of this guide also outline sources of publications and multimedia content associated with communicating Safe System concepts.

It should be noted there are two major versions of road safety harm minimisation approaches in existence but most follow the Safe System (or Vision Zero) framework discussed in Section 1.3.

The other version is from The Netherlands which has been actively pursuing their "Sustainable Safety" approach since the mid-2000s (Wegman, Aarts et al. 2006). This approach is articulated in a slightly different way to that of the Australian and New Zealand version of Safe System and is more explicit about the role of planning, road design and infrastructure. Notably, a functional road hierarchy constitutes a key principle of the approach as shown in Table 2.1. The importance of a functional hierarchy for road safety is discussed further in Section 3. The modern version of the Safe System seeks to combine the best features of these two versions.

Table 2.1: Dutch Sustainable Safety Principles

Sustainable safety principle	Description
Functionality of roads	Mono-functionality of roads, as either through-roads, distributor roads, access roads, in a hierarchically structures road network
Homogeneity of masses and/or speed and direction	Equality in speed, direction and masses at medium and high speeds
Predictability of road course and road user behaviour by recognizable road design	Road environment and road user behaviour that support road user expectations via consistency and continuity in road design
Forgivingness of the environment and of road users	Injury limitation through a forgiving road environment and anticipation of road user behaviour
State awareness by the road user	Ability to assess one's own task capability

2.1 The ethical and moral imperative for change

The origin of Safe System thinking can be traced back to developments in Sweden which achieved a historical milestone when the country's parliament adopted "Vision Zero" providing a mandate for the government to pursue road safety in a new way. This new approach was centred on a moral and ethical argument that (Tingvall and Haworth 1999):

> *"It can never be ethically acceptable that people are killed or seriously injured when moving with the road transport system".*

Tingvall and Haworth note that mobility has historically been regarded as a function of the road transport system for which safety is regarded as a trade-off. Vision Zero resets this thinking as *mobility being a function of safety* and that *no more mobility should be generated than that which is inherently safe for the system*.

The Dutch "Sustainable Safety" approach was created to prevent road crashes from occurring and where that was not feasible, to reduce the incidence of (severe) injuries whenever possible (Wegman, Aarts et al. 2006). In similarity with arguments associated with environmental sustainability, it is not acceptable that the next generation inherit an unsatisfactory system as a legacy from the previous generation. Much of the Sustainable Safety logic is based on the fact that crashes are predictable and therefore preventable.

The Tylösand Declaration is another significant milestone that highlights a moral dimension in relation to road safety. The Tylösand Declaration of citizens' right to road traffic safety (Lie and Tingvall 2009) states:

1. Everyone has the right to use roads and streets without threats to life or health
2. Everyone has the right to safe and sustainable mobility: safety and sustainability in road transport should complement each other
3. Everyone has the right to use the road transport system without unintentionally imposing any threats to life or health on others
4. Everyone has the right to information about safety problems and the level of safety of any component, product, action or service with the road transport system
5. Everyone has the right to expect systematic and continuous improvement in safety: any stakeholder within the road transport system has the obligation to undertake corrective actions following the detection of any safety hazard that can be reduced or removed.

It is acknowledged that the complete elimination of death and serious injury (i.e. absolute zero) may not be possible due to unusual or rare events. However, a system increasingly free of severe injuries is thought possible by applying Safe System principles. It is likely that the elimination of harm for certain aspects of system operation will be achieved during the transition to a safer road transport system.

Innocent bystanders and the need for a better response

A focus on road user error and "wrong doing" has generally distracted the road safety response away from opportunities to minimise the harm being done. The following table provides a simple analysis of what could be considered as people in the "wrong place at the wrong time" in a collision, based on reported responsibility for the crash. Although there may be specific issues regarding the attribution of responsibility, even this coarse level analysis indicates that there is still a significant opportunity to do more to protect the 40% of people who find themselves involved in a fatal or serious injury collision with no fault of their own. Road design and traffic management practices that are forgiving of errors and that mitigate crash severity will contribute towards addressing this issue.

Proportion of people killed or seriously injured in crashes in South Australia assessed to be in the wrong place at the wrong time

Fatal or serious injury	2012 to 2015		
Type	Not responsible	Responsible*	% "wrong place at the wrong time"
Driver	325	1291	20.1%
Rider	330	526	38.6%
Passenger	620	0	100.0%
Pedestrian	116	214	35.2%
Total	1391	2031	40.6%

*Note: * Road users judged responsible for a crash if they were in the responsible unit and were not a passenger.*

Source: CASR

2.2 Where does the system currently fail us?

The ways in which crash data is collected have a bias towards identifying road user errors which reinforce a perception that most problems and consequent solutions are associated with road user performance. When a crash occurs, it is instinctive to ask: *Who or what caused the crash?* Under the Safe System, the appropriate question to ask is: *How did the road transport system allow this death or serious injury to occur?* At present very few databases collect adequate information on system performance outside of the road user. Practitioners should be aware that our perception of the road safety problem is based largely on factors associated with crash causation rather than crash severity. *Crashes should be considered as a "system failure" rather than a road user performance failure.*

There is a need to acknowledge that the current road system is inherently unsafe and that road users are frequently placed in circumstances where errors are to be expected (Austroads 2012b). If this is to be accepted, then the scenarios that govern planning, road design and traffic management need to be added to. For example, just ensuring that sight distances at an intersection are sufficient should no longer be adequate – the governing planning and design scenario should also include features that mitigate the injury outcomes if a collision were to occur.

No matter how well trained or skilled road users are, it must be acknowledged that errors are inevitable when using the road system. It is unrealistic to expect road users to be operating at peak performance all of the time and many of us can relate to being tired, distracted, emotional, stressed, inexperienced or unwell when using the road system.

It is a common community perception that the road safety problem is associated with extreme behaviours involving speeding, impaired driving and high levels of risk taking. Media coverage of crashes often reinforces this perception and often it is only the police who are asked to provide comment on the crash, usually from an enforcement and behavioural perspective. While such behaviours contribute to the road safety problem, they by no means explain the full extent of the problem.

Our perspective of road user error must change

Crashes are complex and in the majority of cases human error is usually a contributing factor.

Our understanding of what constitutes an error needs to change – errors are not always a matter of intentional behaviour or deliberate violation.

We need to acknowledge that road users are frequently placed in circumstances where the road environment invites certain errors to occur – roads must be engineered to become more "error tolerant" (e.g. forgiving roadsides) and "error resistant" (preventing errors through infrastructure design).

Instead of asking who or what caused the crash, we should instead be asking: *"how did the road transport system as a whole allow this death or serious injury to occur?"*

A crash needs to be considered as a system failure and not just a road user failure.

In a study of circumstances behind fatal and serious injury crashes in South Australia, Wundersitz, Baldock et al. (2011) found that perceptions that the road safety problem was associated with extreme behaviours was unfounded (Table 2.2). In most non-fatal injury crashes, extreme behaviours such as drink driving and excessive speed were not contributing factors. Ninety-seven percent of non-fatal injury crashes in metropolitan areas (91% in rural areas) were the result of system failures (including illegal system failures). In this context 'system failures' were defined as those resulting from non-deliberate errors by otherwise compliant road users and 'illegal system failures' were defined as resulting from non-compliance that was not considered as extreme (such as low level speeding or lack of restraint use). Fifty-four percent of fatal crashes were the result of system failures. The higher proportion of fatal crashes resulting from extreme behaviour is perhaps not surprising, as higher incidence of extreme behaviours such as drink driving and speed are associated with an increased injury severity (Wundersitz, Baldock et al. 2011).

Table 2.2: The role of system failures and extreme behaviours in fatal crashes

Data source	Extreme behaviour (%)	Illegal system failure (%)	System failure (%)
Fatal crashes 2008-09	45.5	23.8	30.7
Non-fatal metropolitan injury crashes 2008-09	3.3	9.9	86.8
Non-fatal rural injury crashes 2008-09	9.4	16.6	74.0

Source: Wundersitz, Baldock et al. (2011)

Elvik, Hoye, Vaa and Sorensen (2009) predicted that complete driver compliance with the road rules would only result in a 60% reduction in fatalities and a 40% reduction in all injuries. This corresponded to around 37% of fatalities and 63% of serious injuries not being the result of road users breaking road rules. This implies that:

- it is routine human error that results in crashes – something that is a part of human functioning
- simply focussing on achieving road user compliance with the road rules will result in some crash reduction, but will not alone achieve the desired Safe System outcomes of zero deaths and serious injuries.

There is the possibility of substantial benefit through driver education and achieving higher rates of compliance, but further focus is required on improvements to infrastructure and vehicle safety in order to provide a forgiving system. This further emphasises the need for a shift in philosophy, from blaming the road user to 'shared responsibility' in addressing safety risk.

The example that follows highlights how crashes have not conventionally been considered in the context of a system failure. The three photographs in Figure 2.2 shows the scenario of approaching traffic at a T-junction from the perspective of a motorist wishing to make a right turn.

In the first picture a rigid truck and a passenger car are noted as approaching the intersection. The rigid truck has entered a left turn lane for its approach. In the second picture, both vehicles have come nearer and it is likely that the motorist turning right is preparing to go once the passenger vehicle has passed, noting that they may scan again to the left prior to pulling out.

In the third photo the passenger car has passed but another passenger car suddenly appears. During the whole sequence the view of the second passenger car was obstructed by the rigid truck. Although the motorist waiting to turn right may have made an error and moved forward after the first passenger car had passed, many would relate to the fact that in the circumstances this would be an understandable error. This phenomenon, termed dynamic visual obstruction, was identified as a feature of common intersection designs in (Austroads 2011b) and demonstrates how road users are placed in circumstances where errors are inevitable.

In this particular case, the crash would be recorded as a fail to give way type error and the crash database would support a finding that the road user performance was the issue. Whilst this is partially true, the performance of the vehicle in protecting the occupants or the road in mitigating the crash consequences would rarely be considered.

Figure 2.1: Sequence of photos showing traffic conditions for a motorist intending to make a right hand turn

Source: DPTI

A series of studies undertaken by Stigson and her colleagues in Sweden were used to take a holistic approach when applying Safe System principles to the scenarios of fatal and non-fatal crashes (Stigson, Krafft et al. 2007, Stigson, Krafft et al. 2008, Stigson 2009, Tingvall, Stigson et al. 2009). A number of datasets containing fatal and non-fatal crashes occurring on Swedish roads were used for the studies. A range of safety performance indicators (SPIs) related to road users, road design and vehicles were assessed with an aim of identifying which SPIs are useful for identifying deficiencies in the road transport system.

The safe road transport model developed by the Swedish Road Administration was used as the basis for the system components:

- **Safe Vehicle:** Vehicle supports correct use; protects driver and passengers; protects other road users (Criteria: EuroNCAP 5-star level and Electronic Stability Control, ESC)
- **Safe Road:** Road supports correct use; is forgiving in terms of injury mitigation (Criteria: EuroRAP 4-star level)
- **Safe Road User:** Road user has the knowledge, capability, capacity, willingness to correctly use the road transport system (Criteria: Wears seat belt, complies with speed limits, is sober).

While each factor was shown to have a substantial impact on safety performance, road design was singled out as the greatest contributing factor; 75 (of 230 total) fatal crashes were determined to be a result of inadequate road design alone, compared to 43 and 27 fatal crashes being a result of road user non-compliance or inadequate vehicle safety alone, as shown in Table 2.5 (Stigson, Krafft et al. 2008).

Table 2.5: Fatal crashes linked to compliance with safety criteria

Compliance with safety criteria	Number (& percentage) of fatal crashes linked to safety criteria
Road user (speed compliance, seat belt usage, not driving under the influence of alcohol)	43 (18.7%)
Road (European Road Assessment Program [EuroRAP] rating)	75 (32.6%)
Vehicle safety (European New Car Assessment Program [EuroNCAP] rating and presence of Electronic Stability Control [ESC])	27 (11.7%)
Multiple (two or three of the above) factors interacting in a crash	85 (37.0%)
Total number of cases assessed	230 (100%)

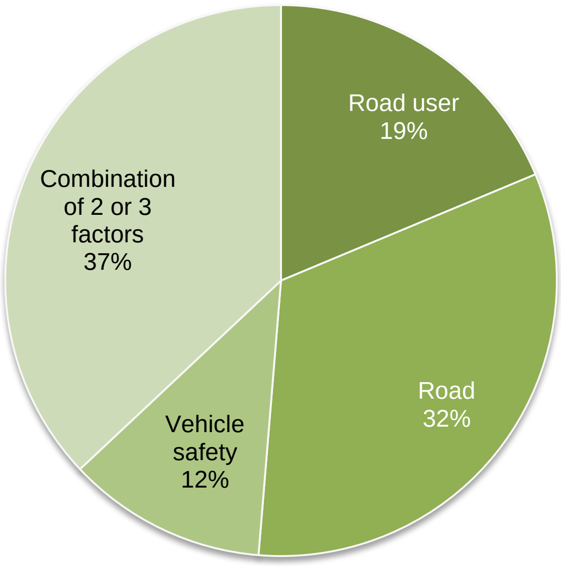
Source: Stigson, Krafft et al. (2008)

Most fatal crashes were, however, suggested to be the result of multiple factors (Figure 2.3). Whether or not a road was divided was suggested to be a substantial contributing SPI. However, 52% of fatal crashes occurring on undivided roads were also contributed to road user SPIs, including driving while under the influence of alcohol, excessive speeding and seatbelt non-use (Tingvall 2009). Non-adherence to these road user SPIs were identified as contributing to more than 50% of all fatal crashes, while accounting for only 5.2% of traffic flow. Non-compliant road users were suggested to likely most benefit from improvements to road design and vehicle technology, as conventional education and enforcement approaches are unlikely to affect such behaviours (OECD 2008). Vehicle technology was also recognised as a contributing factor in many fatal crashes. Although vehicle technology plays a substantial role in reducing road trauma, most of the fatal crashes included in the study would have nonetheless resulted in a fatal outcome, irrespective of the vehicle safety standard, as crash energies resulting from vehicle to vehicle impacts and impacts with roadside objects and other factors were beyond reasonable limits (Stigson 2009).

Despite the commonality of multiple contributing factors, road design was highlighted as the most critical area for improvement, being that most likely to reduce the incidence of fatal outcomes. It was suggested that lives could have been saved in 100 (90%) of the 112 fatal crashes occurring on EuroRAP two-star rated roads by improving road design. In comparison, fatalities could have been prevented in only 55 and 34 of these fatal crashes by improving road user non-compliance and vehicle safety, respectively (Stigson 2007). On EuroRAP four-star rated roads (the highest star rated roads identified in the study), fatalities in only one-third of fatal crashes could have been prevented with improved road design. This was far lower than the number of fatalities that could have been prevented through improvements to road user non-compliance and vehicle design.

Although the EuroRAP star rating system was shown as a good SPI, whether or not a road is divided so as to prevent centreline incursions was highlighted as being a more beneficial SPI than the EuroRAP rating alone. Only 5% of fatal crashes in Sweden in 2004 occurred on a divided road where adherence to all three road user SPIs was an associated factor, compared to 41% on undivided roads (Stigson 2009).

Figure 2.2: Fatal crashes linked to compliance with safety criteria



Source: Stigson, Krafft et al. (2008)

Some key insights emerge from the work of Stigson (Austroads 2016e, International Transport Forum 2016):

- Combining safe speed, safe vehicles, safe roads and safe road users should ensure a safe road transport system and compliance with these criteria would go a long way towards eliminating death and serious injuries
- Most fatal injuries occurred when two or all three of the components did not meet the criteria
- Strong interactions were identified between the three pillars (roads / people / vehicles) of the Safe System but the road and roadside were the most strongly associated with fatal crash outcomes
- Divided roads were the most effective factor in avoiding fatalities among vehicle occupants
- While road users may be motivated to change their behaviour over a short period of time
- for a more sustainable result both vehicle and road design must support the road user
- A different perspective of road safety is obtained if crashes are categorised based on factors that contributed to the crash severity outcome and not just crash causation.

2.3 How are things different under a Safe System?

A safe system that is accommodating of road user error will mean increasingly less severe road trauma. Many practices and designs in use today will continue to find application but new and different ways of doing things will also emerge. There will be a significant shift in philosophy as to what criteria govern decision making in relation to road safety matters especially when crash consequence is considered. There will also be a need to initiate systemic changes in the road system as the inherent risk of current design practices and injury mechanisms become better understood. Frameworks will also be developed that place a greater emphasis on seeking solutions across the pillars, rather than only within a single pillar. Design tools and stereotypes will emerge that associate design elements with injury severity outcomes. An example of differences between conventional and the Safe System approach are shown in Table 2.6.

Table 2.6: Differences between the conventional and Vision Zero approach to road safety

	Conventional	Safe System
What is the problem?	Accidents	Fatalities and Serious Injuries
What causes the problem?	Mainly poor road user performance Speeding, drink driving, inattention, deliberate risk taking	System failures
Who is ultimately responsible?	Individual road users	System designers and operators
What is the major planning approach?	Incremental approach to reduce the problem with an associated residual crash problem	A systemic approach to build a safe road system and minimise the harm
What is the appropriate goal?	Optimum number of fatalities and serious injuries based on competing objectives	Towards the virtual elimination of death and serious injuries
What is the trade-off?	A balance between mobility and safety	Maximising safe mobility
How is the effort coordinated?	Incremental gain within individual pillars (roads / speeds / vehicles / people)	Optimise solutions across pillars (roads / speeds / vehicles / people) – pillars compensate for each other where performance is poor
What are the cultural manifestations?	Legal liability avoidance and risk aversion	Risk assessment, innovation, trials and demonstrations
Context of tools in use	Bias towards pre-existing crash history, understanding crash causes and likelihood, optimising the network for motor vehicles	Risk analysis based on network design attributes supplemented by crash data, understanding crash consequence, optimising the network for all road users and human frailty

Source: Adapted from the Swedish Transport Administration and Austroads SS2061 Workshops

Fundamentally for planners, designers and traffic managers, the task will be to adopt a systemic approach to build a safe road system focusing on core injury mechanisms. Safety needs to be the default position from which variations are justified as opposed to many current practices that lead to the need to justify changes to “add on” safety.

How Safe System solutions may evolve (after ITF 2016)

Over time, and with the enlightening experiences of developing a Safe System, insights will develop and evolve. Openness and flexibility are needed with respect to updating views on what constitutes a Safe System and on the speeds that the system can accommodate to provide protection to users. Furthermore, with the steady incorporation of inherently safer vehicles into fleets, with both crash avoidance technologies and occupant protection, a greater part of the injury problem will be managed within Safe System limits. However, reducing the probability of fatal injuries may require greater efforts across the entire system.

…

A shift to a more holistic view of safety, well-being and economic productivity appears to be underway, however, and it may be that in future a more sophisticated understanding of the impacts of transport systems on the lives of humans, for better or worse, will provide better solutions – likely it will give greater weight to lower traffic speeds, enhanced vehicle safety features and greater separation of road users where pedestrians and cyclists are expected. It is likely that many of the Safe System principles that work for vehicle drivers - such as intuitive, “self-explaining” roads – are likely to be universally applicable.

Historical approaches to road safety have been based on incremental improvements that make roads safer in an inherently unsafe system. While significant advances have been made using this approach, there remains a significant crash residual for which those still involved in high severity crashes are not generally assisted. Past treatments and countermeasures have largely been associated with addressing crash likelihood and have not had a focus on dealing with crash consequences should a collision occur. Also limiting the effectiveness of this approach has been the consideration of safety as a “trade-off” against mobility.

The response to the problem under the Safe System is associated with maximising safe mobility. The emphasis is to focus treatments and countermeasures that also address crash severity. In this way, the long term goal is to transform the road transport system into one that is inherently safe and virtually free from death and serious injury.

The most fundamental shift is therefore associated with making an inherently unsafe road system inherently safe. In practice, it is important is that safety improvements and new projects utilise treatments that achieve alignment with the Safe System. Practitioners should challenge the notion that simply building a new facility will result in optimal safety and crash severity is the a dimension that requires consideration. Much new infrastructure may incrementally reduce the likelihood of crashes but may need to be retrofitted in the future to reduce crash severity. Current Safe System approaches aspire to systemic step changes over small incremental improvements. Improvement is sought wherever it can be obtained, however the focus is on addressing the systemic safety issues.

2.4 Shared responsibility

The Safe System acknowledges the fact that everyone has a role to play towards a safer road system. This breaks away from a common community perception that road safety is something that only governments manage through infrastructure, education and enforcement activities. Other than individual road users, the role of family members and peers is now acknowledged. The role of work related transport is receiving increasing attention from the corporate sector (see nrspp.org) and fleet purchasing practices may demonstrate immediate benefit with companies and long term benefit when the vehicles make their way into the community years later. Local Government has a key role to play due to their management of a vast network of lower volume roads and their grass root connections with the community. Reducing road trauma on local government roads will also provide considerable challenges into the future particularly against a background of limited funding and capacity.

The contribution of practitioners is regarded as critical and the range of practitioners will vary during the life cycle of the road covering the phases of planning, design, construction, operation, maintenance and review. Optimisation can only occur if there is coordination and alignment across each of these activities.

Saving lives on the Melba Highway with median wire rope barrier

The Transport Accident Commission (TAC) in Victoria has made a median wire rope barrier collision the subject of a television advertisement that celebrates the success of safe infrastructure and importantly demonstrates an alternative perspective to a very common fatigue crash scenario. Typically, media coverage of this type of crash would consider the fact that someone fell asleep at the wheel and focus on the elements of human error rather than the unforgiving road environment. The advertisement celebrates the success of dealing with a common error and moves the focus away from “victim blaming” to an implied expectation of safe road infrastructure.

Source: http://www.tac.vic.gov.au/about-the-tac/media-room/news-and-events/current-media-releases/saving-lives-melba-highway-wire-rope-barrier

2.5 The business case for the Safe System

A common point of resistance regarding the pursuit of the Safe System is the perceived cost associated with a harm minimisation approach. Such perceptions are based on the constraints applied when safety remains a trade off against other competing demands – “safety versus mobility.” When the perspective of “safe mobility” is taken into account, the business case becomes compelling.

The International Transport Forum (2016) highlights some of the key arguments and considerations in the business case for a Safe System including work by iRAP and emerging ways of mobilising resources beyond the scope of road agency budgets.

iRAP (2014) has provided an analysis for the global business case for road safety investment suggesting that an additional USD $681 billion (or less than 0.1% Global GDP per year for 10 years) could prevent an estimated 40 million deaths and serious injuries over 20 years. This would provide a return of eight US dollars for every dollar invested on a global basis. This becomes five US dollars when high income countries are considered.

Social Impact Bonds (or “impact investing”) are a way to bring those who benefit from reductions in road trauma into business case considerations. A pilot study is currently being undertaken by the FIA Foundation, iRAP, the Traffic Accident Commission (TAC) of Victoria, VicRoads, the Australian Road Research Board (ARRB), and the Royal Automobile Club of Victoria (RACV) in Victoria, Australia, to develop a social impact bond calculator to measure the financial savings to all stakeholders from an investment in safer roads (McInerney et al., 2015). The approach could leverage new ways of freeing resources to lift the large injury burden from health systems and individuals as opposed to only trying to facilitate resources through road agencies. The current TAC Safer System Roads Infrastructure Program (SSRIP) being delivered by VicRoads is another example where the business case for safety improvement is being considered in alternative ways.

The business case for investment in a Safe System (ITF 2016)

Approximate spending on land transport is about 0.7% of GDP annually in most countries (ITF, 2013b). Assuming a similar global spend and world GDP equal to USD 75 592 billion (World Bank, 2015), a rough approximate estimate of the world road industry is USD 530 billion a year. Assuming targeted road safety interventions equate to 2-5% of total budgets, the investment in targeted road infrastructure safety is in the region of approximately USD 10 to 26 billion a year. This means that total world road infrastructure safety investment amounts to approximately 0.5% to 1.4% of the estimated global cost of fatal and serious crashes (USD 1 851 billion), or one US cent of investment for every dollar of road trauma costs (McInerney et al., 2015).

With this base funding as a starting point, road agencies have typically set design standards, warrants and investment levels to work within these funding constraints. This approach has led to undivided high-speed roads, dangerous roadsides, high-speed cross roads and urban settlements without footpaths all being considered as in accordance with the standards at certain volumes of traffic and therefore deemed acceptable by road agencies and engineers. In many cases the belief that road crashes are the road users’ fault has provided a convenient excuse by funding agencies, politicians and engineers for maintaining the status quo. That is, within the constraints of available budgets, road authorities have had to compromise on road safety performance – and accept a level of death and injury on the road network.

…

The key to an appropriate level of investment in improved road safety is the recognition of those who benefit from reductions in road trauma (emergency services, hospitals, health and welfare systems, insurers, business and treasury) as opposed to the traditional organisations involved in funding and managing the road network (road agencies).

…

It is worth noting ….. that specific or additional Safe System funding is not needed when Safe System principles are integrated in the process of building new infrastructure from the outset. This will actually save money in the long term, both in the health system and in the transport system through avoiding retrofitting.

3. Assisting Road Users to Be Safe Through Planning and Design

Planning, road design and traffic management approaches in Australia and New Zealand have historically had a strong focus on optimising conditions for the mobility and movement of traffic rather than a human-centric design focus. A feature of this emphasis has been the creation of a road environment that is heavily reliant on the road users making the right decisions under all types of circumstances. It is clear that in order to have a different outcome in the future, things must be done differently from the past.

Some key developments that are likely to influence future road design and safety solutions are discussed in this section. Collectively they represent a paradigm shift in the way that movement is considered and catered for. Increasingly there will be a focus on more human-centric design, taking into account a renewed understanding of errors, road user performance and how the environment can be better aligned to improve the performance of road users especially in critical situations.

3.1 Safety and road function

A functional road hierarchy is an important consideration when considering safe infrastructure. Although the distinction between a motorway and a local road may be evident, many of the practices and treatments evident on collector roads are also generally evident on arterial roads (such as parking, access and speed limits). This makes a hierarchical approach to safety difficult as there is not a strong distinction about what is desirable and what is not desirable from a safety perspective.

As outlined in Table 2.1, a key aspect of the Dutch “Sustainable Safety” approach is the functionality of roads. Roads are generally engineered to reflect their functionality in a network hierarchy according to Aarts, Van Nes et al. (2009):

- **Through Roads**: enables travel between origin and destination as fast and as safely as possible (traffic has the highest priority)
- **Access Roads:** provide direct access to properties at the origins and destinations (traffic has lowest priority)
- **Distributor Roads:** connect through roads with access roads.

The types of road design element that are adopted is strongly influenced by the road functionality and the Dutch strive to establish roads that are safe and credible roads for road users. In other words, the attributes of the road including design elements, intersection types, access control, speed limits and adjacent land use meet the expectations of the road user in relation to road purpose and functionality and provide a “self-explaining road”. In this way, the road user is encouraged to adopt safer behaviours in relation to travelling speeds and interactions with other road users.

The Dutch have identified specific road and environmental characteristics and their influence on the speed behaviour of motorists as shown in Table 3.1. These features can be utilised when designing new roads or retrofitting existing roads.

Table 3.1: Road Infrastructure elements and their influence on speed

Road Elements	Accelerators (intuitively elicit a high speed)	Decelerators (intuitively elicit a lower speed)
Tangents	Long tangents	Short tangents
Physical speed limiters	Physical speed limiters not present	Physical speed limiters present
Openness of the situation	Wide and open road surrounding	Narrow and closed road surrounding
Road width	Wide road	Narrow road
Road surface	Smooth road surface	Rough road surface

Source: International Transport Forum (2016)

While local government has been adopting Local Traffic Area Management (LATM) treatments for decades mainly in the context of reducing speeds and discouraging cut through traffic (see *Austroads Guide to Traffic Management: Part 8 Local Area Traffic Management*), a resurgence in devices with many similar features is apparent for their ability to achieve harm reduction and alignment with the Safe System. As is discussed in Section 5, such treatments are finding implementation on busier collector and arterial roads where they are specially designed to meet the specific needs of those road conditions. Other treatments that can also be utilised include perceptual countermeasures (using road markings or guideposts) and electronic feedback signs.

An example of retrofitting "self-explaining" roads to a suburb in Auckland follows. The project is notable as aside from the speed reductions and safety outcomes, it was achieved without lowering the posted speed limits in the area and at a comparable cost to a standard LATM speed hump treatment program.

Case study: Point England, New Zealand

The suburb of Point England in Auckland, New Zealand, is typical of a medium-density suburb. The local and collector roads are wide enough to accommodate traffic and parking, but had a lack of differentiation in the look and feel of their function (Mackie 2010). As a result, the suburb had an issue with speeding and a high variability in traffic speeds. There was also a history of a large number of crashes.

Through a process of analysis, public engagement and design, a self-explaining roads template was created for the area (International Transport Forum 2016). The aim was to create local and collector roads that were self-explaining in their function and achieved traffic speeds aligned with Safe Systems principles, without simply resorting to lowering the speed limit (Charlton, Mackie et al. 2010). In order to achieve this, design speeds of 30 km/h for local roads and 40 km/h for collector roads were selected and the self-explaining roads principles were implemented into practice along 11 kilometres of roads throughout Point England.

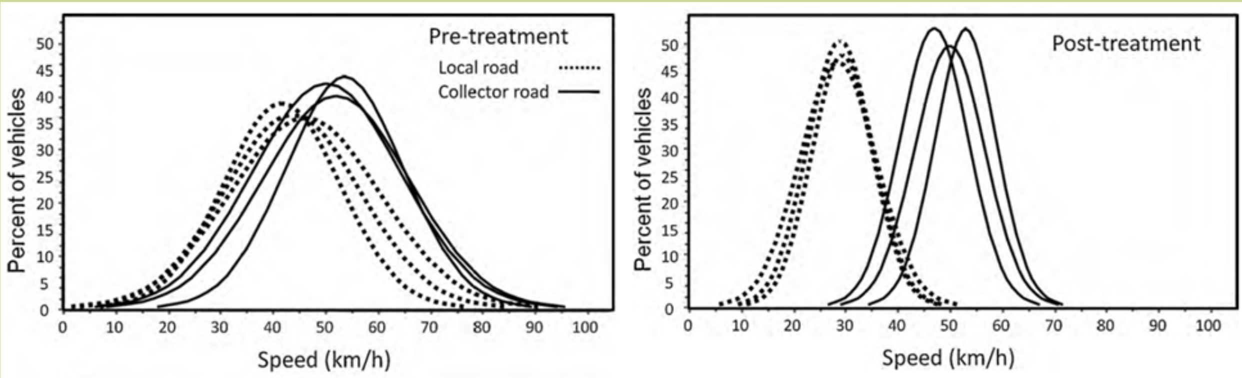
Local (left) and collector (right) self-explaining roads

Source: Charlton, Mackie et al. 2010, Mackie 2010

Before and after analysis of speeds along the roads were carried out and showed a substantial reduction in both the overall speeds and the variability in speeds. Average speeds along local roads were reduced to below 30 km/h, while average speeds along collector roads of around 50 km/h were achieved. Video analysis also revealed an increase in the amount of pedestrians using the roads, with pedestrians appearing to be less constrained and vehicles often giving way to pedestrians (International Transport Forum 2016).

The redesign was also achieved at low cost – about the same as that required for conventional speed hump treatments – with more homogenous reductions in speeds being achieved and greater community opinion than what is normally achieved using conventional local area traffic management treatments (Charlton, Mackie et al. 2010, International Transport Forum 2016).

Distribution of vehicle speeds before (left) and after (right) self-explaining roads treatment for both local and collector roads where the treatment was undertaken



Source: Charlton, Mackie et al. (2010)

3.2 New thinking about road corridor space and movement

Urban planning and design has undergone considerable transformation 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 what could be regarded as 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 (2016b). 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 2016b).

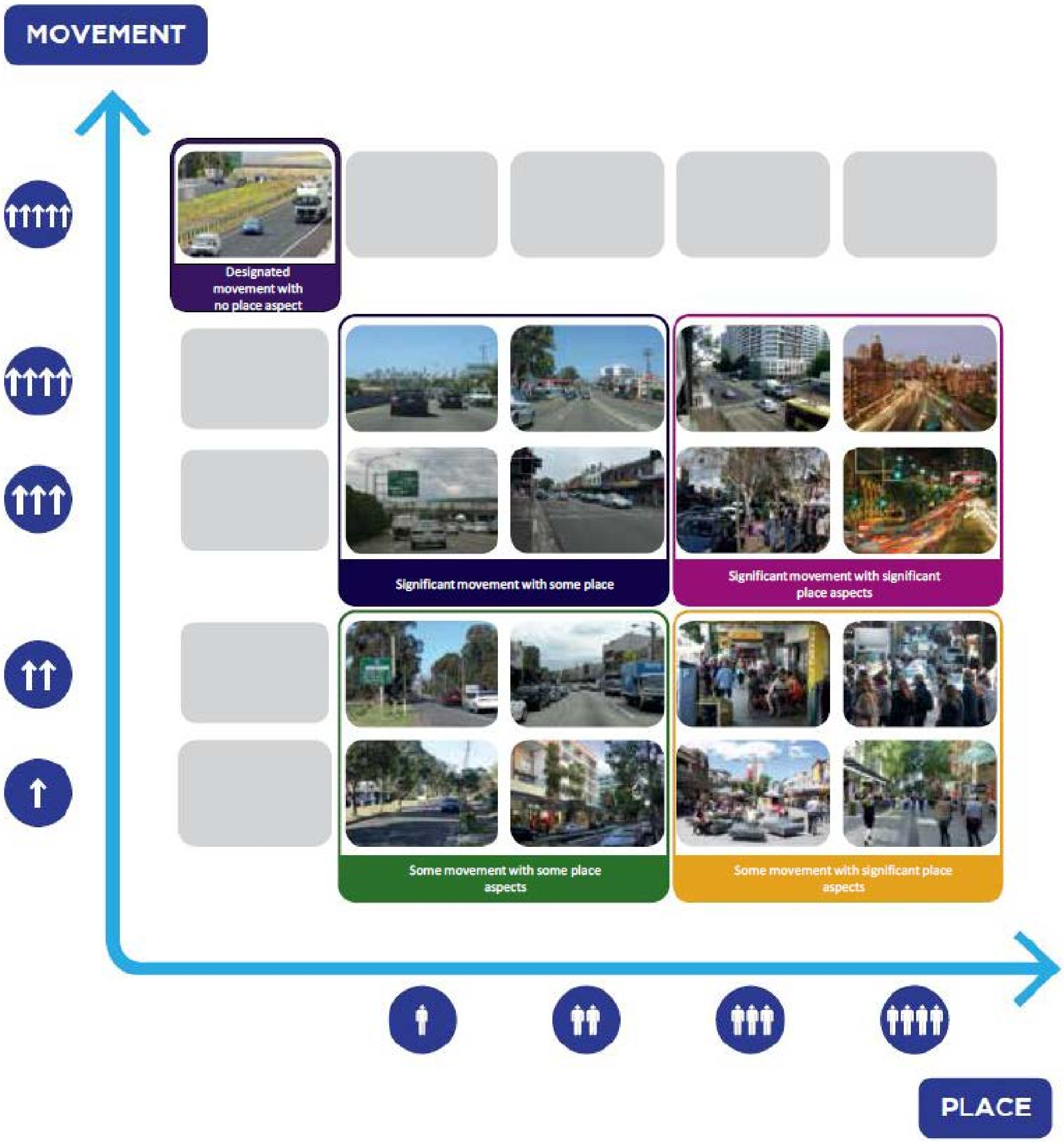
For Movement, the role of a road is to accommodate through traffic, thereby forming part of the wider traffic network. The road may be used by different modes, including private vehicles, heavy vehicles, buses and light rail. In this role, the primary function of the road is to provide a conduit for 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 3.1) 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, identified by its role in the broader network. The position of the road on the “place axis” is based on the strategic importance and community value of the road to act as a place (Figure 3.3). The process of how to determine the Movement and Place status for a road are discussed in further detail in (Government of South Australia 2012, Austroads 2016b).

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.

Figure 3.1: An example of a Movement and Place matrix



Source: Government of South Australia (2012)

The following guidance in Table 3.2 briefly summarises design philosophies towards specific road user types and situations in the context of the South Australian "Link and Place" approach (Government of South Australia 2012).

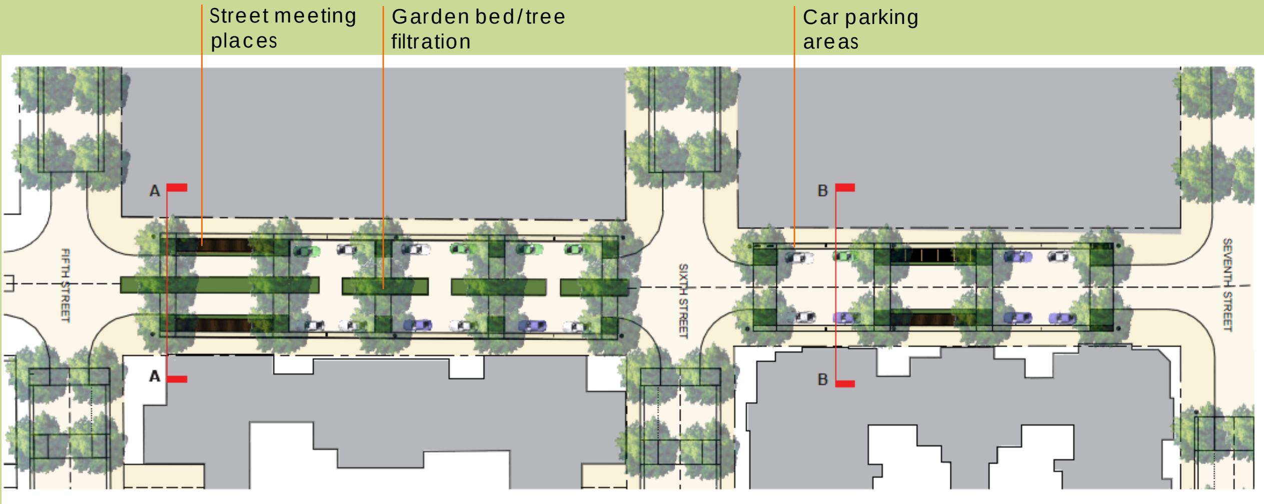
Table 3.2: Design philosophies aimed towards specific road user and road user interaction types

Road user/interaction type	Design philosophy
Cars	• Establish appropriate speed environment, in accordance with street's strategic role • Good connections from 'slow' local networks of 30 km/h and below to faster arterial networks • Preference for passive speed control measures • Use urban design techniques for speed control: minimising carriageway width, limiting visual length of street sections, varying surface materials at intersections and crossings, etc.
Cycling	• Cyclists considered and incorporated into all streets, as priority street users • Preference for sharing street space in low speed environments • On busier streets: segregated continuous lanes and safe crossing points • Cycle paths should be direct, continuous, smooth and barrier-free • Good connections to important destinations and end-of-trip facilities • The optimum position for locating a cycle lane is between the pedestrian footway and any car parking spaces
Walking	• Pedestrians should be prioritised in most street environments, with facilities such as footways of 1.5 m and wider, crossing facilities at appropriate locations and waiting times at signals not exceeding much beyond 60 seconds, climate protection, seating at frequent intervals, good levels of lighting, etc • Pedestrian needs should be considered for all street types • Streets should be designed on a 'human/pedestrian scale', responding to the needs of pedestrians • Underpass-type crossings should be avoided • Streets should offer good connections of small grain • Streets should encourage staying activities and interaction for a diverse range of users • Street environments should be adaptable and flexible
Shared Streets	• An alternative approach to street design suitable to streets with 'design' speeds below 25 km/h • 'Shared streets' integrate street functions by removing barriers separating users • It calls for a different design approach, avoiding conventional signage, traffic islands and markings, etc. • Local expression within the street space should be enhanced and encouraged

3.3 Implications for road safety practitioners

There are strong synergies between urban design and the harm minimisation objectives of the Safe System approach to road safety. Much of this revolves around the desired functionality of a street and its surrounding area and taking into consideration the many activities that are supported beyond the motorised traffic movement function that streets provide. This represents a holistic perspective of road safety taking into account the many activities and circumstances that could lead to conflict in a corridor. Where applied, this perspective is likely to result in a greater adoption of design elements that avoid and minimise harm over and above what could be achieved with a traffic-centric assessment of the corridor. Importantly, the most vulnerable road users provide the starting point for considerations.

Main Street Design – Bowden, South Australia



The Main Street in Bowden was designed to cater for all road users with the starting point of pedestrians – the most vulnerable road users. The design of the street incorporates trees and objects in the roadway that support a very low speed environment and also provide a pleasant environment for non-mobility related activities. In essence, the design represents a self-explaining road where it is apparent that motorised traffic function is secondary to other human activity.

Specific features of the design include:

- A shared single surface street environment resulting in highest pedestrian accessibility
- Median garden bed/tree planting that will encourage slow speeds and provide shading
- Street sections of varying alignment (median planting on one section will control driver speed by introducing variety
- Wide meeting areas on both sides of the street to promote staying activities
- 'Design speed' of approximately 30 km/h, creating safe cycling and pedestrian environment
- High priority for street trees with a view of creating a continuous tree canopy.

Practitioners should be open to the possibilities that urban planning can contribute to safety (amongst a myriad of other benefits) and seek opportunities where the common objectives of both can be combined in projects. The best features of "self-explaining" roads should be considered when considering treatment options in urban areas. On Movement corridors the design is usually for higher speeds and pedestrians and vulnerable road users need to be separated from higher speed / mass vehicles. At Place locations a lower speed environment is typically required and the vulnerability of pedestrians and cyclists provides the starting point for design considerations. The environmental amenity that is created in these locations should also encourage the many social activities that occur. It is important that decisions are made about the road function so that the right infrastructure and speed environments can be created to support this. The community has a role in defining this function and therefore ownership of the design and appropriate speeds. The next chapter outlines how speed is such an integral part of road functionality.

4. The Role of Speed in Harm Minimisation

What do we know?

- Speed management is at the core of a forgiving road transport system
- Impact speed is a primary determinant of injury outcome
- Travelling speed also influences vehicle controllability and crash likelihood
- The risk of loss of control and injury increases with travelling speed
- In a 60 km/h speed limit zone, the risk of involvement in a casualty crash doubles with each 5 km/h increase in travelling speed above 60 km/h
- Reducing rural speeds by 5 km/h is likely to reduce rural casualty crashes by about 30%
- Reducing urban speeds by 5 km/h is likely to reduce urban casualty crashes by 26%
- Reducing urban speed limits would lead to major reductions in pedestrian and cyclist injury
- Speeds limits have usually been regarded as a trade-off between desired mobility function and other competing demands including safety
- The understanding of the relationship between speed and injury outcomes will continue to be refined over time
- Low speed thresholds exist (20 km/h) when taking into account both fatal and serious injury
- Aspirational impact speeds aligned to Safe System performance are:
  - 30 km/h where pedestrians and cyclists interact with traffic
  - 50 km/h where cars may collide at right angles at intersections
  - 70 km/h where cars can collide head-on
- The effect of reducing speed limits on travel times is commonly over-estimated
- Road users can be poor at assessing risk on the road especially in relation to speed so infrastructure elements to support road user behaviours are required.
- Any way in which planning, road design and traffic management can guarantee safe speeds at facilities will be highly beneficial (eg raised pedestrian crossings) and aligned with harm minimisation principles
- Small changes in speed can have large benefits so any reductions are better than nothing at all
- Speed management has the potential to deliver the highest injury reductions at the lowest cost when compared to other safety interventions; however this can only be regarded as a primary treatment if reductions are achieved down to survivable levels
- Road function and speed management are inextricably linked; the best features of self-explaining road design are likely to maximise the ability to achieve harm minimisation outcomes in the context of “Movement and Place” considerations.

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.

The effect of a small travelling speed change into an injury outcome

A small change in travel speed
↓
A relatively large change in stopping distance
↓
A much larger change in impact speed
↓
A still larger change in impact energy
↓
A very large change in probability of death and serious injury

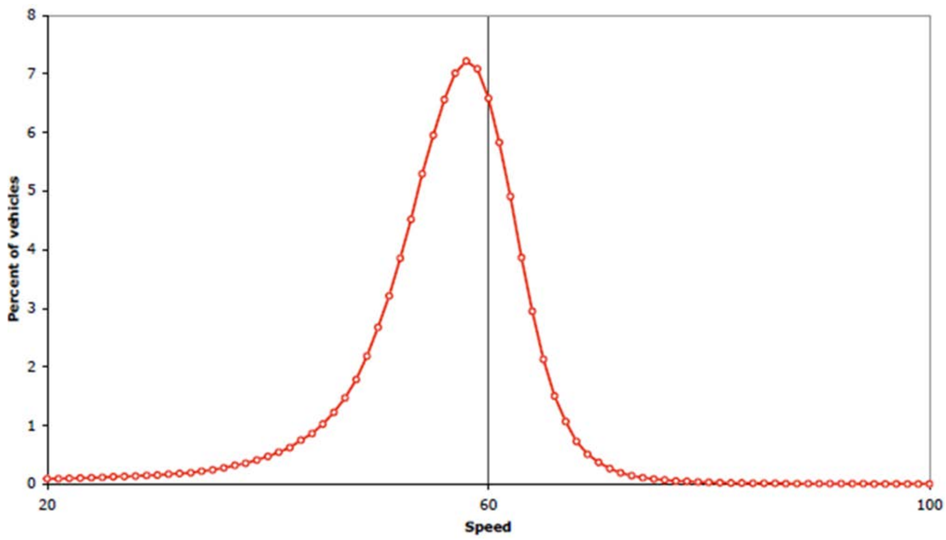
In this context, all aspects associated with speed are important. Even small reductions in travelling speed can have large effects on injury outcomes and the creation of an inherently safe road system is largely dependent on the kinetic energy in the system. The transition towards the Safe System will be dependent not only on the adoption of speed limits compatible with harm minimisation but also the integration of solutions that guarantee safe interaction speeds where conflict occurs or where lane departure is possible (e.g. with driver assist technologies). From a road infrastructure perspective, this means the greater use of design features to ensure that survivable interaction speeds are actually being achieved.

4.1 The range of speeds on the road network

Vehicle speeds on the road network tend to follow a normal distribution with the bulk of vehicles slightly above or slightly below the speed limit (see Figure 4.1). It is usual that mean speeds are a few kilometres per hour below the posted speed limit and there is a tail of a few vehicles travelling at very high speeds and vehicles at very low speeds. It therefore follows that the same situation will exist on the approaches to intersections or on mid-block sections of road. Although the planning, design and management of the road network is based on certain operating speeds, historically less was done from the engineering side to guarantee that speeds of interaction were actually safe.

In this context, road users are expected to make critical decisions at intersections or when overtaking, and perceive and compensate for the range of speeds usually encountered on the network. Some of the best speed management treatments provide very clear guidance on the appropriate speed, guarantee safe speeds of interaction and also narrow down the variation in speeds encountered.

Figure 4.1: Example of a typical speed distribution for an arterial road

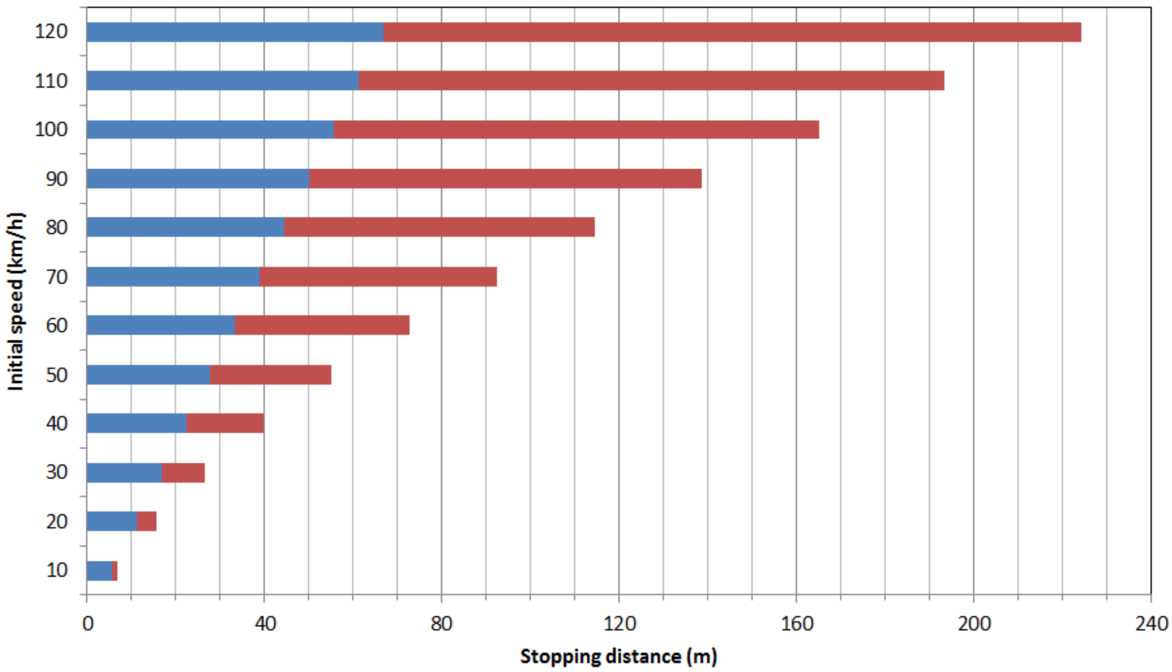


Source: CASR

4.2 Stopping distance

A fundamental aspect of safe road design is the provision of adequate sight distances where conflict between road users can occur or where there might be an objects lying on the road. Assumptions are made that drivers and riders can recognise a safety critical situation and respond to the situation in a timely manner (usually a 1.5 to 2.5 second reaction time). If braking, the distance required to bring a vehicle to rest to avoid a collision is reliant on the reaction time, travelling speed of the vehicle and the condition of the pavement surface. As shown in Figure 4.2, higher speeds result in proportionately longer stopping distance.

Figure 4.2: Stopping distance as a function of reaction time and braking on a wet sealed pavement surface*

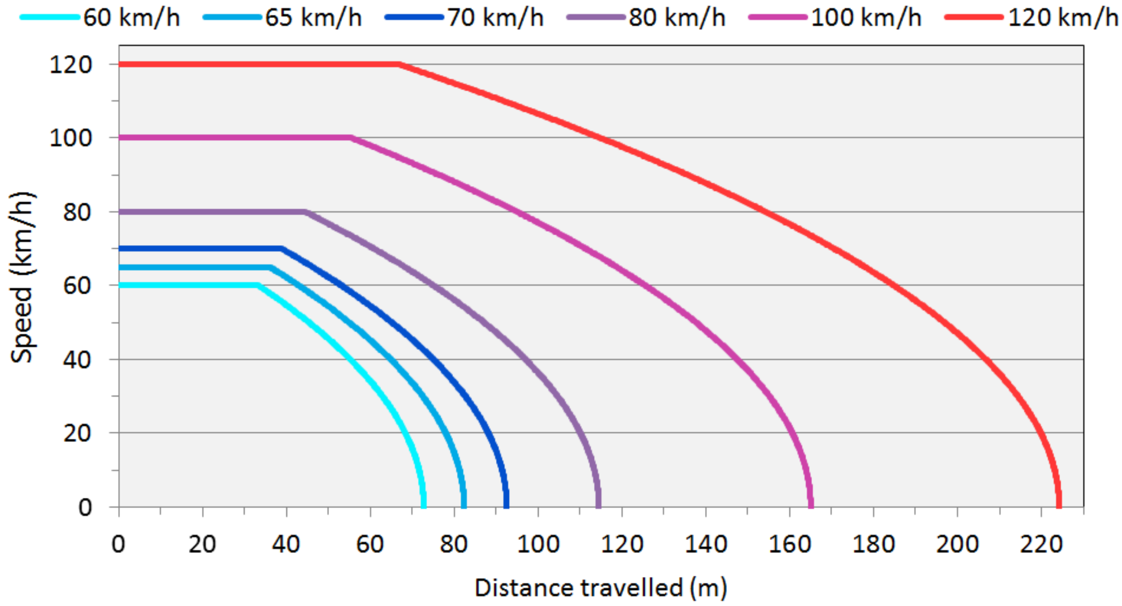


*Note: * Combined distance travelled by a vehicle during the time it takes for a driver to react (blue segment) and then brake (red segment) at different initial travelling speeds. A reaction time of 2.0 seconds and a friction factor of 0.36 are assumed constant. Situation represents a 90th percentile value and a wet sealed pavement.*

The first component of stopping, reaction time, is the time it takes for a driver to see the conflict and react to it by initialising braking. During this time, no braking is actually performed and the vehicle's speed does not change noticeably. The distance covered during the reaction time is linearly proportional to the initial travel speed. The second component of stopping is braking. This is the time from when the driver initializes braking to the time the vehicle stops. Braking distance is proportional to the square of the initial travel speed.

While an increase in travel speed of 5 or 10 km/h may not seem substantial, it has a considerable effect on stopping distance. Figure 4.3 shows how speed decreases under typical braking conditions on a wet sealed pavement. Very little speed is actually lost in the early stages of braking and most speed is lost in the final stages of braking once a considerable amount of distance has been covered. Therefore any late reaction and braking is likely to be biased towards higher impact speeds.

Figure 4.3: Speed versus distance travelled for vehicles travelling at different initial speeds before braking on a wet sealed pavement surface*



*Note: * A reaction time of 2.0 seconds and a friction factor of 0.36 are assumed constant.*

While the various sight distance considerations form an essential foundation of road design, from a Safe Systems perspective compensation is still required for the scenario that a driver or rider does not react in time and impact forces are still beyond the threshold to serious injury.

4.3 Energy transfer

Kinetic energy is the energy associated with the movement of an object and is determined by a combination of speed and mass such that:

$$E_k = \frac{1}{2} m\, v^2 \qquad (1)$$

where

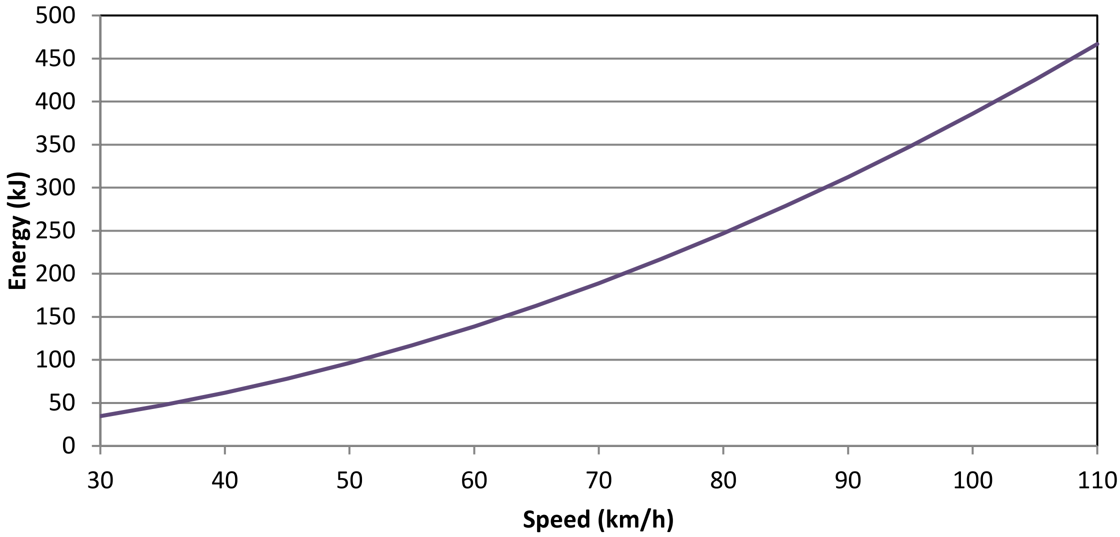
E_k = kinetic energy (Joules)

m = mass (kg)

v= velocity (m/s)

A 1000 kg vehicle travelling at 60 km/h will have 139 Kilojoules (kJ) of kinetic energy. The same vehicle travelling at 80 and 100 km/h will have 247 and 386 kJ of kinetic energy respectively. A plot of the relationship between speed and kinetic energy is shown in Figure 4.4. As a comparison, in terms of potential energy, this is the equivalent to the same car falling 14 m, 25 m and 40 m respectively.

Figure 4.4: The relationship between speed and kinetic energy (assuming constant mass)



The squared relationship with speed means that there is a proportionately higher increase in energy as speed increases. Doubling the speed will result in four times the kinetic energy and tripling the speed will result in nine times the kinetic energy. It is therefore apparent that small changes in speed can have large effects on crash energy.

Figure 4.5 demonstrates this in the context of frontal deformation between identical vehicles striking an object at 60 km/h and 100 km/h. Assuming equal mass, the faster vehicle at 100 km/h has 3.4 times more kinetic energy than the slower vehicle at 60 km/h and the outcomes in terms of vehicle deformation are apparent. Note that the collision scenario represents a full frontal collision where the load is distributed across the full front of the vehicle. Such a collision with a tree or an offset with another vehicle would be much more severe.

Kinetic energy has a linear relationship with mass and a doubling of mass doubles the kinetic energy. Therefore an eight ton truck will have eight times the kinetic energy of a one ton car for the same collision.

In reality, the exchange of energy in collisions between vehicles, objects and people is more complicated and there can be many determinants of specific injury such as vehicle orientation in car to car crashes. However, managing energy in the road transport system is a key to managing injury outcomes. Outside of vehicle design, speed management and safety barriers provide a key way to manage kinetic energy. With unprotected road users, safe speeds remain the most practical way for addressing safety. Due to their mass, the consequences of crashes involving heavy vehicles are difficult to mitigate if speed is not adjusted.

"In road injury epidemiology, kinetic energy is the pathogen", LS Robertson – Epidemiologist.

Figure 4.5: Difference in deformation striking a solid object at 60 km/h and 100 km/h

Source: ANCAP

4.4 Complications in perceiving speed risk

Speed limits were initially adopted with little understanding of safety in relation to crash incidence, vehicle occupant protection and vulnerable road users. A range of limits were historically fixed according to an adopted hierarchy and roads were generally designed to maintain these speeds with less consideration given to the benefits of adopting lower speeds on the basis of safety or infrastructure cost. These practices have resulted in a legacy that is taking considerable effort to change, mainly because the population has been living with "high" speed limits not aligned with injury reduction for many decades. Given that many in the population have personal experience travelling at a high speed, it has been difficult to communicate the scientific evidence that population risk can be lowered through speed management in a credible manner.

One of the reasons why the communication on speed limits may appear contradictory is shown in Figure 4.6. Portrayed are six different road environments each with different traffic conditions and safety features. It is evident to road users that risk on the road is not managed in a consistent manner across the network as each of the six road environments has a 100 km/h speed limit. In fact, on this basis a counter argument could be made that because the speed limit is the same in each environment, speed is actually not regarded as a critical variable. Much of the Dutch approach based credible speeds seeks to address this type of inconsistency.

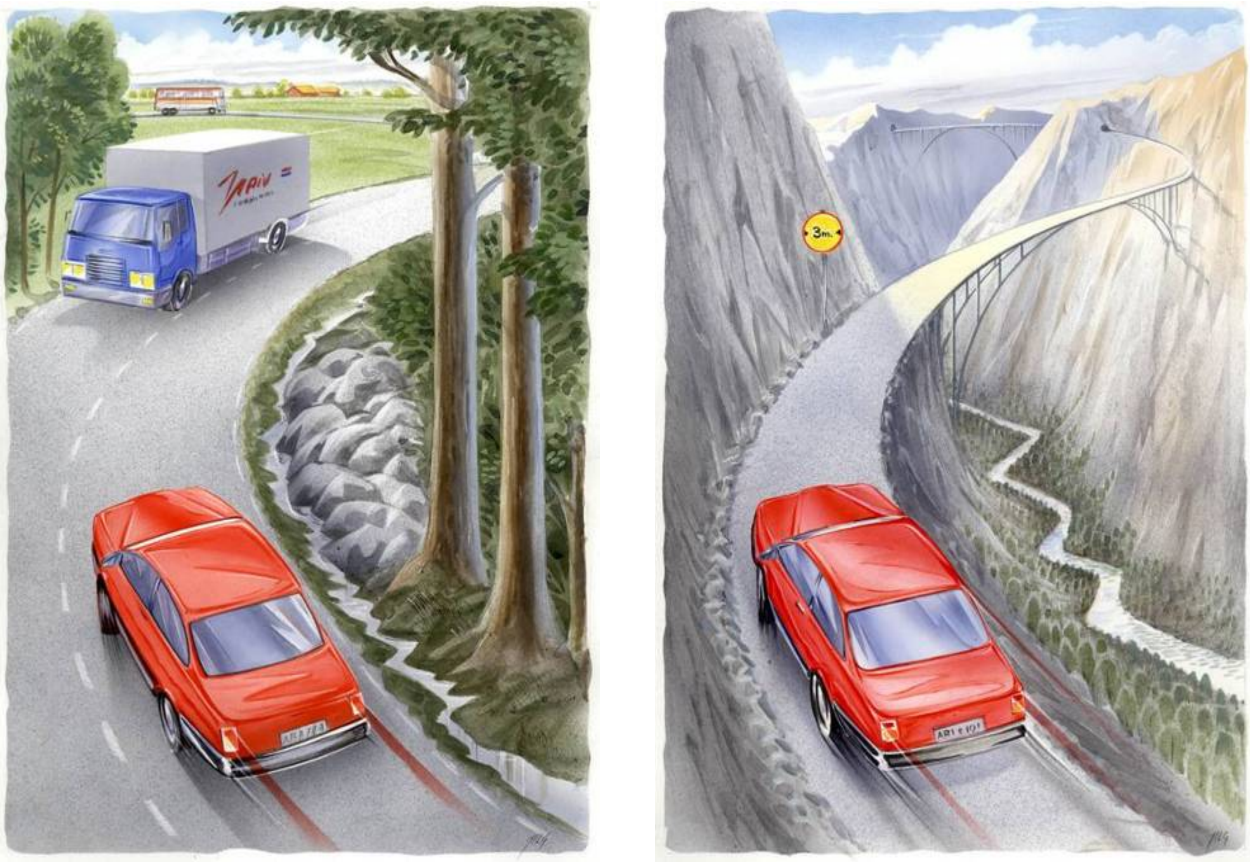
Drivers and riders become habituated to risk as they repeatedly perform tasks within the road system with little or no ill-consequence over a lifetime. The fact is there is very little feedback in relation to risk when using the road system. Given that the individual risk of crashing is small, a doubling of this small risk is also likely to go un-noticed. Often people build up a perception over a lifetime of driving or riding that travelling above the speed limit has very little or no negative safety consequence.

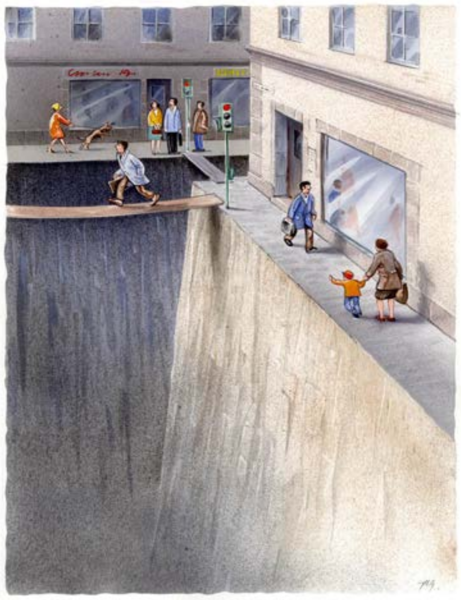
Figure 4.6: Six different road environments all with a 100 km/h speed limit

By contrast, people are generally aware of the risk associated with heights (i.e. potential energy) as the risk is reinforced over a lifetime of feedback. It is appreciated that trips and falls even at ground level have the ability to cause severe and sometimes permanent injury. It is therefore unacceptable to think that a reliance be placed on training and education to prevent people from falling off unprotected balconies. Instead a forgiving environment that is error tolerant is created where balconies are lined with barriers that prevent people from falling off even if they are young, old, distracted or impaired. Extending this analogy a little further, there is not specific cost-benefit analysis for individual balconies that takes account of height of the balcony, wind exposure, width of the balcony, age and experience of people potentially using it, nor the opinions of people in the neighbourhood as to whether it should be protected or not. There is an expectation that designers will provide buildings with balcony protection from falls regardless of circumstance.

Taking this perspective into account, Figure 4.7 shows how a road network appears in terms of the kinetic energy converted to potential energy. If road users were to perceive the energy in the road transport system as potential energy, it is likely that behaviours would be very different. When considering the driver in the car approaching the bridge with no guardrails, a universal response would be to slow down in the interests of self-preservation to maintain control of the vehicle so it did not fall off the bridge. This provides a stark contrast to the comfort people feel when passing other vehicles only divided by a painted centreline or trees close to the edge of the road.

Figure 4.7: Perceived and actual risk in terms of energy transfer





Source: Claes Tingvall, Swedish Road Administration

These factors combined with “Optimism Bias” makes it difficult for individuals to mitigate their behaviour in relation to speed without any supporting measures. Despite these challenges, speed management continues to be one of the most effective ways a transition towards a Safe System can be achieved. Although much focus has been placed on better aligning speed limits with injury reduction, there is significant opportunity to further support road users through road design features at points of elevated risk in the network.

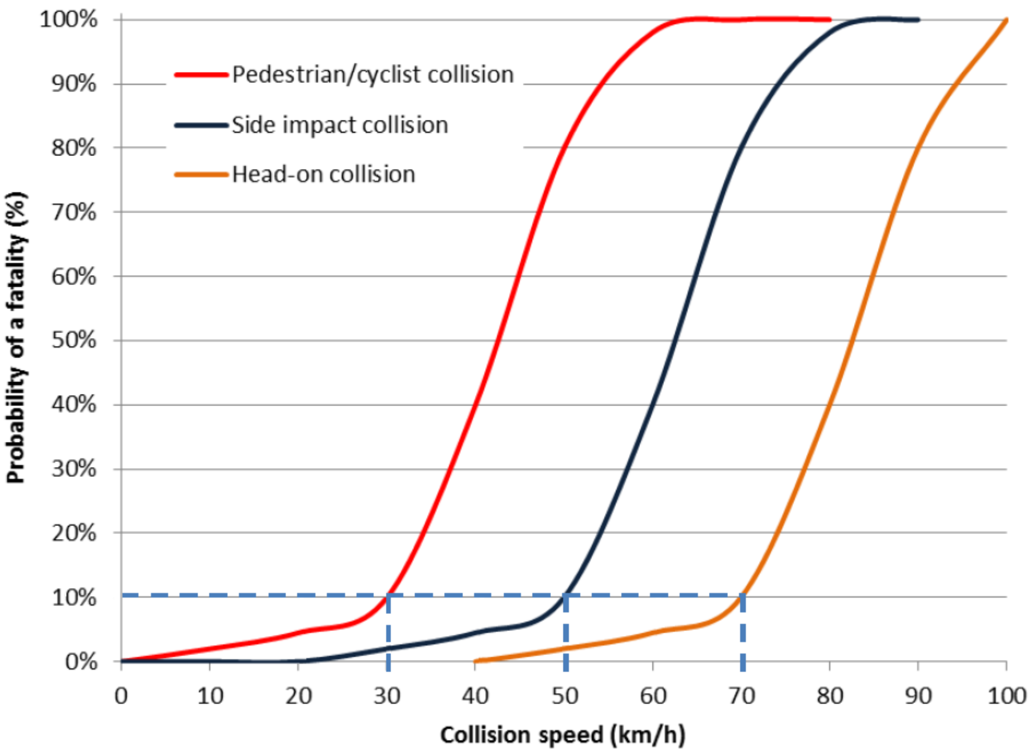
4.5 The association between impact speed and injury

A number of studies have shown the relationship between speed, crash likelihood and severity, with increases in speed increasing both the likelihood of a casualty crash occurring and the severity of injury to the crash participants (Jurewicz, Sobhani et al. 2015). It should be noted that research in this area is ongoing and while the specific definitions of tolerable risk and the shapes of curves may change, current indications are that impact speeds below around 20 to 30 km/h are necessary to prevent severe injury from occurring. As occupant and vulnerable road user protection improves amongst the vehicle fleet, the relationships are likely to change over time; however, the needs of the most vulnerable (the elderly and children) will need to be understood and considered as the aspirational governing design consideration.

4.5.1 Safe System speeds

The Wramborg curves (Wramborg 2005) have been adopted internationally to illustrate “survivable” thresholds against impact speeds as shown in Figure 4.8. 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 illustratory purpose of the curves, the 10% appears to have been universally adopted.

Figure 4.8: Relationships between collision speed and probability of a fatality for different crash configurations



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

Often referred to as the Safe System Speeds, the following aspirational operating speeds are as follows (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 this 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.

It is likely that 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.

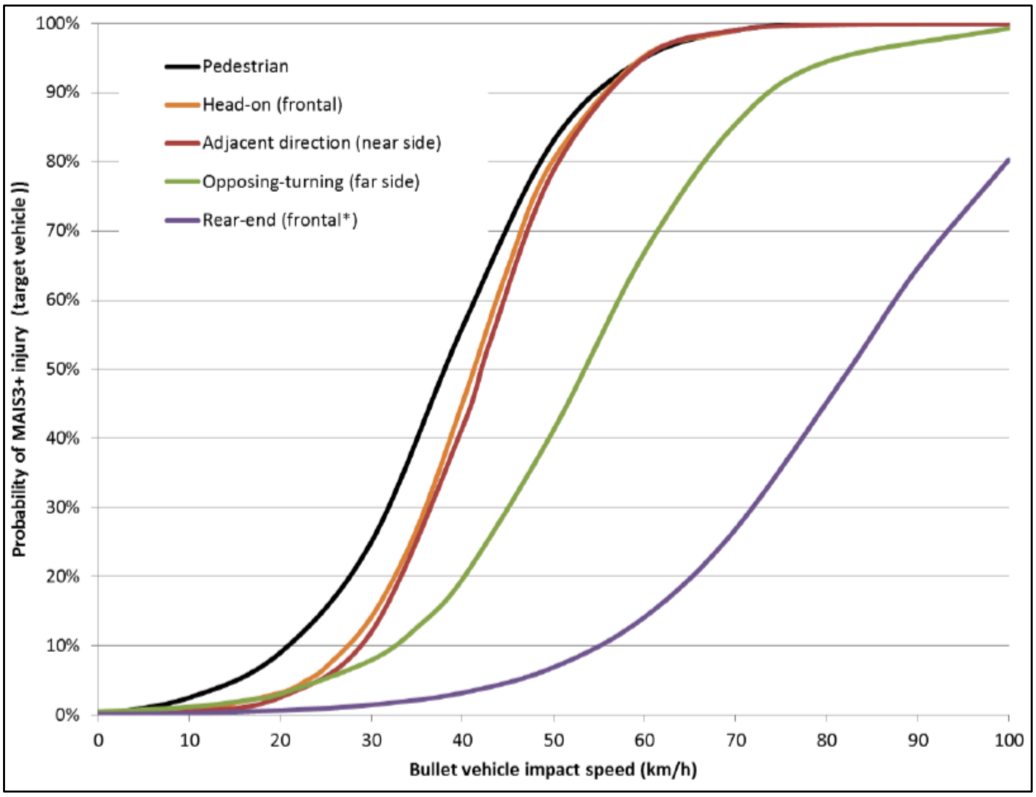
The adoption of 30 km/h in residential streets in Stockholm, Sweden

The following shows public communication material regarding the adoption of 30 km/h in all residential areas in Stockholm in 2004. Municipalities in Sweden were provided with the discretion to implement such limits commencing in 1998.

4.5.2 Further insights on speed and injury severity

There is strong evidence that indicates that the part of the vehicle struck will tend to determine the injury outcomes for the occupants. A number of studies have presented relationships between Delta V (the change in velocity during a crash for a given vehicle) and MAIS 3+ (a measure of traumatic injury). Figure 4.9 shows curves derived by Jurewicz, Sobhani et al. (2015) based on pedestrian crash models by Davis (2001) and vehicle crash models by Bahouth, Graygo et al. (2014).

Figure 4.9: Relationships between bullet vehicle impact speed and probability of a MAIS 3+ injury to a target vehicle occupant for different crash configurations



Source: Jurewicz, Sobhani et al. (2015)

The modelling shows that when considering (serious) injury in addition to fatality risk, the speed thresholds communicated by Wramborg 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.

These relationships provide a good indication of the changing nature of injury severity with increasing speeds. They are, however, limited to certain road user cohorts (e.g. adult front seat occupants) and further work is required to provide more generalized relationships that consider the effects of collisions for all road users of all ages.

These relationships are also generally only indicative of situations where mass inequality does not play a role. Mass inequality will play a large role in the severity of collisions between vehicles of substantially different masses. This is most clearly seen with vehicle/pedestrian collisions but is also relevant to collisions where heavy vehicles are involved.

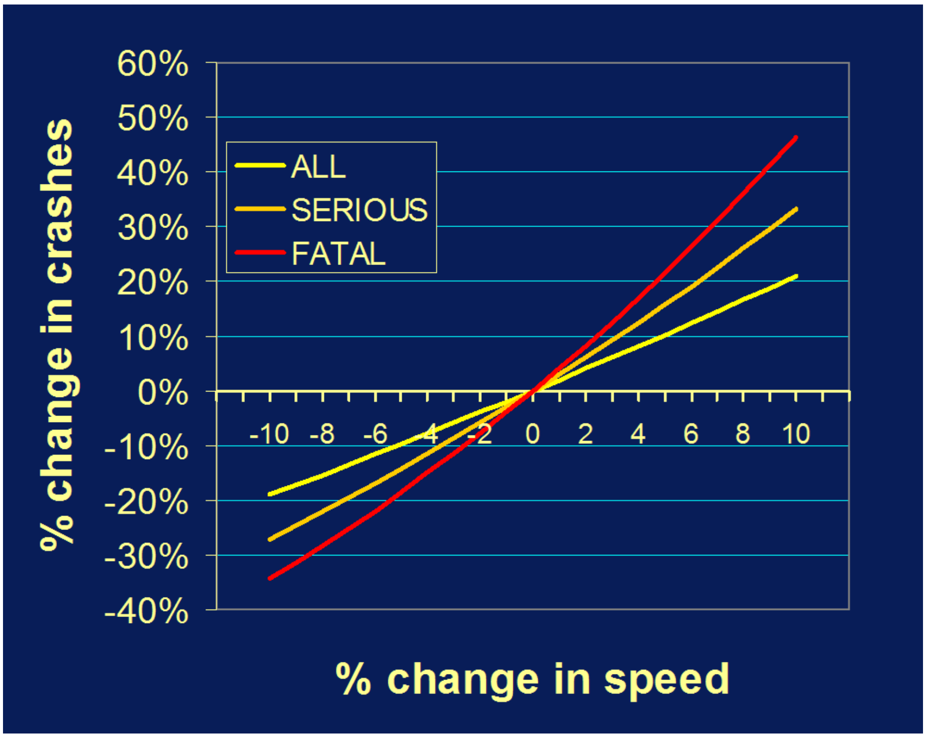
4.6 The association between lower travelling speeds and safety outcomes

There exists a large body of evidence associating lower speeds with reductions in injury crashes and injury severity. The following sections outline the most commonly referenced studies and the basis to their established relationships.

4.6.1 Nilsson's Power Model

A number of studies have modelled the change in crash and casualty numbers with a change in average speed. The Power Models presented by Nilsson (2004) describe the relationships between average speed, the number of injury or fatal crashes and the number of injuries or fatalities. These relationships are shown graphically in Figure 4.10.

Figure 4.10: Nilsson's Power Models relating changes in average speed to changes in crash numbers



Source: Nilsson (2004)

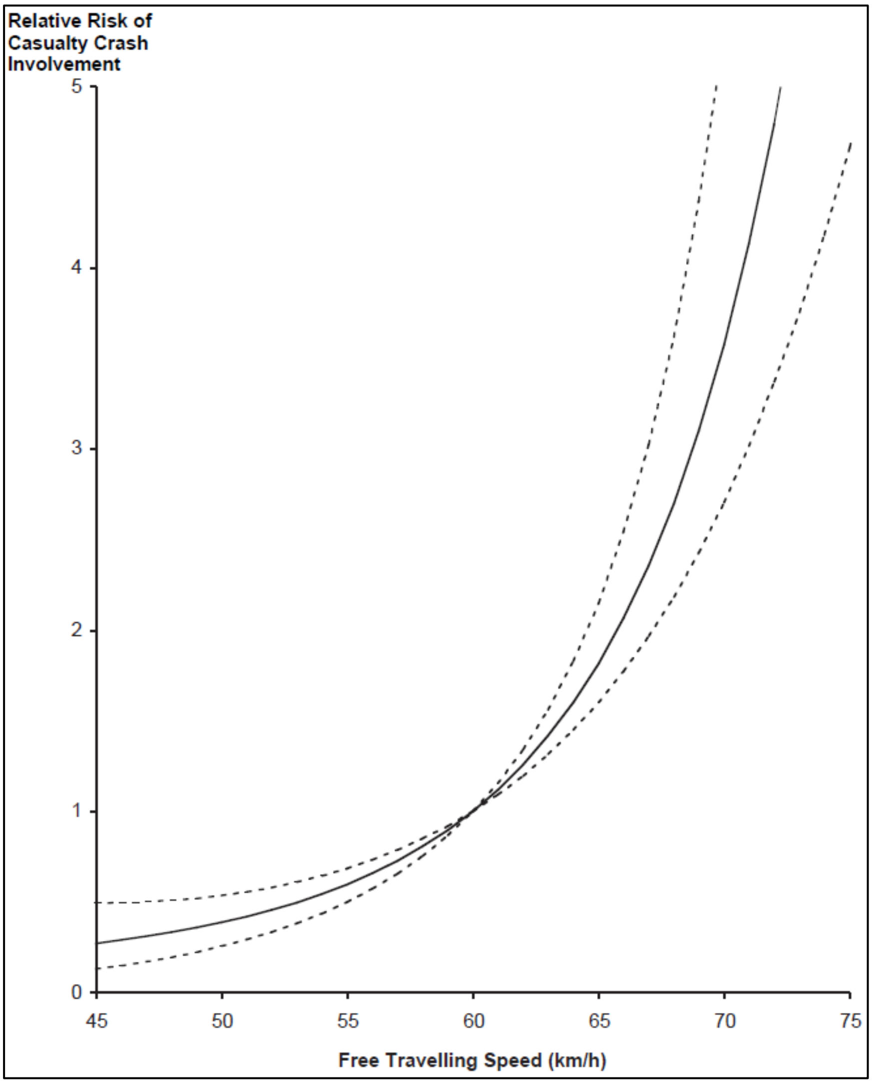
These models were validated against a number of speed limit changes in Sweden during 1967 to 1972. The initial speeds limits were mainly 90 km/h and included one of 130 km/h. Changes in speeds were a 20 km/h decrease, no change (control) or 20 km/h increase.

While Nilsson's Power Models are generally accepted as accurate for speed limit changes on high speed rural roads, their relevance to urban roads and within lower speed environments has been questioned (Cameron and Elvik 2008, Cameron and Elvik 2010, Elvik 2013). In a re-evaluation, (Elvik 2013) constructed a model with an Accident Modification Factor that was better at estimating the change in the number of injury crashes but worked less well for estimating the change in the number of fatal crashes. It was concluded that the Power Model provides a good estimate of the change in serious injuries and fatality numbers associated with traffic speed changes on rural highways. However, it is limited in its applicability to urban roads, where it substantially overestimates the change in crashes for a particular change in traffic speed (Cameron and Elvik 2010).

4.6.2 Kloeden curves

Kloeden, McLean et al. (2002) used in-depth crash investigations as part of a case control study in Adelaide to describe the relationship between a change in travel speed and the relative risk of being involved in a casualty crash. The first of these curves relates the risk of being involved in a casualty crash relative to travelling at 60 km/h in a 60 km/h speed limit zone in urban areas (Figure 4.11). Confidence intervals are shown as dashed lines on the graph.

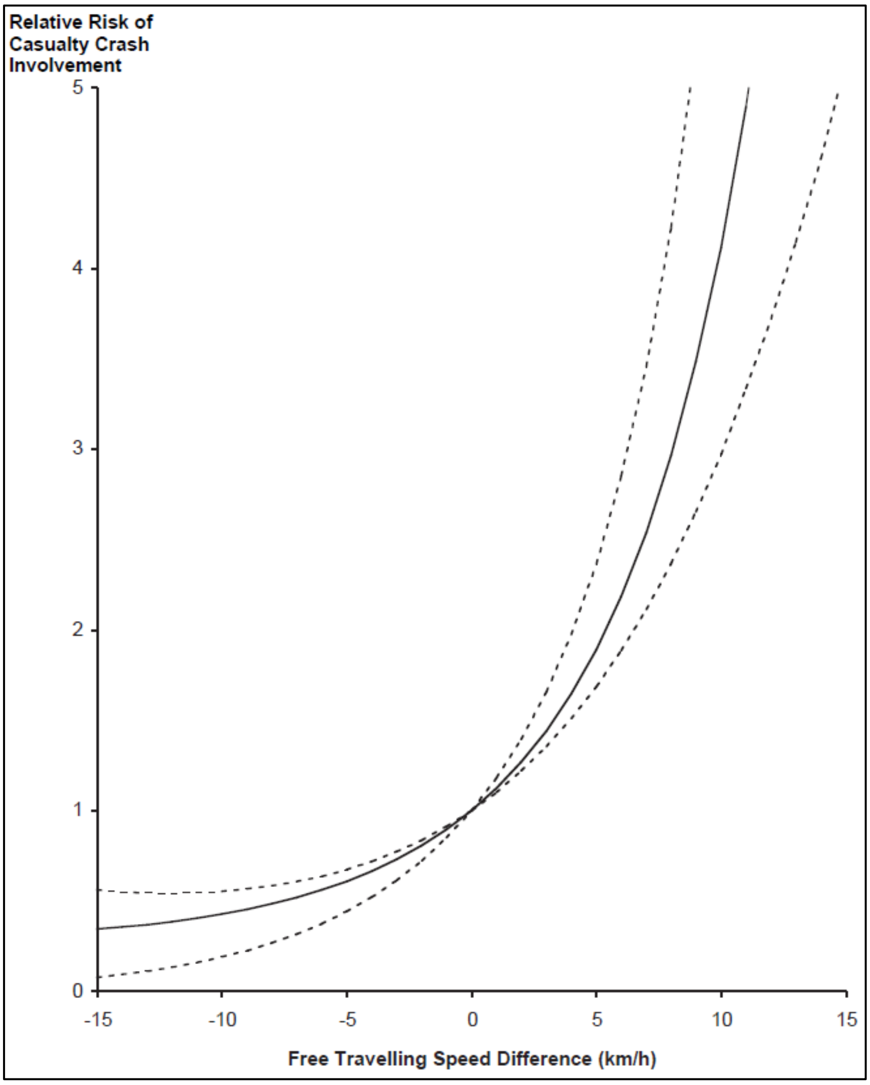
Figure 4.11: Risk of being involved in a casualty crash relative to travelling at 60 km/h in a 60 km/h speed limit zone



Source: Kloeden, McLean et al. (2002)

A second study derived a relationship for rural roads in South Australia. This was considered in terms of average speed because the roads studied had varying speed limits ranging from 80 to 110 km/h. Figure 4.12 shows the risk of being involved in a rural casualty crash relative to travelling at the average control speed for a given crash site.

Figure 4.12: Risk of being involved in a casualty crash relative to the average control speed for a given crash site



Source: Kloeden, McLean et al. (2002)

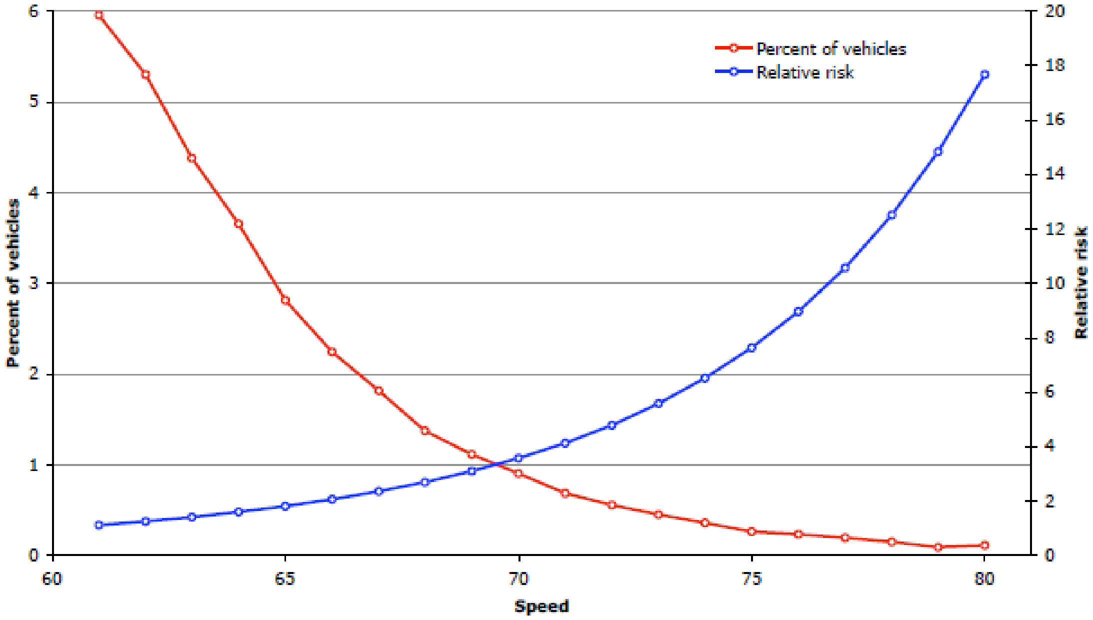
The work of Kloeden et al has led to an understanding that for every 5 km/h increase in travelling speed, the risk of being involved in a casualty crash doubles.

4.6.3 The case for addressing low level speeding

The previous studies point to a common conclusion: increasing speed increases the relative risk of being involved in a casualty crash. A positive relationship between increased speeds and increased crash severity has also been shown (Kloeden, McLean et al. 2002, Elvik 2013). The studies suggest reducing any level of speeding will have a positive effect on casualty crashes. Due to the non-linear relationship between speed and relative risk, reducing a driver’s speed from 75 to 74 km/h has a greater effect on personal risk (i.e. the effect on that individual) than reducing his or her speed from 65 to 64 km/h. However, the substantially larger population of low level speeders (such as those travelling at 65 km/h in a 60 km/h speed limit zone) means that reducing their speed will have a greater collective effect (i.e. an effect over the entire population) than reducing the speeds of the smaller number of drivers involved in higher level speeding (such as those travelling at 75 km/h in the same speed limit zone).

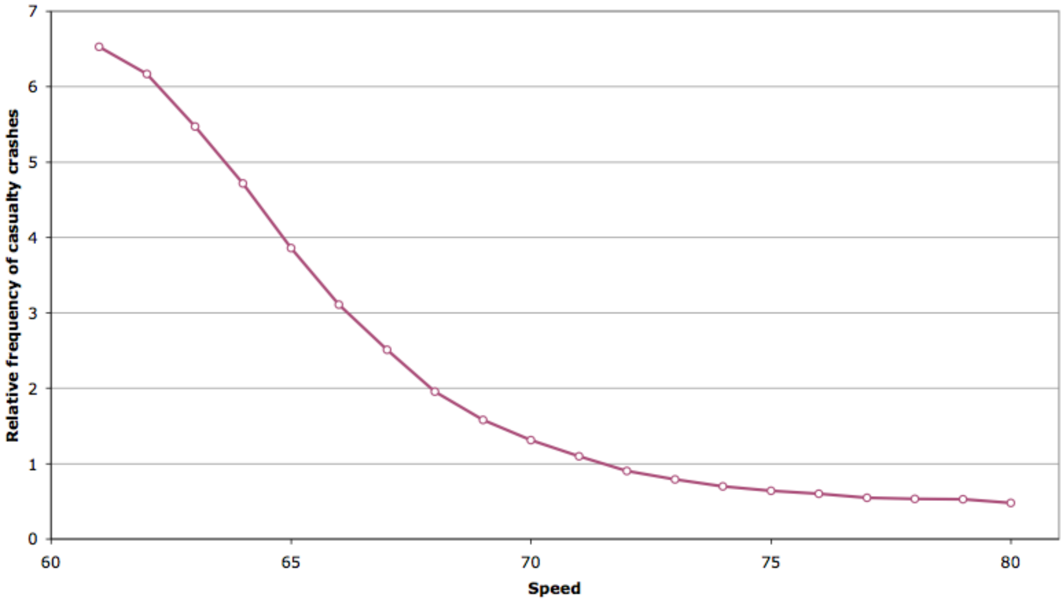
This relationship is demonstrated in a study by Doecke, Kloeden et al. (2011) which showed the relationship between different levels of speeding, reducing the speed of these drivers and the associated potential reduction in casualty crashes. This is presented in Figure 4.13, which shows the relationship between proportion of drivers travelling at different speeds over the speed limit and the relative risk of being involved in a casualty crash at different speeds. The results suggest that the greatest potential for reducing casualty crashes comes from reducing the speeds of low level speeders (Figure 4.14). In some cases, more than 50% of casualty crash reductions can come from reducing the speeds of only those drivers travelling at between 1 to 5 km/h above the speed limit.

Figure 4.13: Relative proportion of vehicles measured at speeds between 1 and 20 km/h over the speed limit in an urban 60 km/h speed limit zone and the relative risk of involvement in a casualty crash



Source: Doecke, Kloeden et al. (2011)

Figure 4.14: Relative frequency of casualty crashes of vehicles measured at speeds between 1 and 20 km/h over the speed limit in an urban 60 km/h speed limit zone



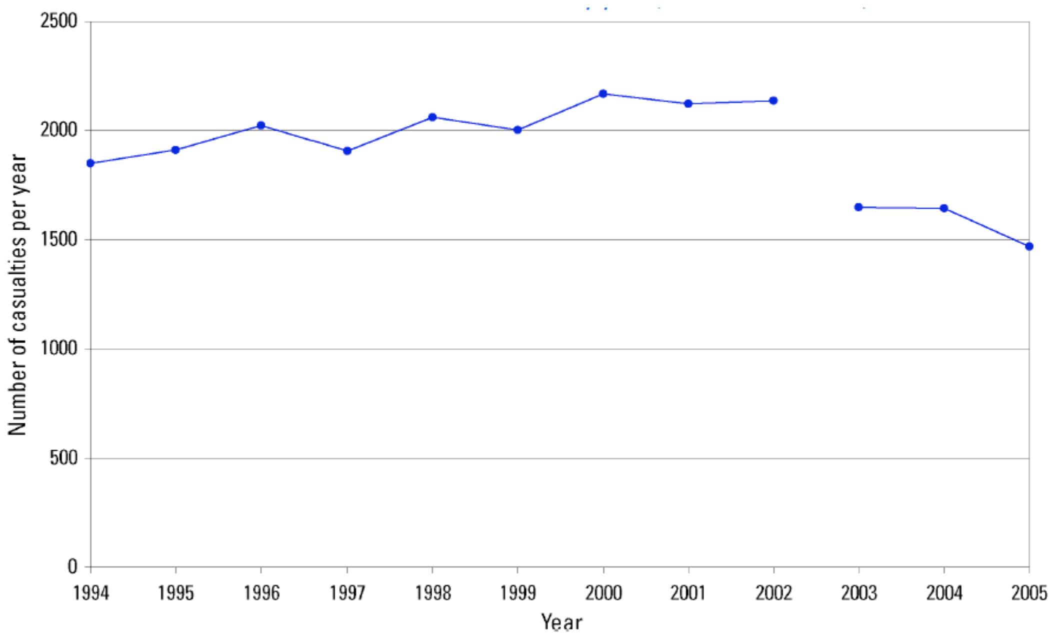
Source: Doecke, Kloeden et al. (2011)

Low level speeding (e.g. up to 5 km/h above the speed limit) is often perceived by the wider community as being inconsequential. The reality of low level speeding however is quite different. While South Australian data has been used to demonstrate this fact, the findings have also been replicated in other states.

4.6.4 Evidence from speed limit reductions

A study by Kloeden et al. (2006, 2007) reported on the effect of a change in the South Australian default urban speed limit from 60 km/h to 50 km/h in March 2003. The results of this study suggested a statistically significant reduction in the number of injuries, injury crashes and fatal crashes associated with the reduction in speed limit. The overall reduction in the number of casualty crashes was found to be 23.4% with an overall reduction in the number of casualties of 25.9%. While crashes along control roads (i.e. those where the speed limit did not change) also reduced after the speed limit reduction came into effect, a substantial step-change in the number of crashes on those roads affected by the change in speed limit could be seen (Figure 4.15). The actual reductions in mean free travel speed associated with the speed limit change were found to be 2.19 km/h (from 51.76 km/h to 49.58 km/h) one year after the change in speed limit, and 3.62 km/h (51.76 km/h to 48.14 km/h) three years after the change in speed limit. These findings not only show a reduction in casualty crashes, they suggest that the number of people being injured in each casualty crash also reduced as there was a greater reduction of casualties compared to casualty crashes.

Figure 4.15: Casualties per year on affected roads before and after the introduction of a 50 km/h urban speed limit (formally 60 km/h) in South Australia

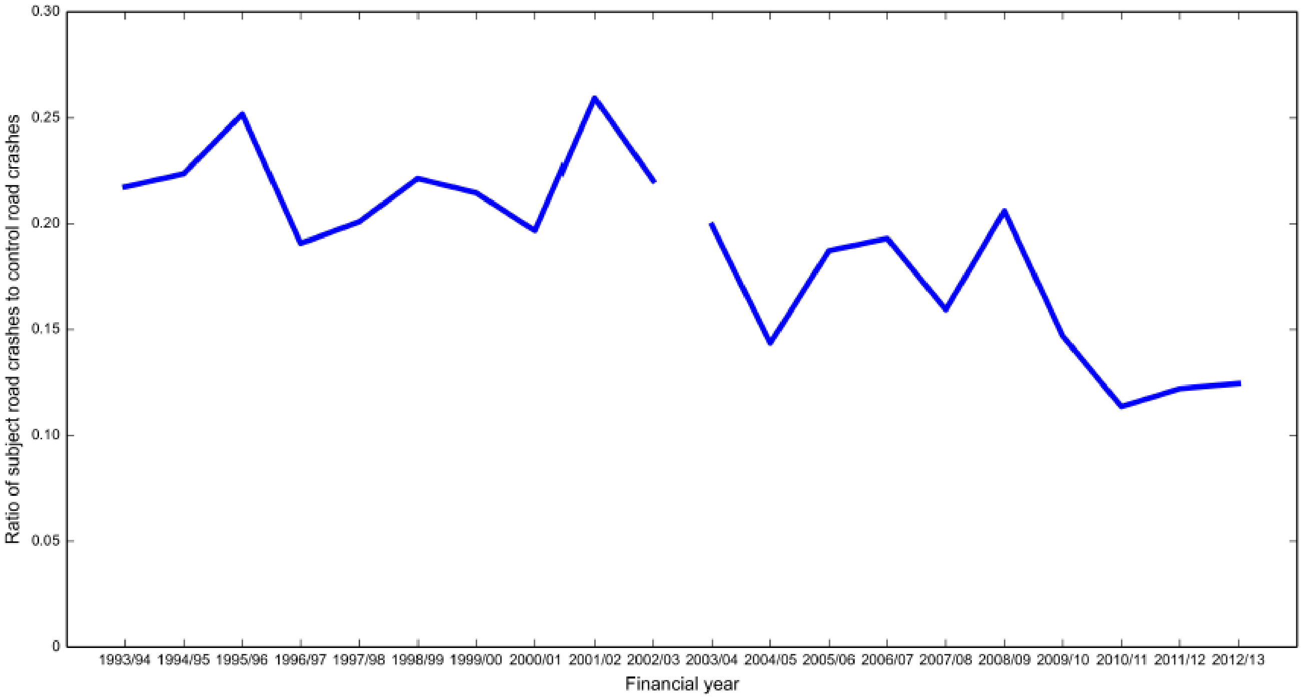


Source: Kloeden, Woolley et al. 2006, Kloeden, Woolley et al. 2007

Another study by (Mackenzie, Kloeden et al. 2015) reported on the effect of the effect of a change in speed limit of 110 km/h to 100 km/h along 1,100 km of rural roads in South Australia which occurred in July 2003. The results of this study suggested statistically significant reductions in the numbers of casualties and casualty crashes of 25.56% and 27.40%, respectively. These figures represented reductions beyond those found for the control roads (rural roads where the speed limit of 110 km/h did not change), suggesting that the change in speed limit alone had a real and substantial effect of reducing the number of casualties and casualty crashes (Figure 4.16). An initial reduction in mean travel speed of 1.9 km/h was found (Long, Kloeden et al. 2006), with continuing reductions in mean and 85th percentile speeds in the preceding 10 years after the change in speed limit (Mackenzie, Kloeden et al. 2015).

The examples presented here are replicated in multiple jurisdictions all over the world as shown in Table 4.1 and Table 4.2. The association between speed and crashes is arguably one of the most robust relationships established in road safety. The encouraging fact is that even small reductions can result in considerable safety benefits and benefits continue to accrue over time.

Figure 4.16: Ratio of subject road crashes (roads affected by the introduction of a 100 km/h speed limit, formally 110 km/h) to control crashes in South Australia



Source: Mackenzie, Kloeden et al. (2015)

Table 4.1: Synthesis of trauma reductions from speed limit changes (International literature)

Jurisdiction	Extent	Observations	Reference
United States	55 mph (89 km/h) national speed limit on interstate and primary and secondary state controlled highways (latterly 65-75 mph (105-121 km/h) introduced in 1974 and repealed in full in 1995	*18% reduction in fatalities* *5-9% reduction in injuries* No reduction in non-casualty crashes (after introduction) *17% increase in fatalities on interstate highways* *(after repeal)*	Kamerud (1983) Farmer, Retting et al. (1999)
Israel	100 km/h speed limit on 115 km of interurban highways (formally 90 km/h) introduced in 1993	*2.5 additional fatalities per month*	Friedman, Barach et al. (2007)
Belgium	70 km/h speed limit along 116 km of Flemish roads (formally 90 km/h) introduced in 2001	*33% reduction in severe (fatal and serious injury) crashes*	de Pauw, Daniels et al. (2014)
Iowa, United States	70 mph (113 km/h) speed limit along interstate highways (formally 65 mph or 105 km/h) introduced in 2005	*25% increase in all casualty and non-casualty crashes* 52% reduction in night-time fatal crashes	Souleyrette and Cook (2010)

Note: Italicised figures have been statistically tested and are quoted as being statistically significant in the respective literature from where they were sourced.

Table 4.2: Synthesis of trauma reductions from speed limit changes (Australian literature)

Jurisdiction	Extent	Observations	Reference
Victoria	50 km/h default speed limit in built-up areas (formally 60 km/h), introduced 22 January 2001	21% reduction in fatal crashes 3% reduction in serious injury crashes *12% reduction in all casualty crashes* *41% reduction in fatal and serious injury crashes involving pedestrians*	Hoareau, Newstead et al. (2006)
South-east Queensland	50 km/h default speed limit in built-up areas (formally 60 km/h), introduced March 1999	*88% reduction in fatal crashes* 20% reduction in serious injury crashes *23% reduction in all casualty crashes* *2.2 km/h reduction in mean speed*	Hoareau, Newwstead et al. (2002)
Western Australia (metropolitan Perth area)	50 km/h default speed limit in built-up areas (formally 60 km/h), introduced December 2001	25% reduction in fatal crashes 4% reduction in serious injury crashes *21% reduction in all casualty crashes* *51% reduction in all crashes involving pedestrians*	Hoareau and Newstead (2004)
Victoria	110 km/h speed limit on rural and outer Melbourne freeways (formally 100 km/h), introduced June 1987, with 100 km/h speed limit reintroduced September 1989	*21% increase in fatal and serious injury crashes (100 to 110 km/h)* *25% increase in all casualty crashes (100 to 110 km/h)* *18% reduction in fatal and serious injury crashes (110 to 100 km/h)* *19% reduction in all casualty crashes (110 to 100 km/h)*	Sliogeris (1992)
South Australia	100 km/h speed limit along 1,100 km of rural roads (formally 110 km/h), introduced July 2003	29% reduction in fatal crashes *28% reduction in admitted to hospital severity crashes* *27% reduction in all casualty crashes*	Mackenzie, Kloeden et al. (2015)
South Australia	50 km/h default speed limit in urban areas (formally 60 km/h), introduced 1 March 2003	37% reduction in fatal crashes *20% reduction in admitted to hospital severity crashes* *23% reduction in all casualty crashes* *3.7 km/h reduction in mean speed*	Kloeden, Woolley et al. (2006)

Note: Italicised figures have been statistically tested and are quoted as being statistically significant in the respective literature from where they were sourced.

4.7 Speed reductions supported by engineering treatments

Section 3 introduced the potential for obtaining community support for road function and consequently infrastructure that managed safe speeds in the context of “movement and place.” When speeds are supported in this context, there is a potential for greater compliance, safety improvement and community acceptance as was highlighted in the Point England case study from New Zealand.

There is also growing community acceptance for lower speed limits, particularly at locations where there is higher risk. This has started at schools, has migrated to shopping strips and now is gaining acceptance for lower quality rural roads. Such support has been demonstrated, for example, with the adoption of 80 km/h on rural roads in the Mornington Peninsula in Victoria (Pyta, Pratt et al. 2014) and the adoption of 20 mph zones amongst local authorities in the United Kingdom.

Travelling speed reductions and consequent reductions in road trauma can be achieved virtually instantaneously when a speed limit is changed. This contrasts with a reliance on safe infrastructure treatments that can take considerable time to plan, design and implement. This relationship between speed and road trauma is being increasingly considered by road authorities; Austroads (2010e) provides advice on speed limit setting based around the Safe System principles of harm minimisation and with consideration of road function, road infrastructure and driver selection of speeds.

Speed reductions remain one of the single most cost effective countermeasures available to practitioners for reducing death and serious injury on the road system. Doecke et al. (2011a) performed an exercise in South Australia to compare the cost of implementing infrastructure changes to the state rural road network in order to achieve the equivalent safety gains from a 10 km/h speed limit reduction. As can be seen in Table 4.3, multiple millions and sometimes billions of dollars of infrastructure expenditure would be necessary to achieve the equivalent reductions that a speed limit change could achieve. Many existing infrastructure treatments were unable to deliver the equivalent 20% reduction expected with a 10 km/h reduction in speed limit on 100 km/h roads. For those treatments that can match the 20% reduction, approximately eight billion dollars in expenditure would be required on the 110 km/h state road network. This compares with an assumed cost of less than a million dollars to lower the speed limit and change signage accordingly on the state road network.

Table 4.3: Cost of obtaining reductions on state controlled roads in South Australia with infrastructure changes or speed limits

Speed limit	Treatment option	Serious casualty crash reduction	Cost of treatment ($M)	Cost of 20% serious casualty crash reduction ($M)
100 km/h	10 km/h speed limit reduction	20%	<1	<1
	Shoulder sealing	14%	104	NA
	Roadside barriers	18%	526	NA
	Median barriers	14%	2,142	NA
	Clear zones	9%	545	NA
110 km/h	10 km/h speed limit reduction	20%	<1	<1
	Shoulder sealing	25%	427	338
	Roadside barriers	35%	2,404	1,367
	Median barriers	26%	9,540	7,235
	Clear zones	18%	2,428	NA

Source: Doecke, Kloeden et al. (2011)

The outcomes of the exercise challenge the notion that road authorities can continue to build and retrofit high quality roads to safely maintain high speed limits. Appropriate speed management will be essential in any transition towards Safe System performance. It is also important to note that unless speeds are reduced to survivable levels in the event of a crash, (most effective with the support of engineering treatments), a speed limit reduction can only be considered a supporting treatment and not a primary Safe System solution in its own right.

4.8 Travel time and productivity

A common point of resistance to lower operating speeds in the road network usually relates to arguments associated with lost productivity and increased travel times.

The productivity argument is likely to provide an ongoing dilemma for road authorities. Core issues revolve around how fair and meaningful comparisons can be made between safety and productivity objectives. For example, many argue that the impact of incrementally adding up a five second delay for thousands of vehicles at an intersection cannot be meaningfully compared to equivalent safety benefits at the individual level. Additionally, delay is often calculated from the perspective of motor vehicles and the impact on vulnerable road users is frequently not considered.

Austroads (2010c) has presented a review of literature on the effect of reduced speed limits on network operations. It was concluded that reduced speed limits would have a largest effect on travel time along roads with minimal congestion and number of intersections. It was also concluded that, for arterial roads within urban environments, reduced speed limits would have no appreciable effect during times of congestion.

The travel time argument is often raised by the community around a perception that lower speed limits will dramatically increase travel times and hence fatigue, especially in rural areas. Evidence to date suggests that where speed limits are lowered, net road injury reduces and there appears to be no dominating effect of fatigue crashes. The proportional increase in travel time will generally be less than the decrease in speed limit. There are a number of reasons for this:

- The actual reduction in average travel speed is less than the reduction in speed limit
- Vehicles are unlikely to travel at free speeds for 100% of a journey
- Other sources of influence on a vehicle's speed can include townships, intersections, curves, grade changes and interactions with other traffic.

Dutschke and Woolley (2010) presented a study into the effects on travel times by the change in speed limit from 110 km/h to 100 km/h along a number of rural highways in South Australia. The study found that increases in travel times were proportionally less than the decreases in speed limit. The 10% decrease in speed limit increased travel times by 2% to 8 % for higher density traffic (6000 vehicles per day) and 4% to 10% for lower density traffic (1000 vehicles per day). In relative terms, this means that a journey that took 60 minutes at 110 km/h would take between 61 and 66 minutes at 100 km/h.

Kamerud (1983) presented a study into the effects of the 1974 implementation of a 55 mph (89 km/h) national maximum speed limit (NMSL) across the United States. This law saw the speed limit along interstate highways and many state controlled highways reduce from 65 to 55 mph (105 to 89 km/h) and, in many cases, from 70 to 55 mph (113 to 89 km/h). These represented speed limit reductions of between 18% and 27%. It was reported that, along interstate highways, passenger vehicle travel times increased from 15.30 hours per 1000 miles in 1973 to 17.50 hours per 1000 miles in 1974/75. This represented an increase in travel time of 14%. The increase in travel time for trucks was found to be only 6%. The increase in travel time along state controlled highways was much less, with passenger vehicle taking between 3% and 7% longer than before implementation of the NMSL.

5. Harm Minimisation at Intersections

What do we know?

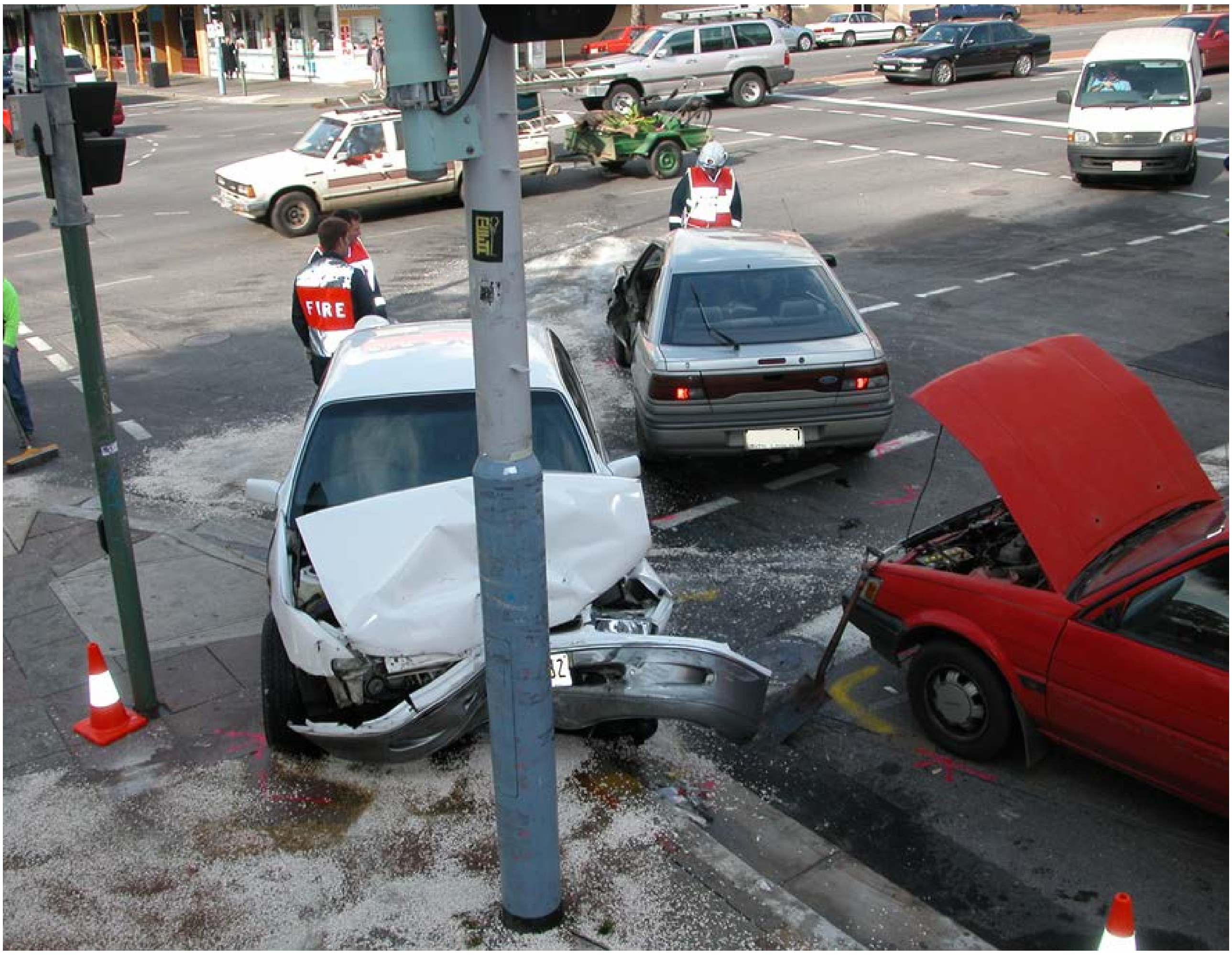
- Intersection collisions are one of the major sources of injury on the road network
- Most harm is associated with unprotected right turns and red light running
- Intersection planning, design and operation relies on drivers and riders recognising that an intersection is present and making the right 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 5.1 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 5.1: 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. As discussed in Section 2.2, intersection collisions need to be considered from a system failure perspective rather than as road user performance failure. Table 5.1 and Table 5.2 highlight some of the differences in features that exist between conventional and Safe System intersections.

Table 5.1: 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 5.2: 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

	Conventional	Safe System
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 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 et al. (2009) and Martens (2011)). Although things such as contrast and conspicuity 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 in Austroads (2012b) as the main likely contributor to many in-depth crashes investigated at intersections. A common scenario involves the situation described in Section 2.3 where left turning vehicles block the view to through vehicles.

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.

5.1 Determinants of injury at intersections

The Wramborg curves introduced in Section 4.5 indicated 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 5.2). Corben, Van Nes 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.,
5. For 90° collisions -impact (and, therefore, travel) speeds need to be less than 50 km/h;
6. 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;
7. 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%;
8. 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 5.3.

Table 5.3: Acceptable conflict angles for corresponding maximum impact speeds

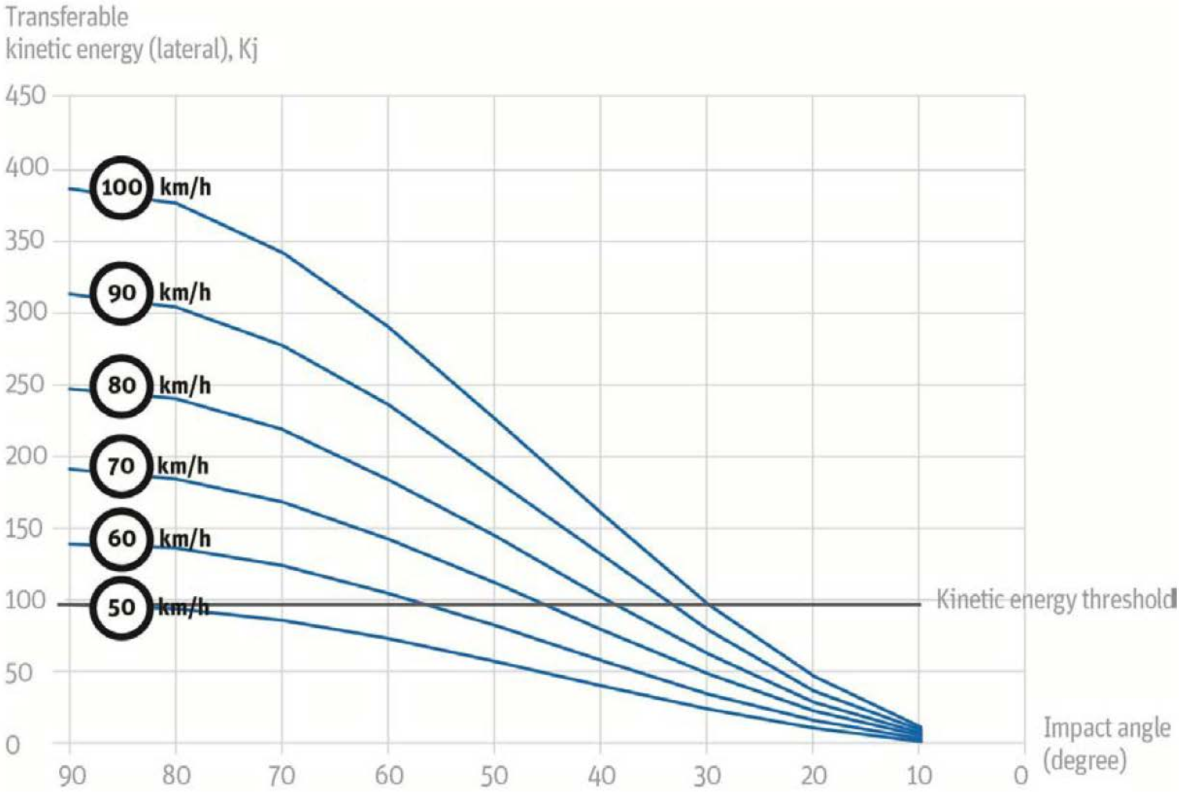
Maximum impact speed	Maximum acceptable conflict angle
40 km/h and below	All OK
50 km/h	90°
60 km/h	52°/128° (from KEMM-X)
70 km/h	0°/180°
80 km/h and above	None feasible

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

The work of Jurewicz, Sobhani et al. (2015) introduced in Section 4 extended the KEMM-X model created by Corben, Van Nes 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.

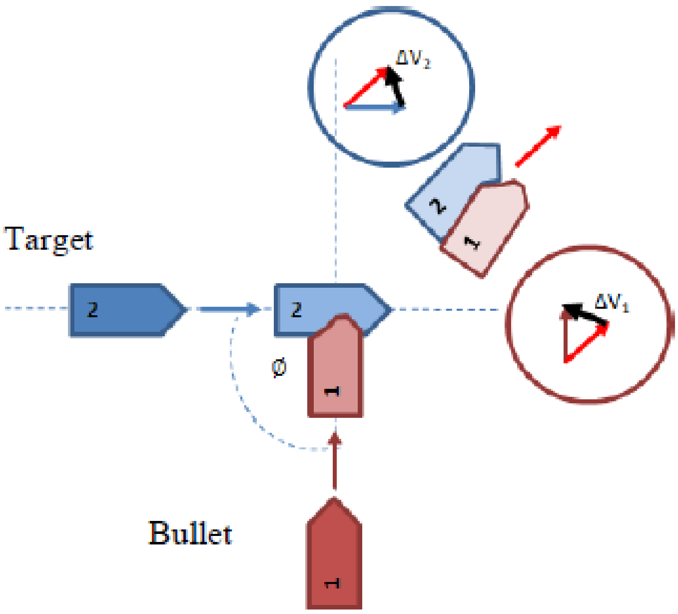
Jurewicz, Sobhani et al. (2015) show the relationship between the impact speed of a “bullet” vehicle and the probability of MIAS3+ injury obtained by a “target” vehicle occupant (Figure 5.2). This model was based on earlier work by Bahouth, Graygo et al. (2014) and Davis (2001). Critical impact speeds (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 (see Figure 4.9 in Section 4). The model therefore presents a different picture of Safe System speeds when compared to previous interpretations of the Wramburg model. Most notable of these is the substantially lower critical impact speed for head-on crashes. The model presented by Jurewicz, Sobhani et al. (2015) is accompanied by a guide to the sensitivity of change to MIAS3+ 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 5.2: Relationship between speed, impact angle and the kinetic energy threshold related to the human biomechanical tolerance to harm



Source: International Transport Forum (2016)

Figure 5.3: Diagram of bullet and target vehicles in a right-angle crash



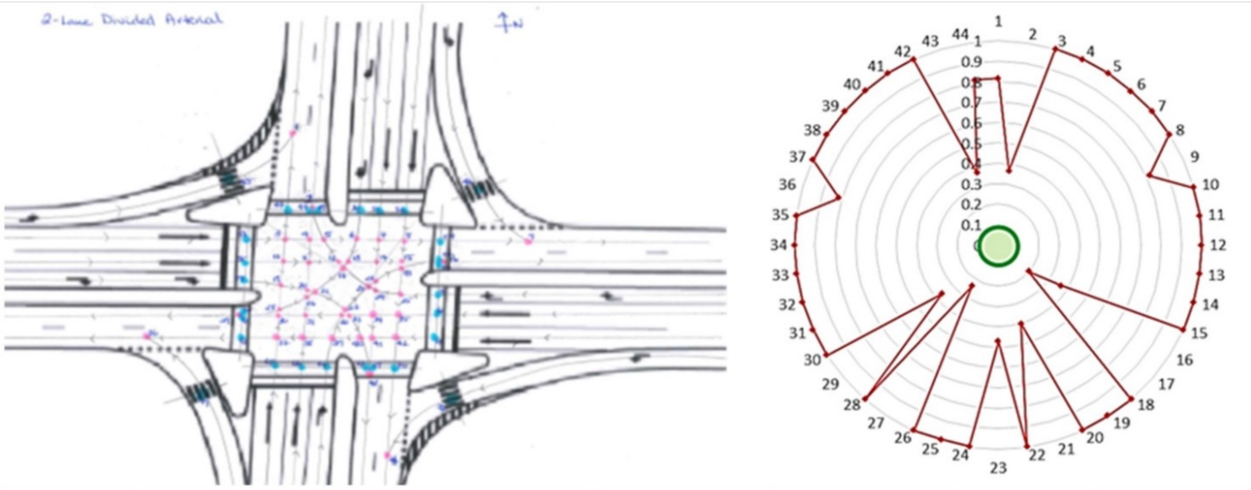
Source: Jurewicz, Sobhani et al. (2015)

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 5.4. 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 5.4: X-KEMM-X evaluation of an 80 km/h signalised cross road intersection

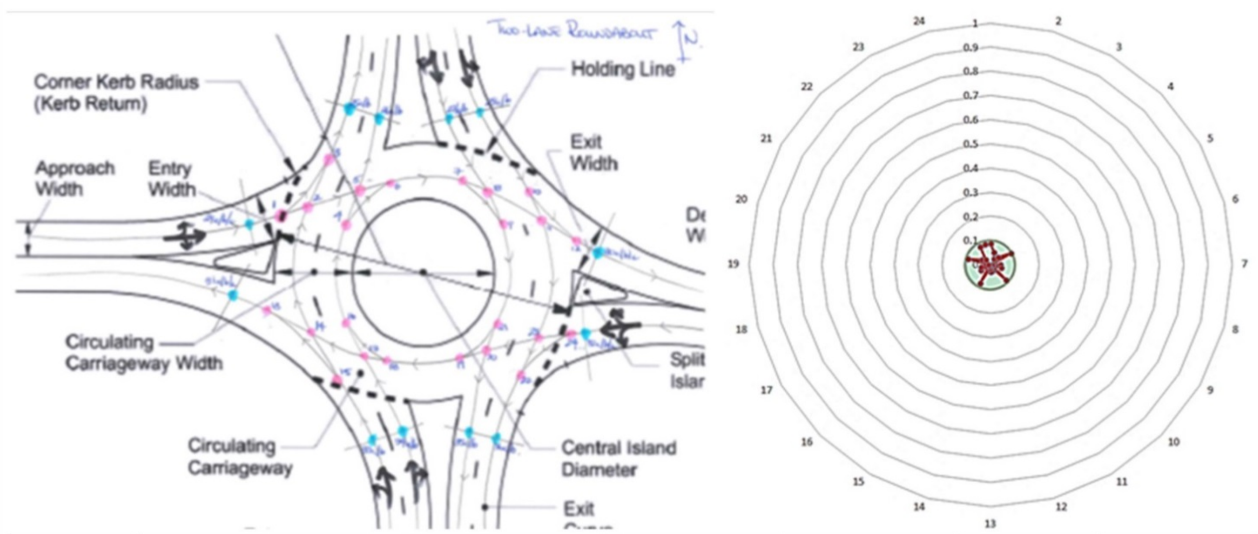


Total vehicle conflict points	Crash types			Vehicle conflict points with Pr(FSI) > 0.1	Pedestrian conflict points with Pr(FSI) > 0.1	Average vehicle Pr(FSI)	Maximum vehicle Pr(FSI)
	Opposing vehicles	Adjacent vehicles	Pedestrian				
44	8	36	28	44	24	0.86	1.00

Source: Austroads (2017b)

The utility of this tool is realised when a comparison is made with a roundabout design as shown in the figure below. 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 5.5: 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

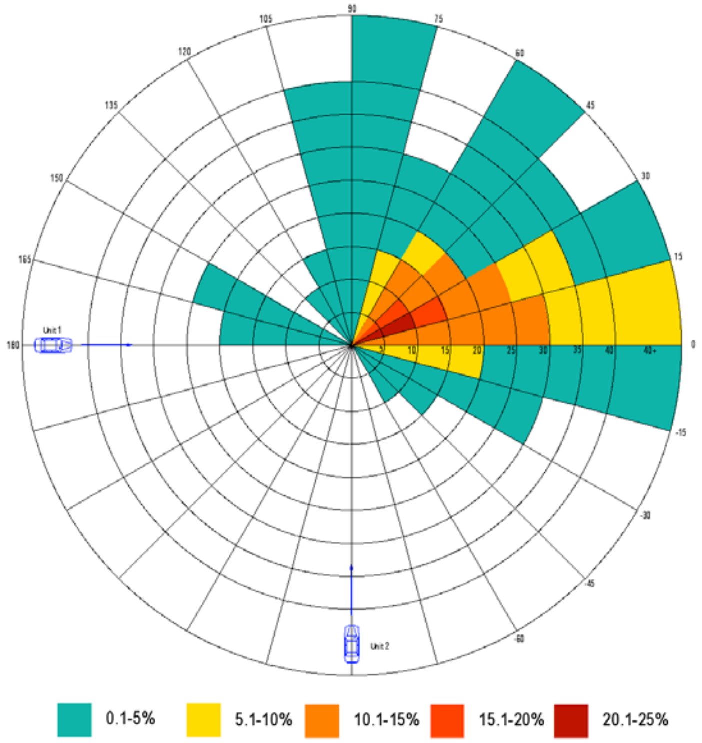
Source: Austroads (2017b)

5.1.1 Post impact vehicle trajectories

Another facet of intersection design that is currently not actively considered are 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 not 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.

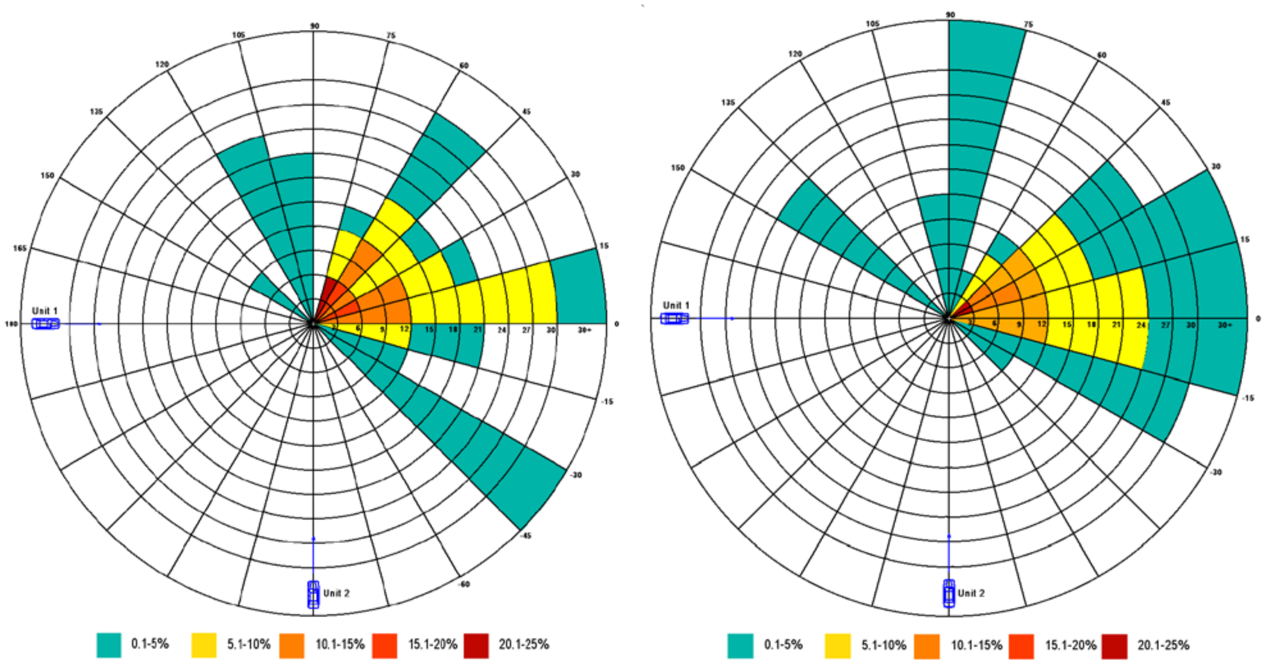
Doecke, Mackenzie et al. (2013) and Doecke, Woolley et al. (2011) conducted an investigation into the trajectory of vehicles following a primary collision at intersections. Each sector % represents the proportion of vehicles from the sample of crashes (n=72) to traverse that sector following a primary 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 5.6 and Figure 5.7) 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 5.6: Crash trajectories at rural intersections



Source: Doecke, Woolley et al. (2011), Doecke, Mackenzie et al. (2013)

Figure 5.7: Crash trajectories at urban signalised (left) and un-signalised (right) intersections



Source: Doecke, Woolley et al. (2011), Doecke, Mackenzie et al. (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.

5.2 Innovation towards harm minimisation at intersections

Austroads (2016a) suggests a hierarchy of treatments that should be considered for intersections (Table 5.4).

Table 5.4: 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
Supporting treatments (does not affect future implementation of Safe System options)	• Redirect traffic to higher quality intersection • Turning lanes • Vehicle activated signs • Improved intersection conspicuity • Advanced direction signage and warning • Improved sight distance • Traffic signals with fully controlled right turns • Skid resistance improvement • Improved street lighting.	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 (2016e)

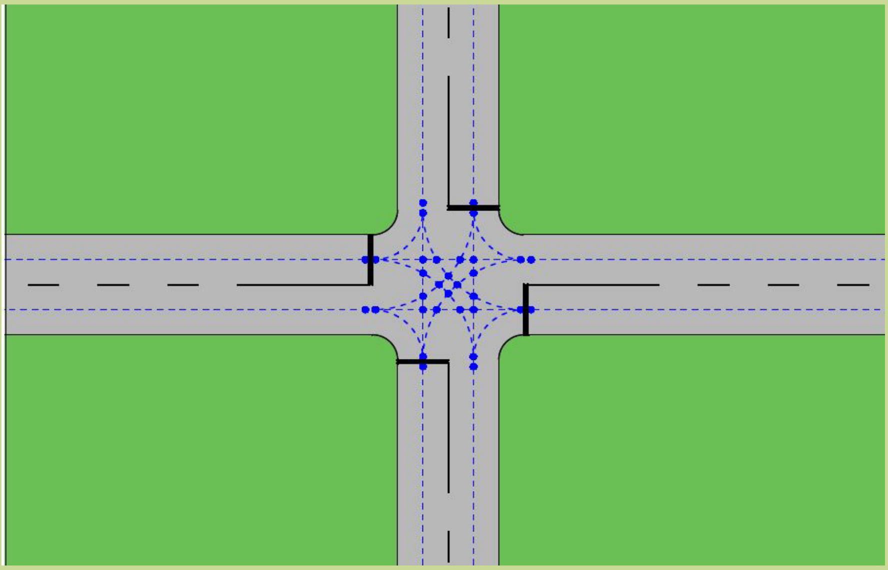
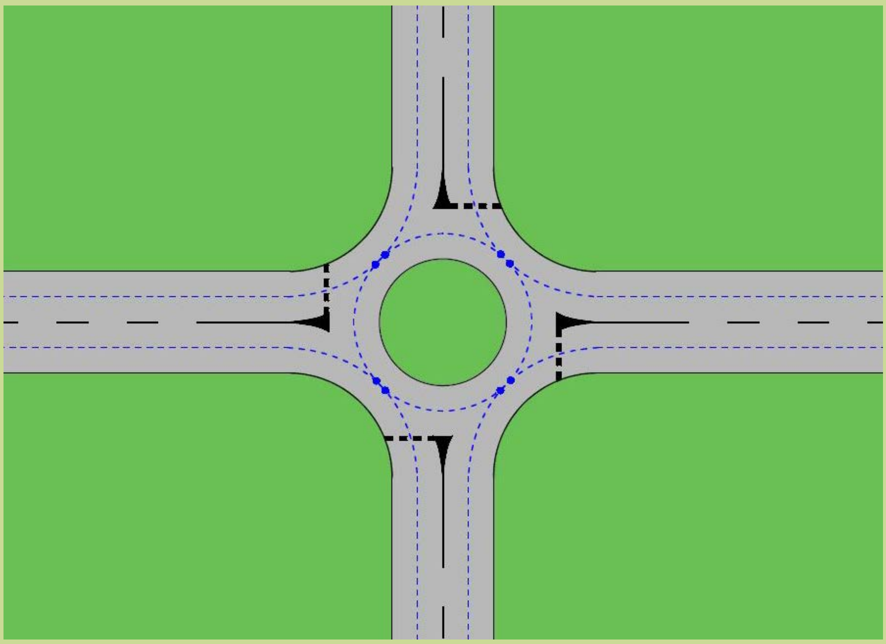
Grade separated intersections provide good Safe System alignment as points of conflict are eliminated from the system. Whilst good for motorized traffic, care is still required to ensure that pedestrians and cyclists are also catered for if in an urban environment. The cost, space and aesthetic considerations 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, it is clear that more innovation will be required to deal with the burden of severe injury associated with intersections.

5.2.1 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 5.5). When road users make errors they are unlikely to be seriously injured in the resulting collision.

Table 5.5: 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 5.6). Although there is a wide variation in roundabout design and implementation, Austroads (2015d) 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 5.6: 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 (2013c)

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 2014b) and further commentary on this is provided in Section 7. Note that there is also an Austroads project currently being conducted investigating cyclist safety at roundabouts (TT1967).

There is still much scope to refine the design and use of roundabouts and some innovations and variations are shown in Figure 5.8. 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 Figure 5.5).

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 (2017b). The cost of implementing a signalised roundabout as an upgrade at 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 5.8: Examples of innovative roundabout design

Signalised Roundabout (UK)

Mini roundabout (UK)

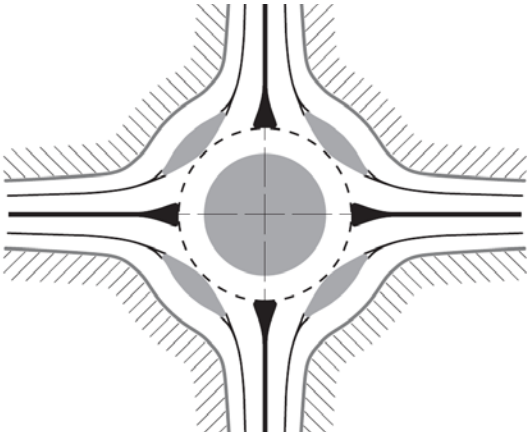
Source: https://www.reddit.com/r/CitiesSkylines/comments/30f5na/traffic_circle_vs_roundabout_and_why_cs_needs/

Hamburger Roundabout (USA)

Source: http://www.fhwa.dot.gov/publications/research/safety/09060/006.cfm

Turbo Roundabout (The Netherlands)

Flower Roundabout Concept (Slovenia)

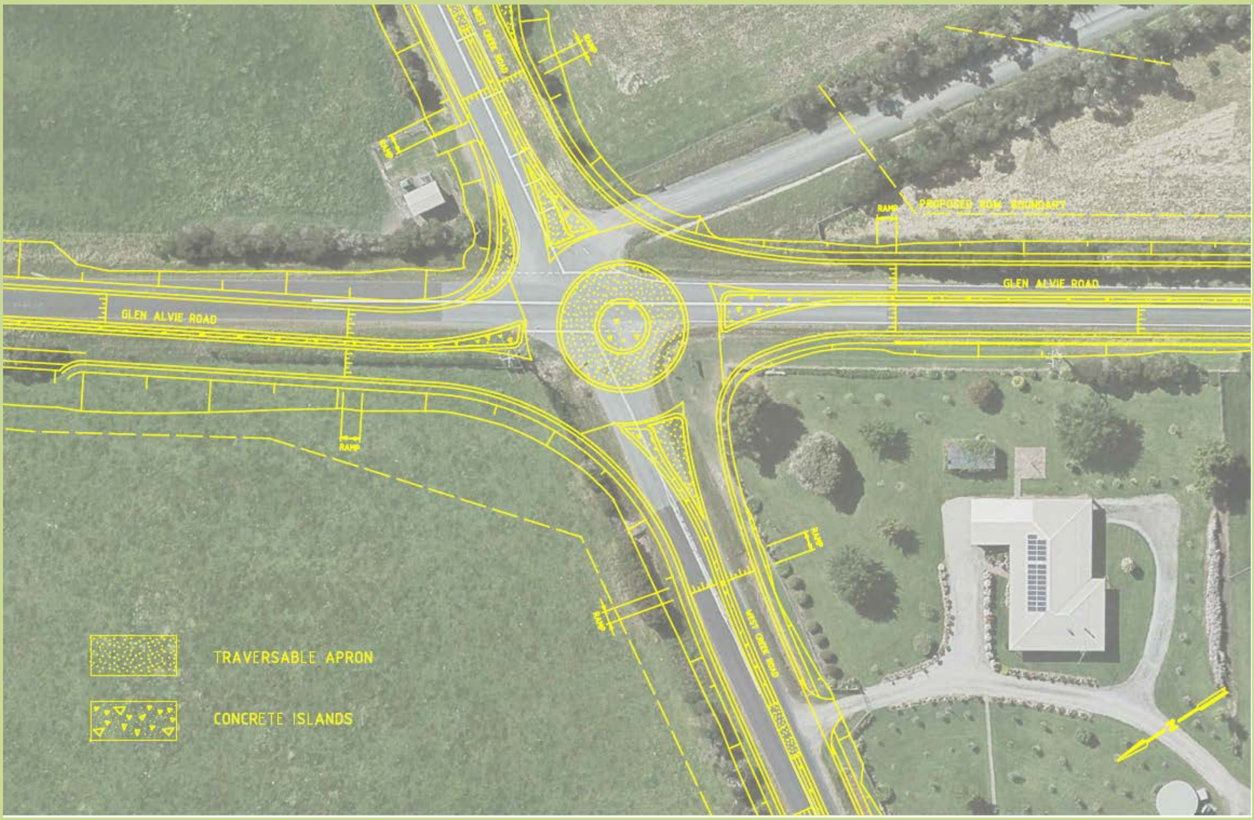


Source: Tollazzi, Renceli et al. 2011

C Roundabout (NZ)

Source: Asmus, Campbell et al. 2012

The development of a lower cost compact roundabout*



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 a 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 (pers comm Wayne Moon, VicRoads).

5.2.2 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, Van Nes 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 5.9. 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 5.9: Examples of innovative signalised roundabout treatments

Retrofit concept design for large footprint signalised intersections (Victoria)

Retrofit concept design for small footprint signalised intersections (Victoria)

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).

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 (2016a) and (Austroads 2014e). Treatments that include vertical deflections (e.g. raised platforms and speed humps) have been used in Australia and New Zealand as part of 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 (2017b) 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.

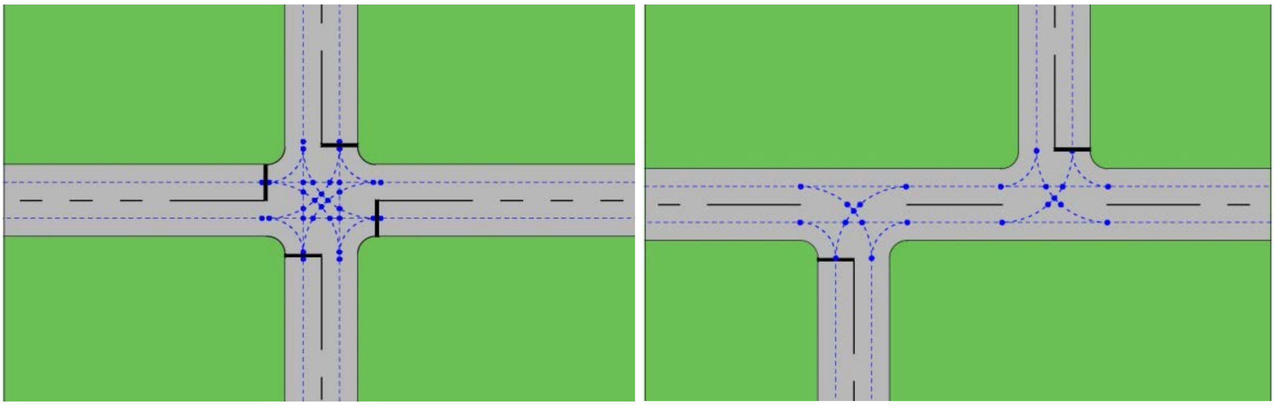
Slope Matters

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.

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 an 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

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 5.11. 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 5.10: 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 (2017b) 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.

6. 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 6.1 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 6.1: 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.

6.1 Reducing the harm of road departures

6.1.1 Treatment hierarchy for road departures

What is evident from the research is that corridor protection 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 after Austroads (2016e) is shown in Table 6.1. The few primary treatment options that exist are associated with kinetic energy management.

Table 6.1: 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 (2016e)

6.1.2 Clear zones

The concept of clear zones can be traced back to studies during the 1960s in North America (Stonex and Skeels 1963, Hutchinson and 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.

Forrest Highway, Western Australia

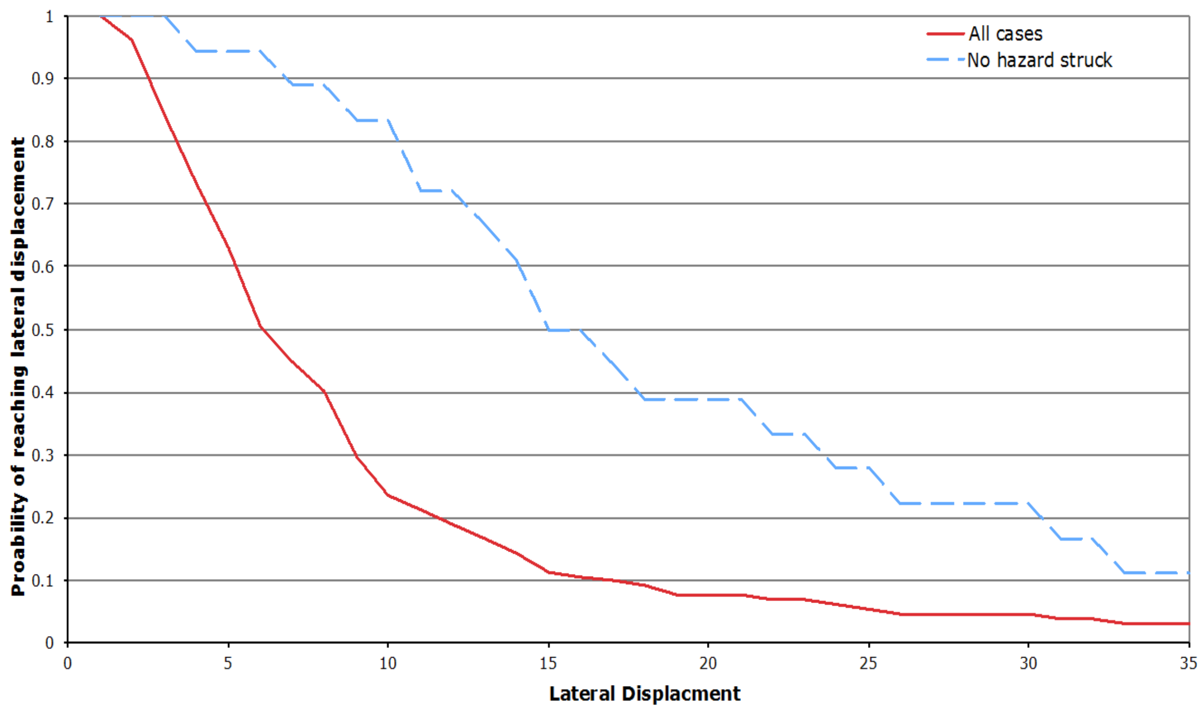
Opened in September 2009, the Forrest Highway project included the construction of 30 km of freeway standard and 38 km of dual carriageway standard roadway between Baldivis and Lake Clifton in Western Australia.

The Road was built to desirable Austroads Guidelines and Australian Standards. Clear zone principles were applied along the road, with roadside barrier being used were 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 (pers comm David Moyses, MRWA).

Doecke and Woolley have conducted studies into clear zones based on a sample of real world crashes in South Australia (Doecke, Woolley et al. 2011, Doecke, Mackenzie et al. 2013). 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 6.2 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.

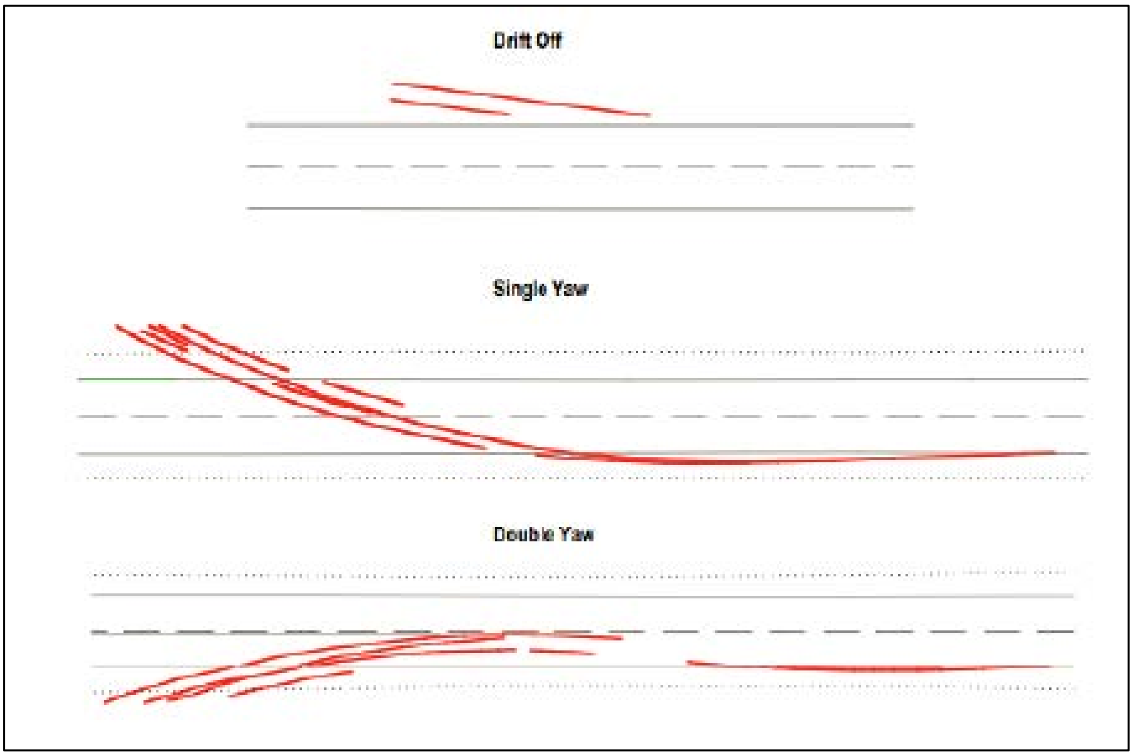
The work revealed that there are three predominant road departure types as shown in Figure 6.3. The drift off represents a low angle departure and is likely the departure best served by a clear zone. If the departure angle is low enough it is likely that a driver can successfully steer back onto the 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 6.2: 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)

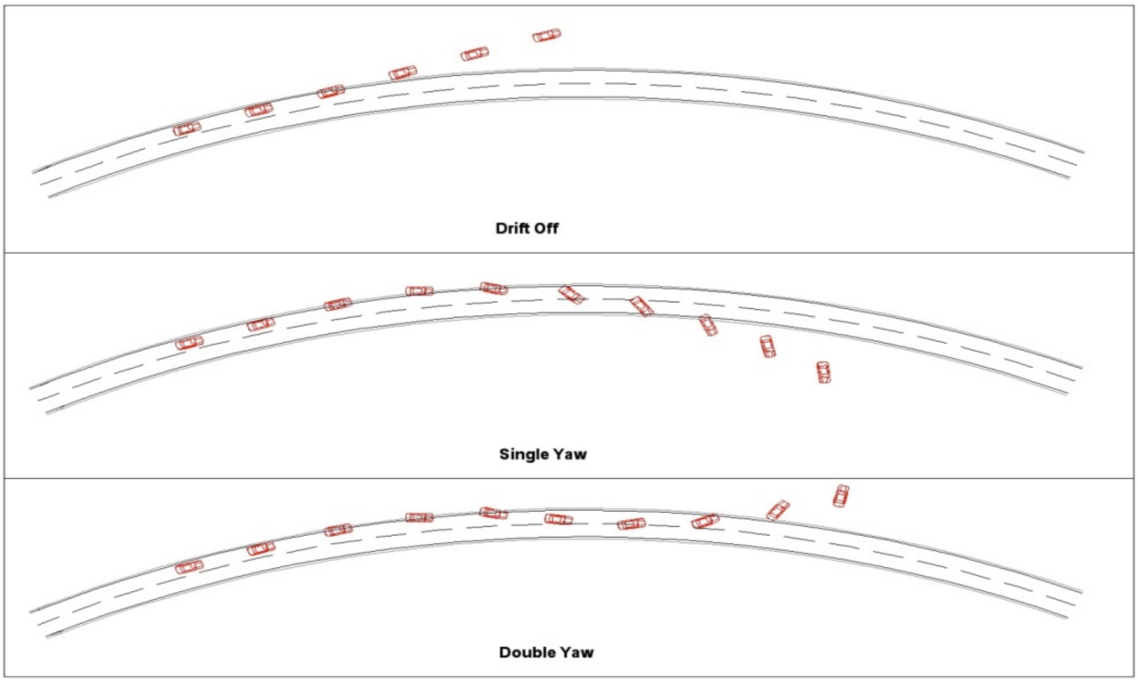
Figure 6.3: The three key road departure types on straights



Source: Doecke and Woolley (2011)

In another study, (Doecke and Woolley 2013) established that similar departure types existed on bends as shown in Figure 6.4. The single yaw scenario is interesting 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.

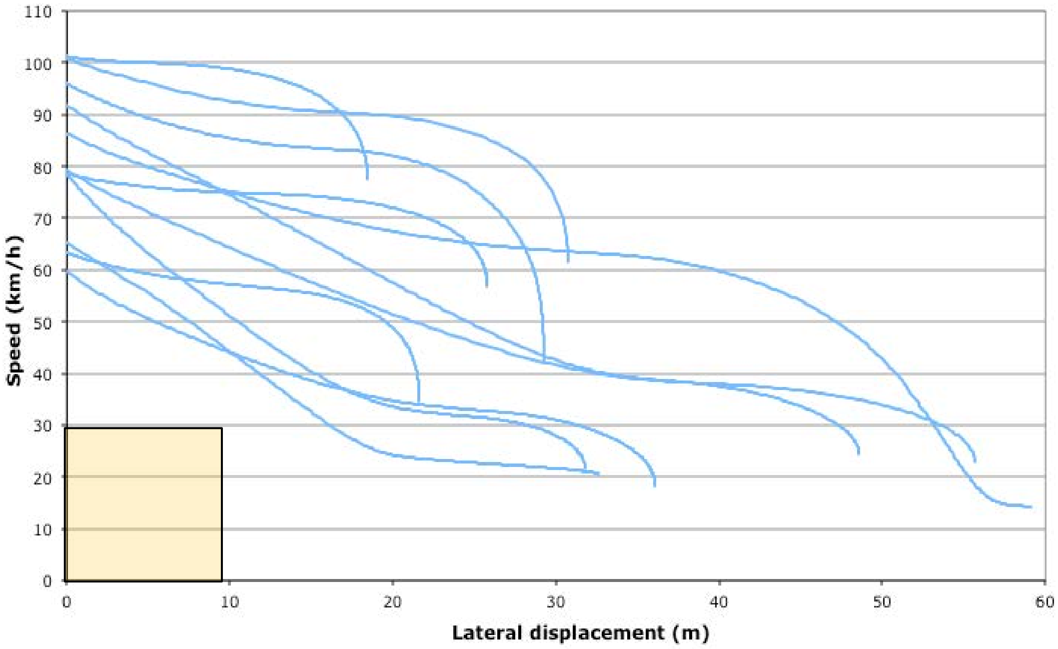
Figure 6.4: The three key road departure types on bends



Source: Doecke and Woolley (2013)

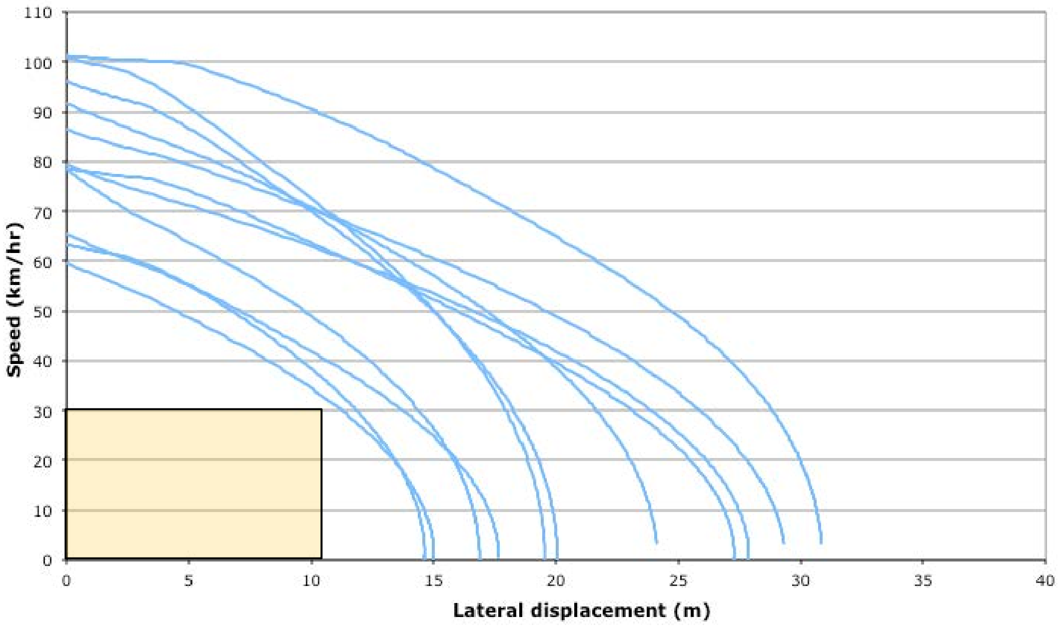
Doecke and Woolley also outlined the two types of driver actions likely in response to the road departure: steering input and emergency braking. In reality a driver may combine the two. However, modelling was performed for independently the two extremes. Figure 6.5 and Figure 6.6 show the trajectories 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 6.5: Simulated trajectories of vehicles in road departures where the driver attempted for steering recovery



Source: Doecke and Woolley 2011

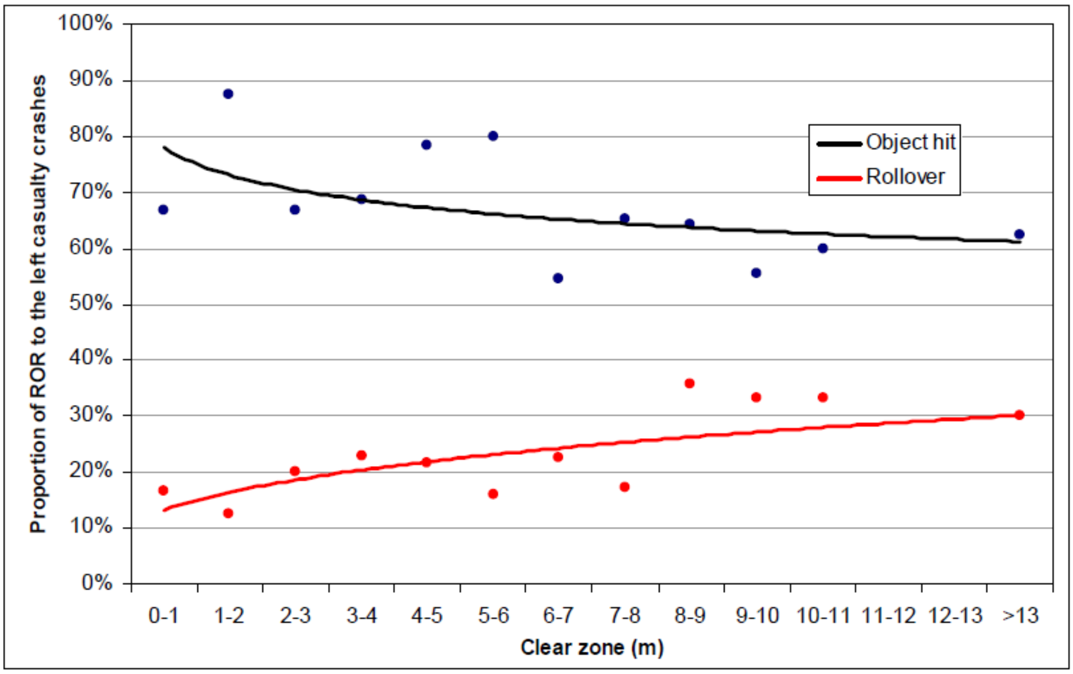
Figure 6.6: Simulated trajectories of vehicles in road departures where the driver attempted emergency braking



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 6.7. It is noted that objects are continuing 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 6.7: Proportions of Object hit and Rollover run-off-road crashes vs. clear zone in Victoria



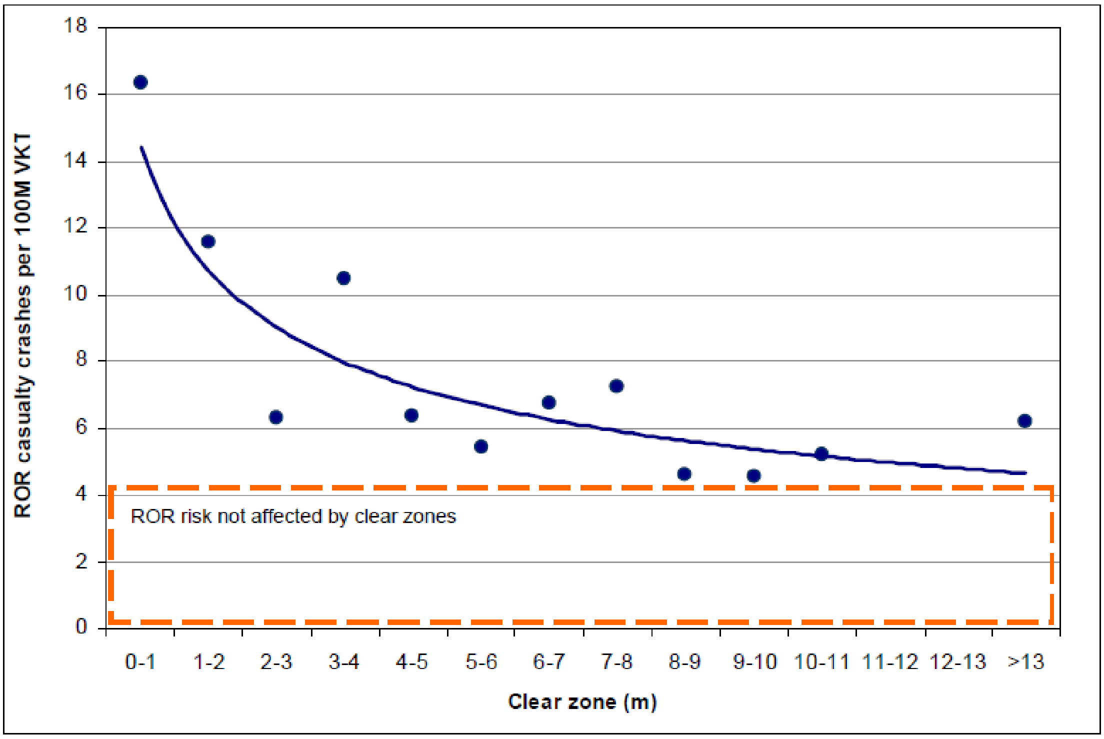
Source: Austroads (2011a)

A presentation of the data in terms of vehicle kilometres travelled is shown in Figure 6.8. 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 2010d). As with Doecke and Woolley, 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, 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.

Figure 6.8: Run-off-road crash rate vs. available clear zone



Source: After Austroads (2012a)

6.1.3 Barriers

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 the Austroads Guide to Road Design Part 6 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.

There are three major types of crash barrier: rigid, semi-rigid and flexible although this simplistic representation is evolving. Each has particular advantages and disadvantages and there are some situations where only one type of barrier may be appropriate for use.

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%).

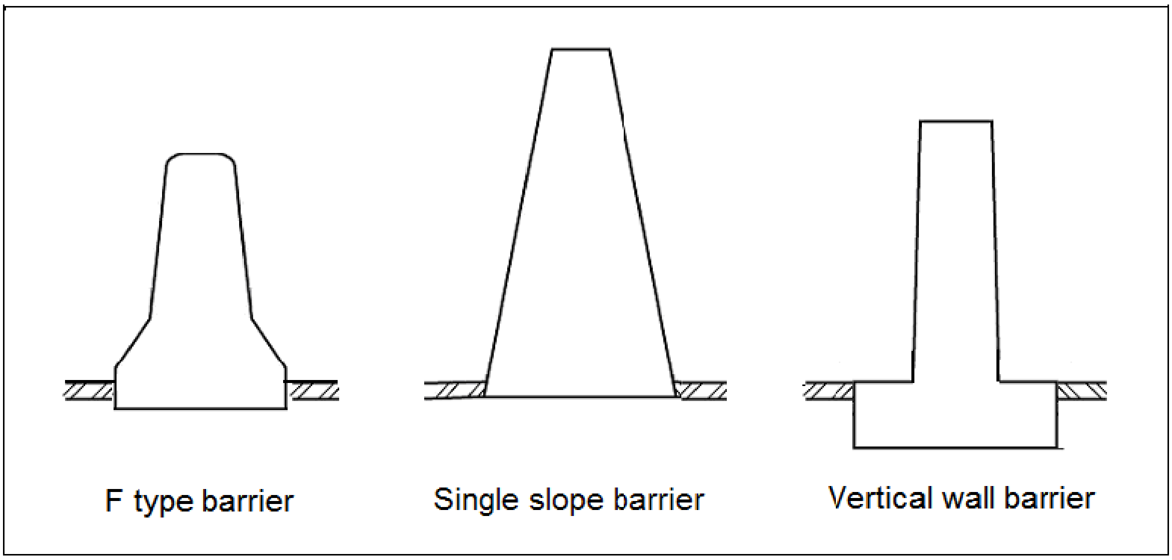
Barrier maintenance Issues

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.

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 6.9). Studies have shown that collisions with rigid barriers tend to result in more severe injury outcomes than other barrier types (Chow and 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 NCHRP 350 and MASH (US based barrier testing standards). 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 6.9: Profiles of different rigid barrier

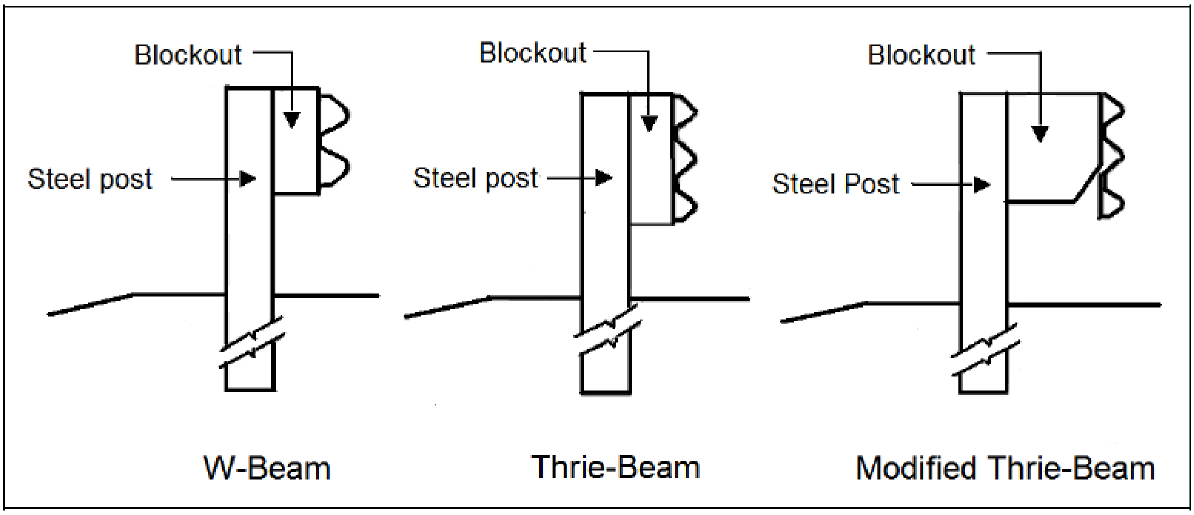


Source: Austroads (2010b)

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 6.10). 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 and Meuleners 2016).

Figure 6.10: Profiles of different semi-rigid barrier designs



Source: Austroads (2010b)

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 6.11). Upon impact, the posts deflect back and the vehicle is engaged by the steel wires which go into tension 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 and 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 flexible barriers 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 2014). 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 6.11: Examples of flexible barrier designs

Source: Austroads (2010b)

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 (MWRSB) along a section of the Victor Harbor Road known locally as Willunga Hill (Dua and 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.

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 and 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.

The evidence for using flexible barriers as roadside protection is presented in Table 6.2. 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 for 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 KSI Crashes per million vehicles.

Table 6.2: Evidence for the high safety performance of flexible wire rope barrier systems (Australian and New Zealand literature)

Candappa, D'Elia 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 (2015d)	• 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 (2014d)	• 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 (2014d) 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 a study of 100 km of wire rope barrier, (Candappa, D'Elia 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 (2015d) 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.

Terminal Ends

Barriers have evolved significantly since their introduction however a historical problem has been the safety performance of terminal end treatments. There have been many treatments applied over the decades in Australia and many obsolete examples can still be found in the field. For W-beam crash barriers, 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. 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. Even with WRSB, non-crashworthy terminal ends found application during the 1990s.

The deliberate use of the terminology “continuous lengths of barrier” in this report relates to reducing the number of terminal end treatments along a corridor to reduce injury risk and maximise the protection offered by barrier spans.

6.1.4 Unprotected or protected corridors?

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 and 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. Information related to motorcyclist specific hazards and treatments is documented in Section 7.3. Table 6.3 and Table 6.4 provide an overview of the key evidence relating to corridor protection philosophy.

Table 6.3: 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, Huet 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 and Quincy (2001) Martin, Huet et al. (1997)

Table 6.4: 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 et al. (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 (2010d) Austroads (2009d) Austroads (2015d)
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 (2014f)
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)	Corben et al 2003
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 et al. (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, Huet 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 6.5 shows the crash severity according to the first impact.

Table 6.5: 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 6.6 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 6.6: 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, Huet 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”.*

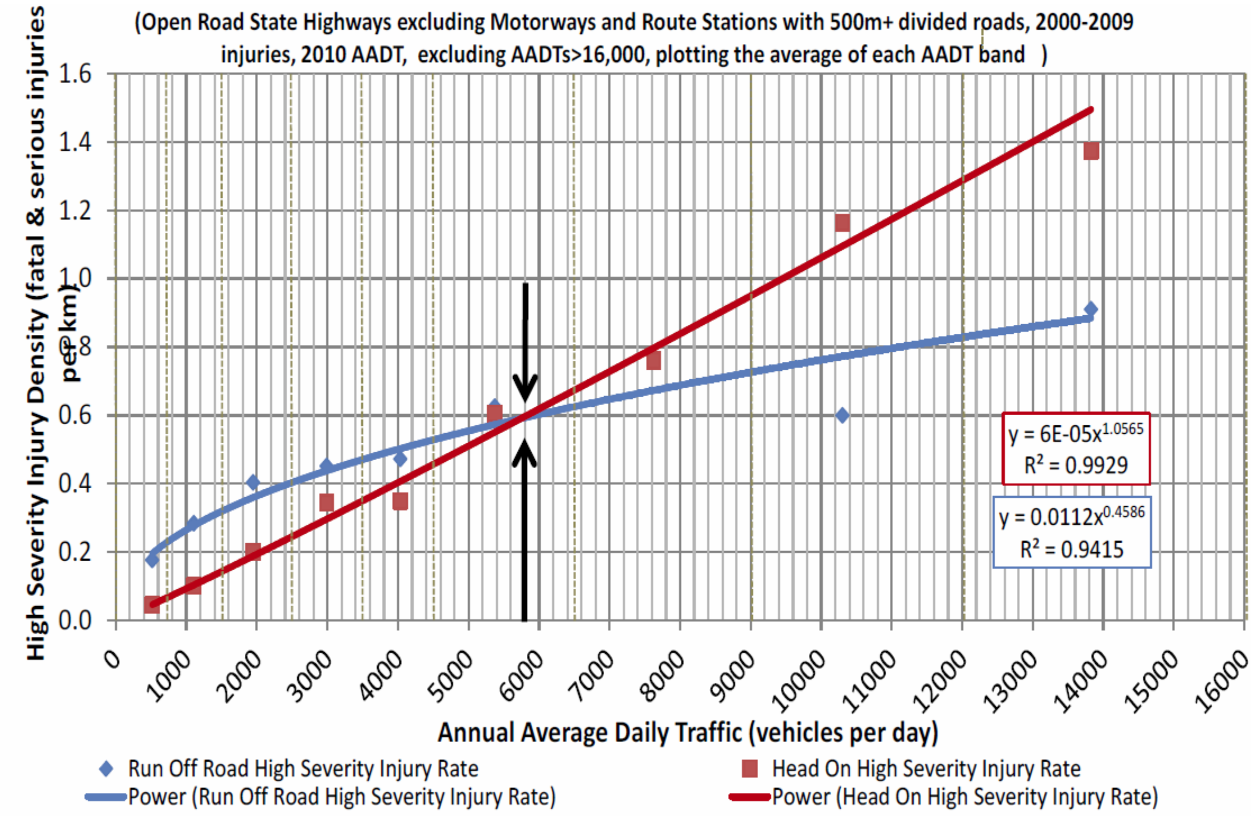
A study on the Naples Candela motorway in Italy by Montella and Pernetti (2010) also produced findings consistent with the Martin et al study.

6.2 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 (2013c) 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 6.12). 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 6.12: Head-on and run off road FSI injuries per kilometre for rural undivided state highways in New Zealand



Source: Austroads (2013c)

6.2.1 Treatment hierarchy for head-on crashes

The hierarchy of treatments for head-on crash types based on Austroads (2016e) is shown in Table 6.7.

Table 6.7: 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 (2016e)

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 and 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 and Carlsson 2001).

A full description of the 2+1 treatment used in Sweden can be found in (Bergh and 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 MWRSB 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.


Source: Derr (2003)

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 and 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.

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 6.8 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 (pers comm David Bobbermen).

Table 6.8: 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 ATLM	Reduced speeds Drivers more likely to remain entirely within their lane (reduced crossing of centreline)	Connell, Smart et al. (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 et al. (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 et al. (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)

6.2.2 Centreline barriers on undivided roads

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 accident area, passing and parking restrictions, wide yellow coloured barrier centrelines with ATLM and red coloured edgeline 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 and 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 and 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 and 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.

Source: Marsh and Pilgrim 2010

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 appear to dominate discussions (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.

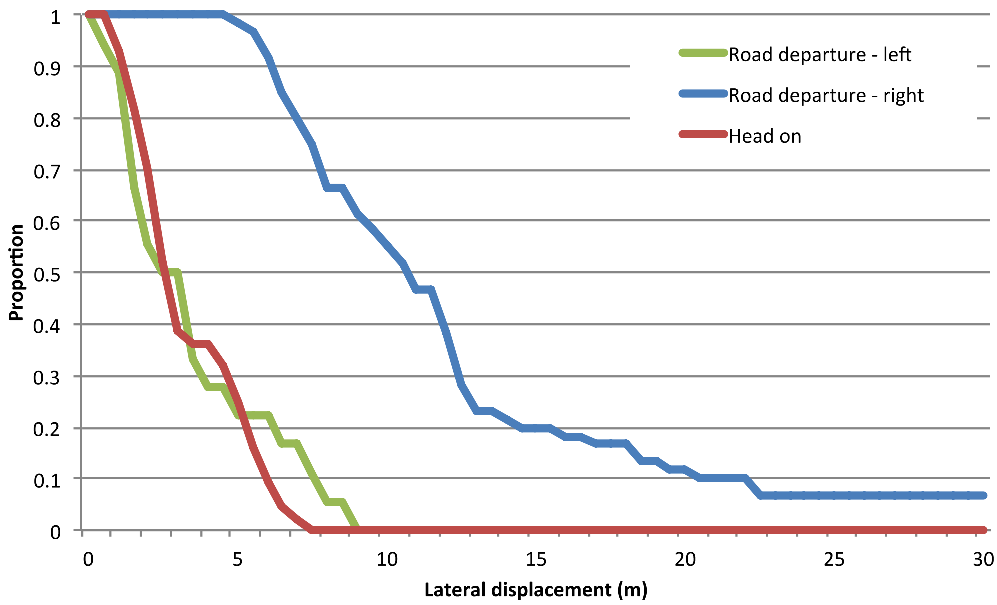
There is to date little evidence to inform the third consideration. However, Austroads (2015d) reports an increase in average crash severity of 3% per metre in the context of roadside barriers. The NZTA has also developed a tool to assist practitioners make decisions in relation to nuisance hits on WRSB and semi-rigid barriers (Smith, Hyde 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 et al. (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 6.13). 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.

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) discussed in Section 2 that highlighted that divided roads were the strongest factor in eliminating fatalities among car occupants in their analysis of Swedish fatality data.

Figure 6.13: Cumulative distributions showing lateral displacement over the centreline by road departure type including those resulting in head on collisions



Source: Doecke and Woolley (2013)

6.2.3 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 6.9 outlines some of the research evidence supporting this (Austroads 2015d):

Table 6.9: Literature regarding the use of barriers on divided roads

Ray, Silvestri et al. (2009)	100% reduction in median cross over incursions >90% reduction in cross median road departures
DoT (2009)	64% reduction in severe injury median crashes 44% reduction in fatal median crashes
FHWA and Turner-Fairbank Highway Research Centre (2008)	83% reduction in fatal cross median crashes 89% reduction in all cross median casualty crashes

6.2.4 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 and 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 et al. (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 6.14). 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 (pers comm David Bobbermen, Austroads, and Colin Brodie, NZTA).

Figure 6.14: 0.5 m wide painted median along the Pacific Highway

Source: Levett, Job et al. (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 6.15). 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 6.15: 1.0 m wide painted median along the Pacific Highway

Source: Levett, Job et al. (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 MWRSB treatment, crashes reduced from 46 total and two fatals before installation to 33 in total and one fatal after installation (Figure 6.16). 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 MWRSB, 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 6.16: Painted median with MWRSB along the Pacific Highway

Source: Levett, Job et al. (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 6.17). 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, Smart et al. 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 6.17: Newell Highway wide centreline treatment

Source: DPTI (date unknown)

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, Smart et al. 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.

Approximately 700 km of wide centreline treatment has been installed on the Bruce Highway in Queensland. Refer to the case study in Section 9 for more information on this.

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 6.18). The treated sections of the highway extended from Tailem Bend to the Victorian Boarder (Bishop, Butler et al. 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 6.18: Wide centreline with ATLM along the Dukes Highway

Source: DPTI

Wide painted medians incorporating MWRSB have been installed along the Waikato Expressway near Rangiriri, New Zealand (Figure 6.19). 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 MWRSB. The previously upgraded section of road near Rangiriri is due to be upgraded again in 2016.

Figure 6.19: Before (left) and after (right) installation of wide painted medians and MWRSB along the Waikato Expressway

Source: NZTA

6.3 Safe rural road stereotypes

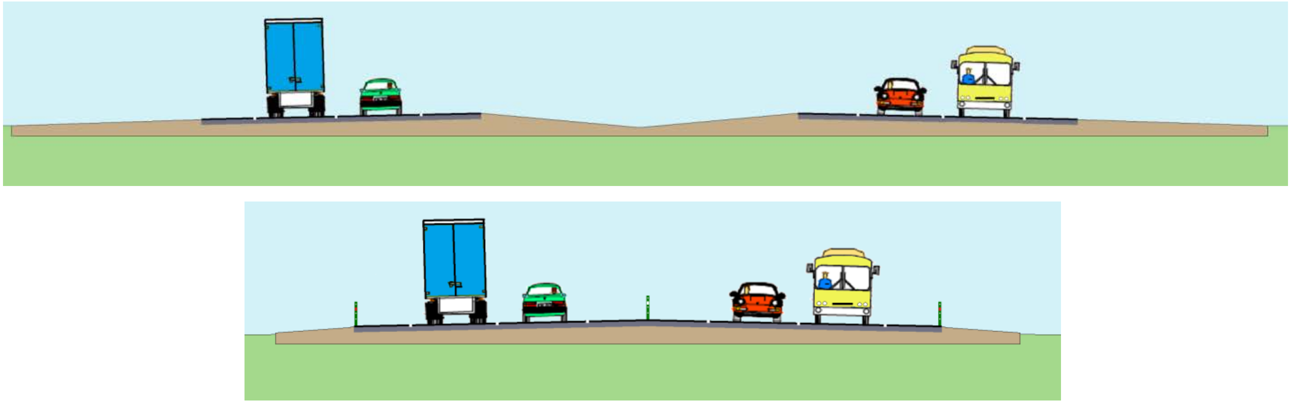
Austroads is currently in the process of establishing rural road stereotypes to provide practitioners with better guidance on how to transition in steps from current road layouts towards the aspirational Safe System designs shown here.

The difference in cross sections between a typical high standard rural road and an aspirational Safe System road is shown in Figure 6.20. 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 Table 6.10. 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 6.20: Difference in cross section between typical and proposed 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 and 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 Table 6.11. 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 Table 6.10 with the exception that the number of lanes has reduced from four to two.

Table 6.10: Comparison between a typical divided road and an example of a safe system road

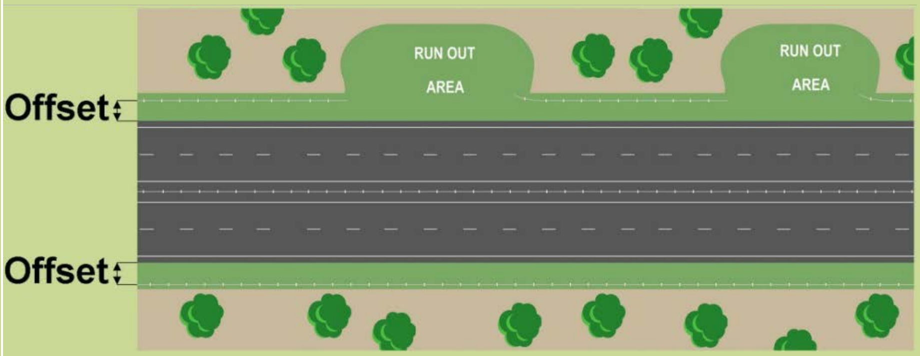
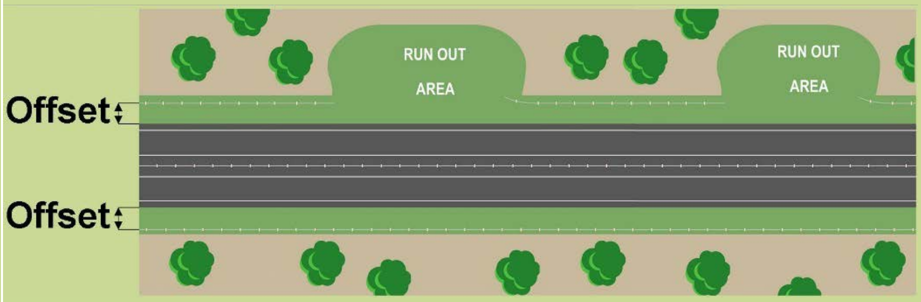
	Example
Typical	
Safe System	

Table 6.11: Comparison between a typical undivided rural road and an example of a safe system road

	Example
Typical	
Safe System	

7. Harm Minimisation Amongst Specific Road User Groups

The legacy of the road network in Australia and New Zealand is that it has been optimised to cater primarily for the operation of passenger vehicles. Changing this situation and safely accommodating a wider range of road users will take considerable time and much transformation of the physical environment and a greater acceptance of the role of speed management. One of the reasons why the road network is inherently unsafe is because the main determinants of crash severity (ie speed and mass) are not compensated for when combining different road user groups together. There are emerging solutions and design philosophies that offer the potential for a step change in the way the safety of the different road user groups can be accommodated.

7.1 Pedestrians

What do we know?

- Walking and pedestrian activity are acknowledged as essential components of successful and vibrant cities
- There are considerable health and environmental benefits from walking activity
- Many cities globally are undergoing urban renewal embracing place-making and acknowledging the need to provide for spaces that people would like to interact in
- Intoxicated pedestrians still present a considerable challenge and account for about a third of pedestrian fatalities
- Right turns at traffic signals remains a significant pedestrian safety issue
- Roundabouts can be hazardous yet they can be made safe for pedestrians under some scenarios.

What does this mean?

- Low speed environments (30 km/h or less) are amenable to pedestrian and vehicle interaction and needs to be considered in the planning of future urban areas
- Where a low speed environment cannot be achieved look to segregate and minimise conflict
- Treatments that target speed reduction (safety platforms, constraining geometry) show much promise when used at pedestrian conflict points
- Consider opportunities to provide harm minimising protection to pedestrians at bus and tram stops
- A shift is required away from reactive approaches to pedestrian safety issues and a move towards a more structured approach based on road function; the “movement and place” approach should be used to enhance the safety of urban environments.

At some stage virtually everyone becomes a pedestrian whether they walk to work, drive a car, take public transport or even cycle. There is of course a diversity of pedestrians incorporating children, elderly, and those with temporary or permanent physical or mental disability. Pedestrians are vulnerable in the current road system as they are unprotected (unlike car occupants) and their mass and speed is much lower than that of virtually all other road users. The Safe System aspires to interaction speeds of around 30 km/h where pedestrians are involved. Even then, there is still an elevated risk if the pedestrian is young or elderly or the striking vehicle is a heavy vehicle.

There are considerable health benefits to walking and many government policies exist that promote active transport modes. The strong emphasis on catering for motor vehicles in past decades has resulted in an inherently unsafe environment for pedestrians. Recent additions to the Austroads Guides have acknowledged this and provided pedestrian oriented advice for use by road practitioners (Austroads 2013a). Urban planning and design also recognises the role of pedestrian activity in the context of "movement and place" and importantly seeks to accommodate the myriad of activities along a street corridor beyond that of traffic movement. The urban design perspective is discussed in more detail in Section 3.

According to the DIRD (2015b) report on *Pedestrians and road safety*, there has been a downwards trend in pedestrian fatalities in Australia in the past two decades. Pedestrian fatalities as a proportion of all road fatalities have also decreased from nearly 20% of fatalities in 1995 to 13% in 2014. While these statistics have been attributed to progress made in the area of pedestrian safety, it is argued that these are also a result of a decrease in pedestrian mobility, especially for children. While most age groups are evenly represented with close to the average of 0.65 fatalities per 100,000 population, the 75+ age group is a notable exception, with 2.31 fatalities per 100,000 population in 2014, and had been so for at least the past decade. While both male and female fatalities have been trending downwards, males account for twice as many fatalities as females.

According to DIRD (2015b), the highest proportion of fatal pedestrian crashes occurred in 50 km/h (27.2%) and 60 km/h (33.4%) speed limit zones, while comparatively few occurred in 40 km/h or slower speed limit zones (3.0%). While school zones throughout Australia are posted at 40 km/h (25 km/h in South Australia), only 5.4% of fatal crashes involving pedestrians aged 0 to 16 occurred in 40 km/h speed limit zones. Three-quarters of all fatal pedestrian crashes involved passenger and/or light commercial vehicles only, while 12.5% involved heavy vehicles only. A smaller proportion involved buses only (3.2%), while motorcycles and bicycles were involved in very few fatal crashes. Seven percent of fatal pedestrian crashes involved a combination of vehicles types. Between 2009 and 2013, 2.45 times more fatal pedestrian crashes occurred at non-intersection locations compared to intersection locations.

DIRD (2015b) has also reported on where and when pedestrian fatalities are occurring in Australia, with the vast majority occurring in major cities. While the absolute number of fatalities is trending downwards as the location is moving further from populated areas (i.e. from major cities to regional to remote areas), the rate of fatal crashes involving a pedestrian per 100,000 population is trending in the other direction. For instance, between 2009 and 2013 major cities had a rate of 0.69 fatal crashes per 100,000 population, while very remote Australia had a rate of 2.39 fatal crashes per 100,000 population. Between 2010 and 2014, pedestrian fatal crashes have predominantly peaked between 9 am and 12 noon and between 6 pm and 9 pm. However, on weekends there is a third and most prominent peak between 12 midnight and 3 am. The lowest number of fatal crashes has occurred on Tuesdays, while the highest numbers have occurred on Thursdays through Saturdays, inclusive. For most age groups, the majority of fatal crashes have occurred during weekdays compared to weekends, with this trend being more prominent as the groups increase in age. A notable exception to this is for 17 to 25 year olds, where similar proportions occur on weekends compared to weekdays.

7.1.1 Treatments for pedestrians

Historically, pedestrians were catered for with the provision of signalised and unsignalised crossings. Fences are sometimes used to segregate pedestrians from motor traffic and concentrate crossings at the provided crossing facilities. The emphasis has been on providing priority for motorized traffic and providing areas for pedestrians to safely cross. A novel approach is to switch the emphasis to the pedestrian. Examples of this include shared zones that move away from the appearance of a conventional roadway, at-footpath-grade crossings that bring motor traffic up to the pedestrian's level and restriction of motor traffic lane numbers and widths in favour of greater pedestrian areas (Government of South Australia 2012, NACTO 2013, Austroads 2016a) as shown in Figure 7.1.

Figure 7.1: Examples of novel design approaches including shared zones (left) and at-footpath-grade crossings (right)

Source: Government of South Australia (2012)

One of the challenges in addressing pedestrian safety is the high speed environment that exists on the road network. Where Safe System speeds cannot be managed, there are only limited primary options available to practitioners (see Table 7.1).

Table 7.1: Safe System Assessment Framework hierarchy of pedestrian related treatments

Hierarchy	Treatment	**Influence (E = exposure L = likelihood S = severity)**
Safe System options ('primary' or 'transformational' treatments)	• Separation (footpath) • Separation (crossing point) • Very low speed environment, especially at intersections or crossing points	E L L, S
Supporting treatments (compatible with future implementation of Safe System options)	• Reduce speed environment/speed limit • Pedestrian refuge • Reduce traffic volume.	L, S L E, L
Supporting treatments (does not affect future implementation of Safe System options)	• Pedestrian signals • Skid resistance improvement • Improved sight distance to pedestrians • Improved lighting • Rest-on-red signals.	L L L L L, S
Other considerations	• Speed enforcement.	L, S

*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 (2016e)

Where there are concentrations of pedestrians, it is logical that the environment is changed and speed management is used to reduce risk. This is currently practiced in schools zones, some strip shopping centres and in shared spaces. Despite this, the majority of the road network does not have pedestrian crossing facilities. The single most effective countermeasure that has been achieved to date is the adoption of lower urban speed limits. Vehicle design is also moving towards enhanced survivability when pedestrians are struck by passenger cars.

A particular issue associated with pedestrian safety is that of intoxicated pedestrians. A third of fatalities involve some sort of alcohol related impairment. This places further emphasis on the need to achieve a suitable speed environment, ensure visibility and calm traffic where such pedestrian activity is to be expected. Central business districts and commercial precincts with considerable night life would justify an area wide treatment approach. An example of an innovative solution using existing infrastructure is the “Dwell on Red” phase in which traffic signals on all approaches are held on red until a vehicle is detected. In this way traffic in a high risk area is calmed and overall speeds reduced.

A key to pedestrian safety over the long term will be the transformation of urban environments along the principles currently being adopted in urban planning (see Section 3). This might require coordination with a network planning approach to inform the road design response where medium to high volume roads are involved.

7.2 Cyclists

What do we know?

- There are considerable benefits to cycling including community health and environmental outcomes
- There is considerable variation in cycling activity from long distance commuters to short distance utility cyclists, including cyclists of all ages and abilities
- Data on cycling exposure is limited but observations range from minimal increase on current levels (Arnold 2015) to a 10% growth (DIRD 2015a)
- The road environment is particularly unsafe for cyclists in situations where the combination of speed, mass and road design practices that have historically had a focus on catering for motorised vehicles in past decades
- There are planning and road design practices that make cycling safer in countries like the Netherlands and Denmark (due to low speed design approaches and separation); care is required in translating them to the Australian and New Zealand context.

What does this mean?

- The most fundamental philosophy is to mix cyclists with traffic where speeds can be managed to safe levels and separate where speeds are too high; use targeted speed reduction where pedestrians and cyclists meet motorised traffic
- Environments with low speed limits (30 km/h) are amenable to cyclist interaction with motorised traffic
- Apply specific speed reduction treatments (safety platforms, small radii corners) to guarantee low speeds where conflicts between motorised traffic and cyclists occur
- Avoid having cyclists and heavy vehicles stand side by side at stop signals
- Consider buffer spaces to counter the potential for collision of cyclists with opening doors
- Where possible locate cycling lanes between the footpath and parked vehicles.

There are many benefits to cycling key amongst which are better health outcomes for individuals and the community and environmental sustainability. There are currently many government policies that strongly promote active transport modes and it is likely that cycling exposure will continue to increase into the future.

Urban planning and design is also embracing synergies between the active transport modes and vibrant public spaces and this is discussed further in Section 3.

Given the past emphasis on optimising the network for motor cars over past decades, the simple reality is that current infrastructure does not adequately support safe cycling activity across most parts of the road network.

Currently, even leading road safety countries are grappling with the task of harm minimisation in relation to cyclists and it is evident that current injury and crash databases do not provide a comprehensive picture of the situation. For example, single bicycle crashes also constitute a part of the injury problem yet is often overlooked as they are not captured in crash or injury databases.

DIRD (2015a) has recently provided an overview report on cycling safety in Australia: *Australian cycling safety: casualties, crash types and participation levels*. The report notes that cyclist casualties which represent 3% of all road fatalities and 15% of all road hospitalisations, are higher today than five or ten years ago. While road fatalities in Australia have decreased from about 1,600 per year in 2005 to fewer than 1,200 in 2014, cyclist fatalities have remained similar to their numbers a decade ago. Nationally, cycling hospitalisations have increased over this time period, with nearly 2,000 more hospitalisations in 2013 compared to 2005. These trends have also been generally consistent within each state. The increasing proportion of casualties being represented by cyclists is also an issue for most OECD countries. The Netherlands has experienced a high increase in proportion with 25% of fatalities now represented by cyclists; a reminder that countries with intensive experience and consideration for cyclists are also not immune to issues surrounding their vulnerability.

While DIRD (2015a) reported that 90% of injury crashes and 76% of fatal crashes involving a cyclist also involve another vehicle(s), it is suggested that the problem of non-reporting to police could be an issue for single-vehicle (cyclist only) injury crashes and as such the 10% of cyclist injury crashes being single vehicle crashes are possibly an under-estimate. While these statistics show multi-vehicle crashes most probably represent the majority of fatal and injury crashes involving cyclists, only 3% of these involve three or more vehicles. Hence, most cyclist-involved fatal and injury crashes are occurring between a cyclist and one other vehicle. Light vehicles represent the largest proportion of other vehicle type being involved in a cyclist-involved fatal or injury crash (66% and 84%, respectively), while heavy vehicles represent a much higher proportion for fatal crashes (22%) than injury crashes (3%). Cyclist versus cyclist crashes represent 5% and 4% of fatal and injury two-vehicle cyclist-involved crashes, respectively. There are also about 60 reported injury crashes per year between a cyclist and pedestrian. Of these, 45% result in injury to the pedestrian only, 13% to the cyclist only and 40% result in injuries to both parties.

Hospitalisation data suggests that 81% of cyclists hospitalised due to a crash with another identified vehicle crashed with a light vehicle, while 3% crashed with a heavy truck or bus and 16% crashed with another bicycle. It is also noted that of the cyclist-involved crashes recorded in hospitalisation data, 25% show the other involved vehicle as being unknown and 25% are recorded as single vehicle crashes.

DIRD (2015a) reported that 29% of multi-vehicle cyclist-involved casualty crashes were adjacent direction (intersection only) crashes. A further 22% each were same direction (sideswipe and rear-end) crashes and manoeuvring (from footpath and from driveway) crashes, respectively. Opposing direction (right turn) represented 14% of casualty crashes, while “dooring” represented 8% of casualty crashes and 5% were coded as “other”. Of special interest are that 36% of casualty crashes with a heavy truck are sideswipe crashes (straight or turning) and 37% are manoeuvring from a driveway or footpath. It is also notable that a far higher proportion of crashes are of the manoeuvring type (from driveway and from footpath) for the 0-16 age group (40%) compared to the 25-60 age group (9%). For single vehicle (cyclist-only) casualty crashes, the majority did not involve a collision with 61% occurring on a straight section of road and 13% occurring on a curved section of road.

According to DIRD (2015a), the highest proportion of cyclist-involved casualty crashes are occurring on local (government) roads, followed by arterial roads – similar to the proportions for all casualty crashes. While a large proportion of all casualty crashes are occurring on highways, only a small proportion of cyclist-involved casualty crashes are occurring at these locations. Roads limited to 50 km/h or below represent the highest proportion of cycling-involved casualty crashes, closely followed by 60 km/h zones. Few of these crashes are occurring on 70 km/h or higher speed limited roads (approximately 10%) presumably reflecting the reduced exposure of cyclists on these roads.

7.2.1 Treatments for cyclists

There are many cycling infrastructure treatments in existence and much innovation is occurring in Europe where cycling has a higher participation rate. The Netherlands have been an early adopter of Safe System treatments applied to the cycling context and publications such as Ploeger, Kroeze et al. (2007) detail the design strategies that have been successfully used. Certain cities in the United States have recently adopted innovative design strategies, which have been detailed by NACTO (2014) and the “Movement and Place” approach is being adopted in urban design in the UK, Australia and New Zealand (Government of South Australia 2012, Austroads 2016b).

While many treatments beyond the provision of bicycle lanes have formerly been overlooked in Australia, innovative treatments are being implemented into the road network and practitioner advice for the use of these treatments is becoming available (Austroads 2014a). Table 7.2 illustrates some of the Safe System options available. Treatments that perform to Safe System standards for motorists may not be as beneficial for cyclists. For example, survivable impact speeds for cyclists are far lower than for motor vehicle occupants (Jurewicz, Sobhani et al. 2015) and roundabouts are still associated with severe crash outcomes for cyclists, especially when high approach and entry speeds into the intersection are possible (Austroads 2015d). Primary Safe System treatments are limited to the provision of low speed environments or where this cannot be achieved, physically separating cyclists from motorised traffic. This is especially important yet most challenging at intersections, where interactions between motor vehicles and cyclists are most likely to occur (Austroads 2015f). Due to the difficulty in providing primary treatments for all cycling corridors, supporting treatments can play a crucial role in moving towards Safe System performance. These treatments commonly take the form of delineating cycling and motorized traffic streams and assigning cyclist priority at intersections.

Table 7.2: Safe System Assessment Framework hierarchy of cycling related treatments

Hierarchy	Treatment	**Influence (E = exposure L = likelihood S = severity)**
Safe System options (‘primary’ or ‘transformational’ treatments)	• Separation (separate cyclist path) • Very low speed environment, especially at intersections.	E L, S
Supporting treatments (compatible with future implementation of Safe System options)	• Shared pedestrian/cyclist path • Cyclist lane (<50 km/h) • Reduce traffic volumes	E L E, L
Supporting treatments (does not affect future implementation of Safe System options)	• Separate cyclist signals at intersections • Cyclist box at intersections • Skid resistance improvement.	L L L
Other considerations	• Speed enforcement • Enforcement of other regulations.	L, S 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 (2016e)

In one of the first instances where Dutch practices have been used to support best practice by an Australian road authority, Queensland’s Department of Transport and Main Roads has released a guidance report outlining various road designs aimed at prioritising cycling safety (TMR 2015). The report outlines requirements for both midblocks and intersections – an area commonly lacking in Australian practice.

Appendix A highlights the learnings from the Dutch approach to cycling infrastructure and how the best aspects of the philosophy may be translated into use on the Australian road network using. A Queensland guidance document is used as an example.

Dutch Sustainable Safety philosophy on cyclists and pedestrians (Wegman, Aarts et al. (2006):

Mix traffic where speeds are low

Separate traffic where speeds are too high

And introduce targeted speed reduction where pedestrians and cyclists meet motorized traffic flows

7.3 Motorcyclists

What do we know?

- It is well established that motorcyclists are over-represented in fatal and serious injury crashes and have a much higher risk of injury outcome than passenger car occupants when involved in a crash
- Meeting Safe System objectives for motorcyclists is not yet possible with current approaches and even current primary safe system treatments are associated with motorcyclist safety problems (roundabouts and barriers)
- Motorcyclists are far more vulnerable to injury than car occupants in collisions with objects including trees, embankments, drainage structures, poles and safety barriers
- There are many mis-perceptions about motorcyclist interactions with barriers. Fatal collisions with barriers are relatively rare and represent 4-6% of motorcycle fatalities and 0.01% of all road fatalities. A predominant injury mechanism is associated with impacts with barrier posts and 50% of motorcyclists strike a barrier in a sliding position. W-beam is the most frequently impacted barrier type (70%) followed by concrete barrier (10%) and wire rope (8%), reflective of current levels of exposure to those types
- Barrier design is evolving and designs that consider motorcyclist impact are now emerging that combine W-beam and rub-rail; three systems have been tested in NSW and two have been approved for use in that State
- Treatment programs targeting high crash motorcycle corridors have proven beneficial in several jurisdictions
- Segregated motorcycle facilities has proven beneficial (casualty reductions of approximately 40%) in Malaysia
- Many infrastructure treatments that benefit motorcyclists will also benefit other road users
- The treatment of high crash motorcycle routes has proven to be beneficial and cost effective.

What does this mean?

- Motorcycle fatalities and serious injury will remain a significant problem into the future
- Altering or removing barriers in order to mitigate motorcycle fatalities is unlikely to be effective as such collisions are still relatively rare and 50% involve a sliding impact. Motorcyclists are still likely to receive fatal injuries from collisions with objects behind the barrier and the safety of other road users is likely to be compromised considerably
- Barrier designs are emerging that consider motorcyclist collisions in addition to passenger vehicle collisions; It will be feasible to use such designs on small radii bends and where motorcycle collisions are expected in the network.
- As barrier treatment becomes more prevalent, monitoring of motorcycle crashes will be necessary to determine if there are any unexpected injury trends and injury mechanisms that emerge.

Motorcycle safety is currently one of the most challenging areas of road safety. Unlike car occupants, riders and their passengers are unprotected and are therefore at an elevated risk of death or injury when a crash occurs. Despite the lack of protection from the vehicle itself, motorcycles are permitted to travel at the same speed as cars and are allowed to participate in traffic with few constraints to compensate for their vulnerability. Cohort groups are frequently identified in terms of recreational, commuting, urban and rural riding and countermeasures tailored accordingly. Many of the primary safe system infrastructure treatments do not specifically cater well for motorcyclists (such as roundabouts and many barrier systems) and there are limited options available to the practitioner to dramatically reduce fatal and serious injury crash outcomes in the same way that can be achieved with passenger car occupants. It is evident that the contribution of other pillars outside of infrastructure will be required to a greater extent than other areas to address safety problems.

Although not fully aligned with Safe System outcomes, there have been several developments that are worth noting. Firstly, barrier systems continue to evolve and some have been crash tested in Australia and demonstrated to reduce motorcyclist injury whilst not compromising the benefits to other road users (Baker, Eveleigh et al. 2016). Two systems incorporating rub-rails are currently favoured by Transport for NSW on the basis of this crash testing (Baker, Eveleigh et al. 2016). Such systems could be utilised where motorcycle collisions are deemed likely and in hills environments where there are small radii curves, or on the outside of bends in general.

Secondly, there has been good improvement in safety with the targeted treatment of roads with high incidence of motorcycle crashes. These tend to be roads in hills environments with high levels of recreational motorcycle use (Austroads 2015e).

Finally, it should be noted that the majority of treatments that improve safety for all road users also tend to provide benefits for motorcyclists. This includes sealed shoulders, ATLM, speed management in terms of speed limits and speed at intersections, left in / left out access control, full right turn control at signals etc).

A hierarchy of motorcycling related treatments is shown in Table 7.4.

Table 7.4: Safe System Assessment Framework hierarchy of motorcycling related treatments

Hierarchy	Treatment	Influence (E = exposure L = likelihood S = severity)
Safe System options ('primary' or 'transformational' treatments)	• Separate motorcycle lane (e.g. on freeways)	E
Supporting treatments (compatible with future implementation of Safe System options)	• Roadside areas free of hazards that can trip upright motorcyclists or snag sliding motorcyclists	S
Supporting treatments (does not affect future implementation of Safe System options)	• Consistent design along the route (i.e. no out-of-context curves) • Consistent delineation for route • Skid resistance improvement • Motorcycle-friendly barrier systems. • Flexible sign posts • Flush drainage structures	L L L S S S
Other considerations	• Speed enforcement • Enforcement of other regulations.	L, S 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 (2016e)

Separation is currently the most promising infrastructure treatment option and motorcycle crash reductions in the order of 40% have been achieved in Malaysia using this approach (Austroads 2016c). However, it is likely that the other pillars will be required to play a significant role in addition to infrastructure to improve motorcycle safety. Vehicle based solutions offer much promise and ABS braking technology has been highlighted as a significant contributor towards crash reduction mainly through the mechanism of vehicle dynamic stability and controllability. Differing licencing regimes and competency based development may offer a more feasible alternative to tackling the motorcycle safety issue. There have been previous calls to introduce a safety rating system for rider clothing in Australia (Haworth, de Rome et al. 2007) and Austroads currently has projects looking into this.

Motorcycles and barriers

The issue of motorcyclists and safety barriers is frequently raised by motorcycle advocacy groups and most contentious is the claim that wire rope safety barriers behave like a “cheese cutter” when struck. Whilst it is true that motorcyclists are much more likely than car occupants to be injured in collisions with barriers, there are several facts that should be taken into account.

Jama, Grzebieta et al. (2011) conducted a study of coroner’s files relating to motorcycle fatalities in Australia and New Zealand between 2001 and 2006. Of the 1462 identified fatalities, 77 (5.4%) were confirmed as involving a collision with a roadside safety barrier:

- 7.8% involved a wire rope safety barrier (+3.5% of an unknown steel type)
- 72.7% involved a steel W beam system
- 10.4% involved a rigid concrete barrier.

This incidence no doubt represents the exposure to these barrier types on the road network and it is noted that the majority of collisions occurred on higher speed limit roads (100 km/h 37, 80 km/h 22 and 60 km/h 10 cases respectively). Other key findings from the study were that there was a high incidence of collisions on a bend (81%) and speeding was a factor in 47% of cases. Furthermore, objects likely to be struck if the barrier was not present included trees (35%), embankments (18%) and medians (18%).

Noting that approximately 50% of motorcyclists strike barriers in an upright posture, and the suspected high incidence of speeding involved in collisions, the authors concluded that it is unclear whether any change to barrier engineering design would reduce motorcycle fatalities without compromising other road safety objectives. It is also likely that the removal of the barriers will not reduce motorcycle fatalities and injury as the collisions with objects behind the barriers is also likely to result in fatal and serious injury.

As barrier technology has evolved, in a consequent publication, Bambach and Grzebieta (2015) highlight some of the engineering design principles that should be considered by practitioners into the future as outlined in the box “Motorcycle Barrier Considerations” on the following page.

Some studies have identified continuous concrete barrier systems as having lower injury potential to motorcyclists than other barrier systems. Daniello and Gabler (2011) for example suggest that W-beam guardrail could have a 75% higher fatality risk than concrete barriers when struck by a motorcyclist.

Bambach and Grzebieta (2015) advise caution and imply that the detrimental effects of going to a more injurious barrier type for all road users may not provide a net safety benefit.

In 2016, crash tests were performed by the Centre for Road Safety in NSW on three W-beam barrier types that incorporated rub-rails. Two of these products (the Ingal MPR and the HIASA) demonstrated acceptable levels of injury risk to a sliding motorcylist impacting at 60 km/h, without adverse effect on car based crash performance in protecting vehicle occupants (Baker, Eveleigh et al. 2016).

The main mechanism of injury postulated for motorcyclists with barriers is head and thorax impact with barrier posts, something common to both wire rope and W-beam barriers. Therefore continuous systems that mitigate impacts with posts are preferred.

It is suggested that W-beam with rub-rail can be used in locations where there are small curve radii (ie where wire rope cannot be installed) or on lengths of road where motorcycle crashes are to be expected noting that the Jama, Grzebieta et al. (2011) study found that 80% of collisions were on bends. Into the future, barrier systems will evolve that better cater for motorcyclist impact in addition to passenger vehicle impacts and the business case for installing these systems may change over time.

Motorcycle Barrier Considerations (Bambach and Grzebieta 2015)

"While motorcyclist collisions with roadside barriers are relatively rare events in Australia and New Zealand, they can result in serious and fatal injuries. For example, fatalities constitute around 4% to 6% of all motorcycle fatalities and typically around 0.01% of all road fatalities. To date the design of roadside barriers has been based on passenger vehicle occupant safety which is understandable as these constitute the greater number of roadside and median crash fatalities and serious injury casualties. However, the injury potential of such devices to motorcyclists has not been considered at all in their development until recently. Improving roadside barrier design for motorcycling safety will assist in reducing motorcycling trauma on Australian and New Zealand roadways in black spot areas where motorcyclists regularly ride and have crashes.

…..

"Continuous barriers (rub-rails and concrete barriers) are shown to 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."

The conclusions from a simulated parametric study of a wide variety of impact angles and speeds (between 15° and 45° and 20 km/h and 100 km/h) on several barrier scenarios led to the following conclusions:

- all rub-rails prevented serious thoracic injury for all angles and speeds considered;
- all rub-rails except those with low stiffness connectors prevented serious head-neck injury at 15° impact angles, however at high impact angles and speeds serious/critical injuries were predicted;
- since 15° is the average impact angle in motorcyclist-barrier collisions, rub-rails are predicted to prevent serious injuries (head, neck and chest) at the average collision angle at all impact speeds up to 100 km/h for half of the W-beam barrier impacts;
- concrete barriers prevented serious injuries at 15° impact angles for speeds up to 80 km/h, however at higher speeds at 15 degrees and higher impact angles at around 60 km/h the potential for serious injury was much higher than for rub-rails. Care is also needed in recommending barriers be installed in place of W-beam barriers as this may worsen outcomes for other road users, e.g. car occupants;
- steel W-beam barriers without blockouts were predicted to provide similar performance to those with blockouts, when protected with rub-rails;
- if rub-rails were installed on all W-beam barriers it would potentially only address around 2% of all motorcycle fatalities and less than 0.5 % of all seriously injured motorcyclists who crash. However, targeting black spot areas with retro-fitting rub-rails to existing W-beam barriers, where motorcyclists are over-represented in traffic and crashes (e.g. mountainous and coastline tourist roads), appears to be cost-effective. Similarly, any new installations of W-beam in such black spot areas would also be cost-effective.

Wire rope barriers and the "Cheese Cutter" effect

The claims of wire rope barrier cutting up motorcyclists on impact are thought to stem from an incident in New Zealand in 2007 when a motorcyclist struck a barrier at high speed (estimated between 148-190 km/h). A resource page is available to practitioners that provides useful information on the incident and the benefits of wire rope safety barriers (Victorian Government 2016). Fundamentally, there has been no evidence to date anywhere in the world that substantiates the "Cheese Cutter" claim:

https://www.towardszero.vic.gov.au/making-progress/articles/flexible-barriers-how-they-work-and-the-cheese-cutter-myth

Another common misperception is that wire rope barrier is not used in certain European countries (Denmark and Norway) due to the risk posed to motorcyclists. In these cases political decisions were made in response to pressure from lobby groups and not in response to scientific evidence about the safety performance of the barriers.

The Swedish experience with wire rope barriers and motorcyclists has been positive and one study involving 600 km of barrier noted a 40-50% reduction in risk for motorcyclists being killed after installation of the barrier system (Carlsson 2009).

Treating high crash motorcycle routes

Austroads (2016c) highlighted the influence of road infrastructure elements in motorcycle crashes in Australia and New Zealand and identified countermeasures that have the potential to prevent crashes and/or reduce the severity of crashes when they do occur. The aim of the report was to provide guidance to practitioners, including through a number of recommended updates to the Austroads Guides to Road Design, Traffic Management, Road Safety and Asset Management.

Part of the Austroads (2016c) study was dedicated to identifying where motorcycle crashes are occurring and what types of infrastructure elements are factors in these crashes. A number of key points were highlighted regarding the locations of motorcycle crashes in Australia, which include:

- Most motorcycle-involved crashes are multi-vehicle crashes.
- A higher proportion of motorcycle crashes are single-vehicle crashes when compared to other motor vehicle types
- A majority of motorcycle crashes occur during the commuting period
- A higher proportion of motorcycle-only crashes occur during the recreational period
- A higher proportion of crashes occur on curves during the recreational period
- A higher proportion of crashes occur on straights and at intersections during the commuter period.

While it was suggested that the road environment is rarely the main factor for the occurrence of fatal motorcycle crashes, the road environment was a major factor in the severity of these crashes. Between 1999 and 2003, 75% of fatal single-vehicle crashes and 57% of fatal multi-vehicle crashes involving motorcycles in Australia involved collisions with roadside hazards. The most common types of hazards struck were trees (24-31%), fences and safety barriers (10-12%), street light and traffic light poles (9%) and drainage infrastructure (5%). Other factors were also identified, including poor surface grip and road surface hazards (such as pot holes, oil and gravel, patch repairs), poor and inconsistent delineation, unsealed shoulders and audio-tactile and raised markings on the road.

A number of treatment programs were investigated as case studies by Austroads (2016c). A motorcycle safety route review in New South Wales was conducted along a 156 km section of rural road where motorcycles were involved in 55% of all crashes, with most of these being motorcycle-only crashes. A number of treatments were implemented which ranged from better delineation and expansion of no-overtaking zones to reduced speed limits and police enforcement, to awareness campaigns.

The Victorian motorcycle blackspot program, which has been run since 2003, was also investigated. To date, 130 rural and urban “black-length” and “black-spot” locations have been treated using this program. The treatments undertaken as part of the program aimed to enhance sight lines and delineation, control vehicle speed, improve road surfaces, reduce the risk of crashes with roadside hazards, provide effective signage and controls and better manage traffic flows. An evaluation of the program based on 87 treated sites reported a 24% reduction in motorcycle-involved casualty crashes and a 16% reduction for all other crashes.

Road infrastructure treatments were categorised by hierarchy of control and were focussed on a number of prominent crashes identified during the study. These included collisions with roadside objects, crashes due to poor road surfaces, crashes on curves and crashes at intersections (Table 7.5).

Table 7.5: A summary of Safer Roads treatments aimed at mitigating or preventing key crash types identified

Issue	Elimination of hazard	Substitution of hazard	Engineering control
Roadside object – tree	Removal of tree	Installation of safety barrier*	Provision of wider shoulder to allow recovery
Poor surface texture	Resurfacing the road	High surface friction treatment	Repair of localised defects
Sharp horizontal curve	Realignment of the road	Improve horizontal sight distance	Provide wider lanes and shoulders on curve
Right turn crashes at signalised intersections	Grade separation	Provision of dedicated right turn lane and phase	Provision of right turn lane, improved sight lines

*Note: *It should be noted that installation of a safety barrier may increase exposure to crashes with a roadside object (the barrier itself) and that this may increase the risk of injury to some road users, namely motorcyclists.*

Source: Austroads (2016c)

A number of other crash mitigation measures were also identified as being able to provide a foundation for the reduction of motorcycle crashes where the road infrastructure is a crash factor. These included improved road alignment, cross-section and sight distances, the provision of safe overtaking opportunities, improved surface condition, careful consideration of the type, control and turn provisions at intersection and the location of intersections, the removal of roadside hazards and the provision of motorcycle friendly infrastructure (such as flexible signs) where roadside infrastructure is necessary.

7.4 Heavy vehicles

What do we know?

- Regardless of who is at fault, collisions involving heavy vehicles tend to have higher severity outcomes due to their mass when compared to other vehicle types
- Collisions in urban areas and with vulnerable road users is also an established problem
- The freight task has been increasing in Australia and is set to increase dramatically over the coming decade
- Multiple combination type vehicles have been increasing on the Australian and New Zealand road networks for productivity gains
- There are numerous examples of good safety practice amongst the transport sector showcased by the National Road Safety Partnerships program
- Many treatments that benefit heavy vehicles will also benefit all road users (sealed shoulders, wide centrelines, etc.)
- Rigid barriers are the only barrier type at present that ensures a high level of containment for heavy vehicles.

What does this mean?

- Segregation remains the major option for dealing with severity of heavy vehicle collisions
- Infrastructure solutions that reduce the likelihood of collisions will also be required – those that influence speed and impact energy are most desirable
- Non-infrastructure based approaches across the other pillars will be needed to improve overall safety including more widespread adoption of safety management systems in organisations and the adoption of vehicle based safety technologies.

Heavy vehicles provide a major Safe System challenge as one of the determinants of crash severity is mass. Put simply, heavy vehicles operate at the same speeds as other vehicles in the network despite the large mass differentials that exist. This makes the task of mitigating death and serious injury outcomes difficult within existing parameters.

According to the DIRD (2016) report, *Heavy truck safety: crash analysis and trends*, heavy trucks (a vehicle designed for the carriage of freight with a gross vehicle mass of 4.5 tonnes or more) continue to be disproportionally involved in casualty crashes, with these vehicles also being associated with more severe crash outcomes. The growth rate of heavy truck registrations, particularly for articulated trucks, is also outpacing that of passenger vehicles, meaning that heavy truck related issues may increase into the future as the proportion of heavy trucks increases. While heavy trucks account for 2.45% of registrations and 7% of vehicle kilometres (with 80% of articulated truck kilometres being outside of capital cities), they represent involvement in about 16% of fatalities and 4% of injuries. This means that for both per vehicle-kilometre and per registered vehicle, the rate of fatal crashes is higher for heavy trucks than for passenger vehicles – twenty times higher for articulated heavy trucks than for passenger vehicles when based on per registered vehicle. The rate of heavy-vehicle involved fatal crashes is, however, trending downwards at approximately 5% per year. Available evidence also suggests that in approximately 80% of heavy truck-involved multiple vehicle fatal crashes, fault was not assigned to the heavy vehicle. It should however be noted that assignment of fault is not feasible in the case of all fatal crashes.

DIRD (2016) examined the crash types of heavy truck-involved casualty crashes. A larger proportion of single vehicle crashes occurred on curves with articulated heavy trucks than with rigid heavy trucks or light four wheeled vehicles. For two-vehicle crashes, there was a larger proportion of same direction crashes compared to adjacent direction and opposing direction crashes for heavy truck/light vehicle collisions than for light vehicle only collisions. A higher proportion of heavy truck crashes also involved vulnerable road users than with light vehicle crashes. Twenty-six percent of fatal heavy truck crashes between 2010 and 2014 involved a vulnerable road user.

There are numerous categories and combinations of heavy vehicles using the road network in Australia and New Zealand and policies to enhance productivity have meant that combination mass and length have steadily been increasing over past decades. In addition, the freight task has been growing at a considerable rate over the past decade and all indications are that this is to continue well into the future (Raftery, Grigo et al. 2011b, Austroads 2013b).

There are multiple dimensions to the heavy vehicle problem ranging from long distance interstate journeys to small rigid trucks delivering goods in urban areas. Collisions involving heavy vehicles tend to have more severe outcomes due mainly to the mass involved and consequent high impact energy.

Although an increasingly important aspect of traffic management and road design, there are many circumstances where the interaction of heavy vehicles with light vehicles and vulnerable road users are not accounted for. This includes the dynamic visual obstruction caused by heavy vehicles travelling on the road network and the ability for vehicles to overtake and safely pass long combination vehicles on rural roads. Pedestrians and cyclists being struck by rear axles are an established problem in urban areas especially where heavy vehicles conduct a left turn.

There are a number of regulatory components specific to improving heavy vehicle safety in Australia. These include regulations for fatigue management, load and mass/dimensions, road access, Chain of Responsibility, Performance Based Standards and the National Heavy Vehicle Accreditation Scheme (DIRD 2016). Many of these schemes are complementary to the development of mature safety culture in organisations and the reader is referred to the National Road Safety Partnerships website for numerous case studies and knowledge base regarding the transport industry: http://www.nrspp.org.au/

Vehicle technologies show much promise and heavy vehicles tend to have more safety technologies than light vehicles in a correspondingly younger vehicle fleet that turns over more frequently than the light vehicle fleet. However, take up of these features has been slow and more can be done to expand these into the fleet. Budd and Newstead (2014) estimated that autonomous emergency braking systems (AEBS) save 67 lives per year, lane departure warning systems (LDW) 16 lives per year, electronic stability control (ESC) 11 lives per year and fatigue warning systems (FWS) 10 lives per year. However, there are also a number of areas that have been highlighted as requiring further research. These include fatigue management and seat belt use by heavy vehicle occupants, as well as evaluation of heavy vehicle management schemes and heavy vehicle safety technologies (Raftery, Grigo et al. 2011a). A lack of detail in crash databases in Australia has also been highlighted as of concern, meaning a more intricate picture of heavy vehicle safety – such as in terms of industry sector, load type and vehicle combination type – cannot currently be achieved (Austroads 2013b).

The preferred safe system primary treatment, flexible barrier, may not be suitable in situations where heavy vehicle containment must be achieved. On roads with high proportions of heavy vehicles, rigid barriers may be necessary to stop incursions by heavy vehicles into oncoming traffic or to prevent heavy vehicles from striking hazards. In such circumstances it is difficult to design a forgiving system for all road users and sound engineering judgement must be applied.

7.4.1 Heavy vehicle treatments

The Dutch sustainable safety policy simplifies the philosophy with heavy vehicles to the following (Wegman, Aarts et al. 2006):

- It needs to be acknowledged that there is a high level of incompatibility between heavy vehicles and all other road users
- Everything possible has to be done to prevent unnecessary movement, and then to manage the mileage travelled as safely as possible
- An ideal situation would be to have heavy goods vehicles separated from other traffic as much as possible by place and time and restrict their interaction with vulnerable road users as much as possible by keeping them to the major roads network; light goods vehicles made compatible with other traffic can then use the remaining road network.

A key challenge will be to meet Safe System performance levels while also considering the safety risks presented by heavy vehicles. Barriers are now available that can safely contain errant heavy vehicles however these can be at the expense of reduced safety to other road users. There are few other primary options available. When segregation of heavy vehicles from other road users is not possible, it is important that opportunities for conflict are minimised, including (Austroads 2015g):

- Gap selection and clearance times at intersections
- Conflicts between light vehicles and heavy vehicle trailers when turning at intersections or negotiating roundabouts
- Severe outcomes of conflicts between left turning heavy vehicles and pedestrians and cyclists
- Areas of high risk including grades, curves and merges
- Shoulder sealing and reduced edge drop to assist with heavy vehicle control.

As with motorcycle safety, a significant contribution from the other pillars will be required in addition to infrastructure treatments.

A hierarchy of heavy vehicle related treatments is shown in Table 7.6.

Table 7.6: Safe System Assessment Framework hierarchy of heavy vehicle related treatments

Hierarchy	Treatment	Influence (E = exposure, L = likelihood, S = severity)
Safe System options ("primary" or "transformational" treatments)	• Separation (separate heavy vehicle roadways) • Very low speed environment, especially at intersections • Heavy vehicle rated barriers**	E L, S S
Supporting treatments (compatible with future implementation of Safe System options)	• Wide Centrelines	L
Supporting treatments (does not affect future implementation of Safe System options)	• Shoulder sealing and reduced edge drop to assist with heavy vehicle control	L
Other considerations	• Speed enforcement • Enforcement of other regulations • Evolve a culture of safety in organisations	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.*
*** Note that in general barriers that may contain large mass vehicles tend to have more severe outcomes for lighter vehicle occupants.*

Source: Austroads (2016e)

7.5 Older road users

Australia and New Zealand are experiencing aging populations. By 2031, the proportion of people aged 65 and older is expected to represent nearly 20% of the total population, compared to 14% in 2012 (Austroads 2016d). Along with an older population is an increase in the number and participation of older road users on our road network. A recent report by (Austroads 2016d) has looked into the question of whether the increasing numbers of older road users pose an increased safety risk to either themselves or others and what can be done to reduce the safety risk to this demographic.

As older road users become more dependent on their vehicles as a primary mode of travel and to make more frequent and longer trips, there will be an increase in exposure to older drivers. A review of literature found that older drivers have a higher rate of crashes per distance driven, however this may be the effect of low mileage bias, cohort effects and physical fragility. Impairments to their health and cognitive and functional abilities may also increase the crash risk of older drivers. A review of crash data from Australia and New Zealand showed that road users aged 60 and above represented a growing part of the road trauma problem, when compared to those under the age of 60. The proportion of injured road users aged 60 to 74 increased from 7.6% in 2003 to 10.4% in 2012, with the proportion for those aged 75 and over increasing from 3% to 4%. Despite this, in the same time frame every age group has seen and decline in the rate of crashes per head of population and the increasing proportion of injured older road users is likely a function of a greater crash rate reduction for the group of road users aged below 60, rather than increasing numbers of injured older road users.

Austroads (2016d) suggested that the increased crash risk among older drivers could result in increased crash numbers as the population of older drivers increases. The increased fragility of older drivers compared to younger age groups also means that they are more likely to be seriously or fatally injured in the advent of a crash, meaning there is a risk that serious and fatal injury numbers may increase with an increase in the number of older drivers. Despite these issues, there is growing recognition that the mobility associated with driving is important for the health and wellbeing of an older population. As such, it was suggested that it is important for older people to continue to drive for as long as it remains reasonable for them to do so.

However, as it becomes unreasonable for older people to drive, they may choose to use alternative modes of travel, including those classified as vulnerable road user modes. Vulnerable road users are already at a higher risk of serious injury and fatality in the advent of a crash. Combining this with an increase in the fragility of older people, it means that older road users may be at in increased risk when selecting these alternative modes of travel. Austroads (2016d) found that between 2003 and 2012 in Australia and New Zealand, there was a greater proportional involvement of road users aged 75 and over being involved in crashes as pedestrians than for other age groups. However, they were also less likely to be involved as bicyclists or motorcyclists. An analysis of the in-depth crash investigation program run by the Centre for Automotive Safety Research (CASR) also showed that older pedestrians chiefly contributed to their involvement in crashes with vehicles through no or insufficient observation of traffic before crossing the road. This is in contrast to younger pedestrians, where erratic behaviours due to intoxication, cognitive impairment or a child running onto the road were key factor.

Consultation with a number of jurisdictional representatives from Australia and New Zealand were also performed by Austroads (2016d). Despite the important role that infrastructure has to play in terms of crash prevention and injury mitigation, there was little indication that jurisdictions were implementing infrastructure specifically targeted towards older road users. There was, however, a strong indication among the representatives that the needs of older road users were considered when designing and implementing infrastructure but that older road users were rarely the governing factor for a design. It was also noted that well designed infrastructure is likely to be of benefit to all road users, even if older road users derive particular benefit. Some discussion was also had about the important role that infrastructure plays for the protection of older pedestrians. Programs aimed at assessing walking networks in order to encourage physical activity in the older community were also mentioned.

Several recommendations were made in the report with regard to the implementation of infrastructure benefitting and targeting older road users. Despite the specific consideration of older road users, the recommended infrastructure would likely benefit road users of all ages.

With regard to the safety of older drivers, it was recommended that jurisdictions consider the implementation of infrastructure that improves safety at intersections through the reduction of complexity and speeds. Gap selection was identified as a key area of concern for older drivers through the analysis of in-depth crash investigation cases, leading to the recommendation of eliminating filter right turns at signalised intersections. Speed limit reductions and the implementation of traffic calming devices, such as plateaus, were also recommended in order to reduce intersection through speeds.

There was also an emphasis on the recommendation of infrastructure benefitting elderly pedestrians. It was recommended that jurisdictions continue to install and retrofit infrastructure that protects pedestrians in areas of high pedestrian activity, especially areas where older pedestrians are likely to frequent. It was also recommended that speed limits in high pedestrian areas, especially those frequented by older pedestrians, are set with consideration of the higher injury risk to older pedestrians.

8. Other Considerations

8.1 Intelligent transport systems

Technological advances are progressing at a rapid rate and many autonomous safety technologies have already found their way into current model vehicles (Austroads 2010f). There is constantly the potential for ITS solutions to contribute to safety and a number of Austroads reports detail different ITS infrastructure that are available to practitioners, including:

- Managed freeways (Austroads 2009e, Austroads 2014c)
- Ramp metering (Austroads 2009e)
- Automatic freeway incident detection (Austroads 2010a)
- Variable message signs (Austroads 2009f, Austroads 2010f, Austroads 2015a)
- Speed feedback signs (Austroads 2005, Austroads 2010f)
- Variable speed limits (Austroads 2009b, Austroads 2009c, Austroads 2009a, Austroads 2010f)
- Vehicle activated warning signs (Austroads 2010f, Austroads 2010g)
- Truck activated speed advisory signs (Austroads 2010f, Austroads 2015b)
- Advanced warning signs (Austroads 2011b, Austroads 2015b)
- Intersection safety management systems (Austroads 2010f)
- Puffin (pedestrian user-friendly intelligent) crossings (Austroads 2010f).
- Illuminated road studs (Austroads 2010f).

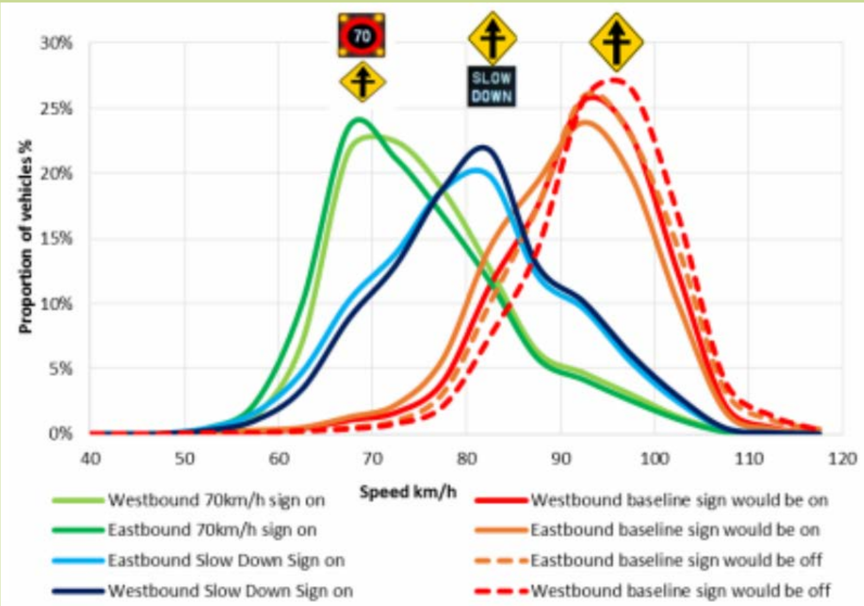
Evidence on the effectiveness of new “smart” infrastructure continues to increase. A recent study in New Zealand for example highlighted the effectiveness of intelligent signage that reduce speed limits at intersections when adjacent vehicles were detected (Mackie, Holst et al. 2016).

Practitioners should be open to the possibilities that ITS solutions can deliver for safety outcomes. Most notable are temporal speed limits that can reduce risk and crash severity outcome according to risk profile during the day. This may overcome the difficulty of finding a “compromise” speed limit that suits all circumstances at all hours. The case study shown here from New Zealand demonstrates the application of these principles in a site specific manner.

Rural intersection active warning system (RIAWS)

In 2012-13, the New Zealand Transport Agency (NZTA) started trials of vehicle activated warning signs with the purpose of reducing the speed of through traffic at high risk rural intersections (NZTA 2012, Mackie, Holst et al. 2016). The idea for these treatments was developed from similar programs that have been successfully implemented overseas, especially the treatment trialled by the Swedish Road Administration (Mackie, Hoist et al. 2014). Known in New Zealand as the *rural intersection active warning system* (RIAWS), it is designed to provide vehicles on the major road of a rural priority controlled intersection to be notified when a vehicle at the intersection on the minor road was detected. A threshold speed of 70 km/h for major road traffic was desired, which was equated to the Safe System aligned impact speed of 50 km/h for a side impact, with some prior braking (NZTA 2012).

Two RIAWS sign types were trialled: one displaying a “slow down” message and the other displaying a “70” speed limit. Each RIAWS sign was paired with the Australasian standard cross road ahead warning sign. Speed surveys were undertaken and the results showed a dramatic reduction in through speeds along major roads with both signs. The greatest effect was seen with the “70” speed limit sign, where average through speeds, on activation of the sign, were reduced to near the desired 70 km/h threshold – a substantial reduction from the average non-activated speed of about 90 km/h (Mackie, Hoist et al. 2014, Mackie Research and Consulting 2016).



RIAWS was installed at 10 sites and a five year before and after comparison indicated that injury crashes had been dramatically reduced. For the five years before, 1 fatal, 19 serious injury and 44 minor injury crashes were recorded. For the five years after, 0 fatal, 1 serious and 5 minor injuries were recorded with the single serious injury unrelated to the system as it involved a motorcycle being struck from behind while waiting on a side road.

8.2 Connected and autonomous vehicles

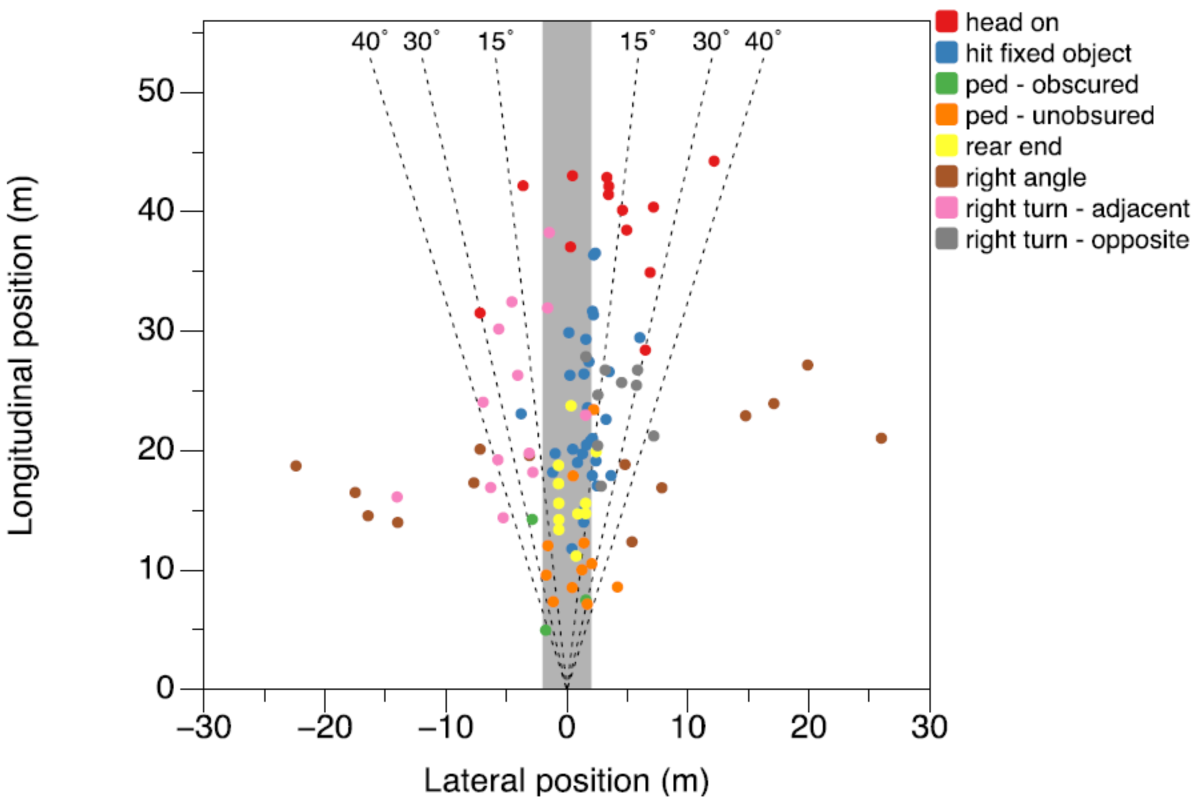
There is much speculation about the impact that increasing automation will have on society and operationally on safety. The most optimistic outlooks consider the possibility of fully automated vehicles that do not require operator input and refuse to crash. While technologically this scenario is currently possible in a closed controlled environment, there are several technological and societal transformations required before such a scenario can occur on a widespread basis on open public roads. Austroads (2017a) provides an up to date assessment of the potential benefit of automated vehicles and Cooperative Intelligent Transport Systems in Australia and New Zealand given certain deployment scenarios.

The more realistic short to medium term scenario is that automated technologies will continue to be developed to assist core driving tasks. It is conceivable that some of these technologies will virtually eliminate death and injury from certain crash types yet there are likely to be situations and circumstances where the systems cannot protect road users. In other words, *considerable crash residuals may still exist* as a result of technological limitations, operator error, environmental conditions (such as smoke, fog, sunglare and heavy rain), or variability in implementation between manufacturers. In this scenario safe infrastructure and vehicle design will still have an important role to play in providing the necessary safety redundancy when the driver assist systems fail or cannot perform optimally.

As an example, Doecke, Anderson et al. (2012) performed a study hypothesising the likely crash benefits of Autonomous Emergency Braking (AEB) systems. Such systems apply braking in safety critical scenarios on behalf of the driver and are included in numerous vehicle models currently on the market.

Doecke et al examined the potential effect of AEB systems on common crash types that involved a frontal collision. To accomplish this, simulations were conducted of 103 real world crashes from the CASR in-depth database with differing AEB system models to determine the change in impact speed that various AEB interventions could produce. Figure 8.1 shows the location of the colliding object one second prior to impact.

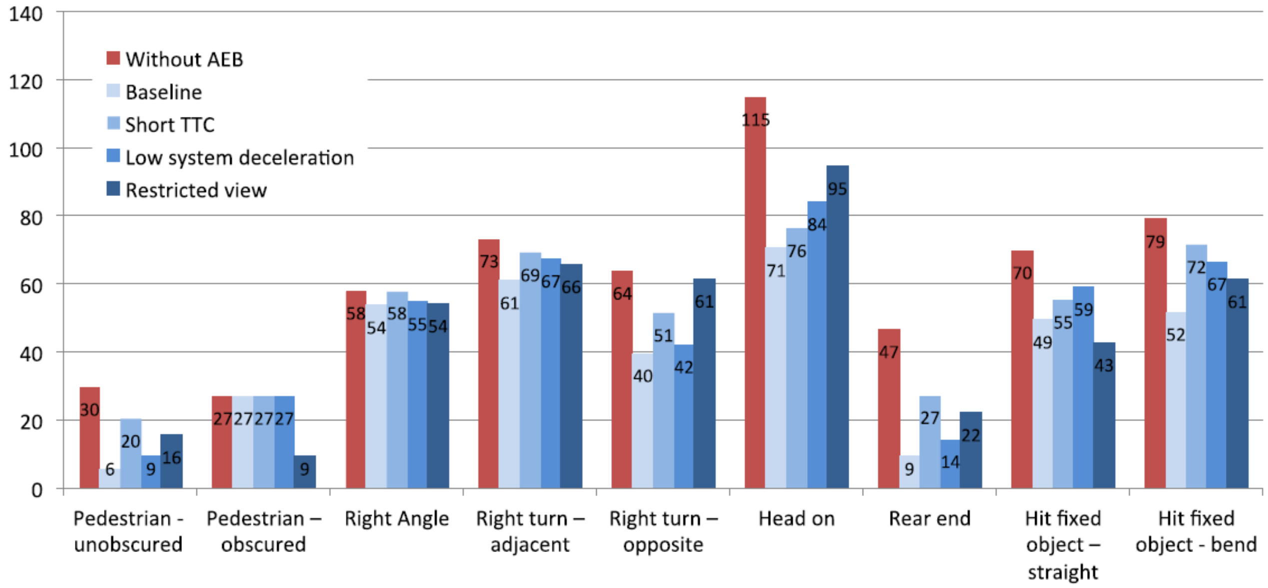
Figure 8.1: Location of crash partner one second from collision by crash type



Source: Doecke et al 2012)

For the modelling conducted, objects approaching from right angles are well outside the field of view of the AEB sensor and many head on collisions are also not in the forward path of the bullet vehicle (indicated by the 4 m wide grey band). A great challenge for vehicle safety engineers is differentiating benign threats from real ones at the point when an intervention has to be made. Given the spatial distribution of objects relative to the bullet vehicle one second prior to impact, it is evident that many collisions cannot be avoided. Figure 8.2 outlines the modelled average speed reductions given differing AEB system parameters for the real world crashes modelled. Note that the modelled scenarios only involved the bullet vehicle having AEB and not multiple vehicles.

Figure 8.2: Average impact speeds by crash type and AEB system specifications



Source: Doecke et al (2012)

What is of most interest is the "Without AEB scenario" compared to the other scenarios. It can be seen that speed reduction for some crash types is minimal. In most cases, speed reductions are insufficient to reduce impact energy to Safe System levels. This work highlights that while there will be some contribution from driver assistance technologies towards improving safety, there is a compromise necessary with the performance of the systems and there is likely to be a crash/injury residual that varies by crash type.

What is important to note is that considering that the vehicle fleet takes in the order of 20 years to turnover, safe infrastructure will still be required to minimise death and serious injury, and provide system redundancy in any transitional and long term scenario.

9. Tools and Prioritisation Approaches

There are various tools and methodologies available to assist with road infrastructure safety management (RISM). The International Road Traffic and Accident Database (IRTAD) released a report on the evaluation of 10 procedures as outlined in Table 9.1 (International Transport Forum 2016). These procedures are aimed at enhancing road safety at different stages of a road infrastructure life cycle from planning and design through construction, operation, maintenance, improvement and major upgrading and renewal.

Table 9.1: Procedures available to assist with Road Infrastructure Safety Management (RISM)

Procedure	Purpose
Efficiency Assessment Tools	Compare different implementation scenarios from a road safety point of view
Road Safety Audit	Compare different scenarios from road safety point of view and identify the most efficient measure from a list of potentially effective measures
Network Operation	Identify infrastructure or traffic related factors increasing injury or accident risk
Road Safety Performance Indicators	Assess the safety of a road network
Network Safety Ranking	Rank elements of a road network based on their safety level
Road Assessment Program	Rank elements of a road network based on road safety and identify infrastructure or traffic related factors increasing injury or accident risk
Road Safety Inspection	Identify infrastructure or traffic related factors increasing injury or accident risk
High Risk Sites	Identify infrastructure or traffic related factors increasing injury or accident risk
In-depth investigation	Identify infrastructure or traffic related factors increasing injury or accident risk

Source: ITF (2016)

International Transport Forum (2016) provides a succinct overview of RISM and related tools and notes that while there are overlaps and similarities there are also some important differences. In general the choice of which procedure to use is linked to the data available and the stage in the project life cycle. One of the key differences is that Network Safety Rankings (NSRs) are typically based on historical crash data while road assessment programs (RAPs) are based on surveys of infrastructure design and quality. One of the key advantages of the RAP approach is that a full cycle of data collection and planning can be made in a pro-active manner towards a strategic network response to road safety, usually in the absence of any reliable crash data.

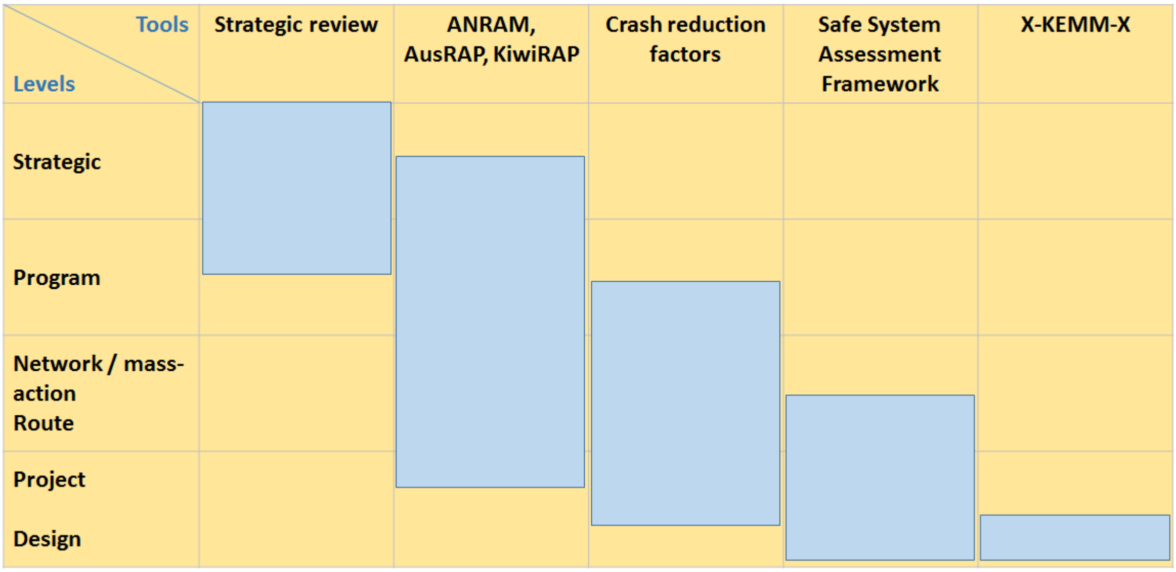
An additional approach not identified in the IRTAD report is the Systemic Approach. This is outlined in the PIARC Road Safety Manual (RSM) (WRA 2015) as an approach that identifies treatment sites that are not typically identified through reactive analytical techniques. Central to this approach is the risk assessment approach, which involves the collection of roadway and traffic characteristics that relate to the selected risk factors and crash types. This is used to help identify the potential for locations or road segments to have severe crash outcomes.

An example by Preston et al. (2013) was provided for an assessment of curves on a rural network that identified a number of sites that had common risk characteristics as locations with severe crash outcomes, but that did not have a documented severe crash. It was noted that the approach can be used with or without crash data. Harwood et al. (2014) (cited in WRA 2015) reviewed the systemic approach, identifying several strengths as well as areas for potential improvement. They suggested that this approach required less roadway data than other tools, did not require crash data to identify specific crash locations, and provided greater flexibility for target crash types and risk factors. However, this flexibility was also seen as a possible weakness, as there is a reliance on users to identify potential risk factors, weight these risk factors, include issues such as traffic volume, and to conduct a cost-benefit analysis (an optional task) as part of intervention selection.

It should be noted that many of these procedures are not necessarily aligned with the Safe System. However, some are evolving to better address fatal and serious injury potential. Others, such as the RAPs, are already aimed specifically at these objectives.

In Australian and New Zealand, various procedures and tools are in use or in development that can be used at various levels of application as shown in Figure 9.1. Several of these procedures and tools are outlined briefly in the sections that follow.

Figure 9.1: Procedures and tools currently used in Australia and New Zealand



Source: Austroads SS2061 Knowledge Transfer Workshops (2016)

9.1 Approaches to prioritising network treatments

With the transition to a Safe System, knowing where to fund improvements in the road network can be challenging. Historically, safety prioritisation approaches have tended to be reactive in nature; that is crashes need to have occurred at a location before remedial action is taken. Further information on this topic is contained in the *Austroads Guide to Road Safety Part 8: Treatment of Crash Locations* (Austroads 2015c).

Earlier chapters have highlighted the need for systemic changes to the road network and the need to engineer severe injury crashes out of the system. Given the theory and knowledge that we now have it is important to note that fixing locations only on the basis of a crash history is not optimal and efforts should be made towards systemically modifying all locations with similar attributes in the network over the long term. There is evidence to suggest that coordinated changes at a corridor level can have better outcomes than the incremental sum of individual site treatments using reactive approaches (Levett, Job et al. 2009, Smart, De Roos et al. 2009).

As prioritization schemes have become more sophisticated, risk based metrics are increasingly being incorporated into current analysis tools. These metrics are most commonly based on road attributes including road function, traffic volumes, speed limit, number of lanes and width, presence of sealed shoulders and crash barriers. Star ratings are an established form of risk rating that can communicate a simple message to practitioners and the community. These have been developed internationally through iRAP (International Road Assessment Program) and local equivalents AusRAP and KiwiRAP.

Various Austroads jurisdictions are currently active or have already developed prioritisation tools to assist with targeting treatment on the road network. Most significant of these are ANRAM (Australian Network Risk Assessment Model) developed for use across Australia and the New Zealand High Risk Guides.

A first generation of dedicated Safe System tools have emerged now providing practitioners with a means for assessing alignment with harm minimisation objectives. These include the Austroads Safe System Assessment Framework (Austroads 2016e) and a Safe System intersection design tool (Jurewicz and Sobhani 2016).

The following sections provide brief background information on the topics introduced above.

9.1.1 Reactive approaches

Reactive approaches are primarily based on crash history and the most notable is the blackspot approach. With this approach sites that exceed a minimum threshold in absolute numbers of fatal or serious injury crashes or crash rates per kilometre (on road lengths) are prioritised for treatment (Austroads 2015c). The blackspot type approach has been in use for many decades in road safety and there is considerable merit when considering how to improve the safety in the network to prioritise those locations with the highest number of crashes. This constitutes a good first order response to the road safety problem when commencing activity to improve safety in a network or where there are sufficient clusters of crashes that obviate the need for treatment.

There are significant limitations emerging in relation to this approach however. The vast majority of severe crashes now occur outside of blackspots and in some countries crashes at blackspot locations have almost been eliminated. Austroads (2016) highlights that 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. 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 crashes.

In addition, the approach has the potential to use up finite resources over very few sites. Conversely there will always be sites that just fail to meet the blackspot threshold and never receive improvement. As the number of crashes decreases over time, their geographic distribution will become more random. This is especially the case in rural areas for example where single vehicle departures have a wide distribution across the network. Finally, as the blackspot approach is reactive, it requires a site to have a crash history in order for remedial action to be taken. The benefits of reactive and proactive approaches are highlighted in Figure 9.2.

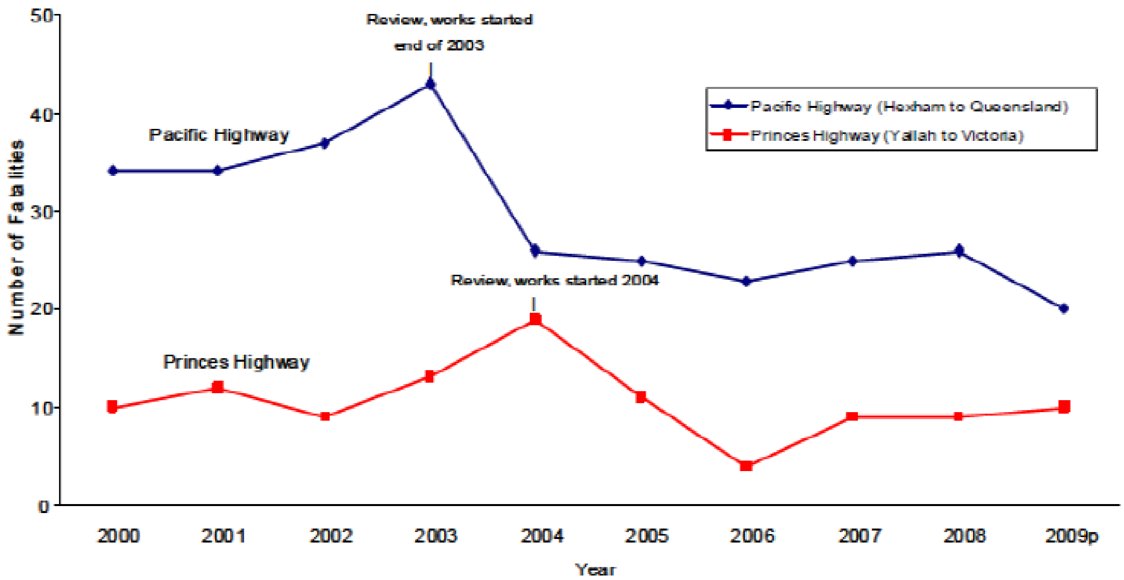
Figure 9.2: The contrast between proactive and reactive processes

PROACTIVE PROCESS (ROAD ASSESSMENTS)	REACTIVE PROCESS (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 by 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 the 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 are 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 biased by category shift and/or regression to the mean, though methods for reducing these risk exist (Elvik, 2006; Job & Sakashita, 2006).

Source: Job (2012)

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. An early demonstration on the ability of this approach to yield higher than normal benefits is outlined by Job (2012) who instigated multidisciplinary route reviews in addition to crash analysis. Reductions in fatalities for route reviews conducted on the Pacific and Princes Highways in NSW are highlighted in Figure 9.3.

Figure 9.3: Changes in fatalities coincident with treatments stemming from route reviews of the Pacific and Princes Highways in NSW



Source: Job (2012)

9.1.2 The Australian Road Assessment Program (AusRAP)

Since its inception, the Australian New Car Assessment Program (ANCAP) has progressively encouraged vehicle manufacturers to raise the safety standards of vehicles sold in Australia, to well above the legal minimum standards (Metcalfe and Smith 2005). The Australian Road Assessment Program (AusRAP) is an initiative of the Australian Automobile Association that was developed with the hope for a similar impact to highways. Based on international road assessment programs (RAPs), the aim for AusRAP is to provide a consistent, independent safety rating system for highways in Australia.

AusRAP uses two protocols; risk mapping and the road protection score (RPS). The first protocol, risk mapping, is used to divide highways into “links” using four criteria; the number of crashes along a length of road, the broad type of road, to have meaningful start and end locations and to be rural in nature. The resulting collective risk metric is then used to score each link based on risk bands, from a low risk rating (best 20% of links) to a high risk rating (worst 20% of links).

The second protocol, the RPS, estimates the injury risk of a road based on its physical features. Data used to calculate a road’s RPS is collected by undertaking a drive-through and collecting video data from a number of cameras attached to the vehicle. The RPS score is based on run-off-road crash type features, head-on crash type features and intersection crash type features. Scores are also able to be determined for pedestrians, cyclist and motorcyclists.

9.1.3 The New Zealand Road Assessment Program (KiwiRAP)

The New Zealand Road Assessment Program (KiwiRAP) was specifically developed for New Zealand after a trial of the Australian road assessment program (AusRAP) was undertaken in 2007 (Waibl, Tate et al. 2012). The KiwiRAP analysis tool (KAT) is able to be used by practitioners across New Zealand to track road safety performance and assess potential improvements across the nation’s highway network.

Similar to international road assessment programs (RAPs), KiwiRAP incorporates three protocols; risk mapping, star rating and performance tracking. The first protocol, risk mapping, uses historical casualty crash and traffic volume data to rate the relative personal and collective risk of sections of the highway network. The second protocol, the star rating, derived from the AusRAP RPS, is used to rate each section of highway based on its physical features and their subsequent effect on the risk of three crash types (run-off-road, head-on and intersection crashes). The third protocol, performance tracking, is used to measure changes in the risk of roads over time in order to assess whether treatments aimed at improving safety have had the desired effect.

9.1.4 Australian National Risk Assessment Model (ANRAM)

ANRAM is a risk-based severe crash assessment tool that was created to support nationally consistent road assessment programs. The ANRAM toolkit is informed by Safe System objectives and can be used to better align a jurisdiction’s road safety treatment programs towards Safe System performance such as a transition towards five-star roads.

The ANRAM toolkit allows practitioners to assess their road network in order to identify severe crash risk locations. It uses the AusRAP protocols to identify risk injury risk based on the features of a road. It also identifies risk from existing crash data. Both predicted and observed severe crashes can be combined to produce an estimate of severe crashes and consequently a severe crash risk score. Using this scoring system, the toolkit can be used by road agencies to:

- Identify the severe crash risk of roads within their jurisdiction and compare risk across jurisdictions
- Select road attributes (and speeds) for potential improvements
- Evaluate and prioritise a number of proactive road safety treatment options, develop treatment based road safety programs and simulate treatment scenarios to estimate severe crash savings
- Estimate economic benefits and preliminary benefit-cost ratios for road safety programs and compare the performance of different road safety programs
- Quantify incremental severe crash reductions based on incremental or periodic maintenance and investment, and provide network performance indicators to show progression towards Safe System performance over time.

9.1.5 New Zealand High Risk Intersection and High Risk Rural Roads Guides

The New Zealand High Risk Intersection (NZTA 2013b) and High Risk Rural Roads (NZTA 2011) Guides were prepared by the New Zealand Transport Agency to provide guidance to practitioners to identify, target and address key road safety issues at high-risk rural and urban intersections and rural roads, respectively. Based on a New Zealand perspective, the Guides are intended to provide national consistency regarding the identification of high-risk locations and the implementation, monitoring and evaluation of treatments by providing:

- A Safe System approach to the treatment of high-risk intersections with a range of tools to assist in identifying and analysing high-risk locations
- A range of Safe System and best value remedial treatments to counter key crash types occurring at intersections and along rural roads
- Guidance for the development, prioritisation and funding of road safety infrastructure programs
- References to further resources and tools for the evaluation and implementation of treatments.

The Guides provide practitioners with a step-by-step process to the use of crash data, metrics for the identification, catagorisation and prioritisation of high-risk locations, and the identification of best value for money treatments aimed at counteracting FSI crashes. The process outlined in The Guides includes:

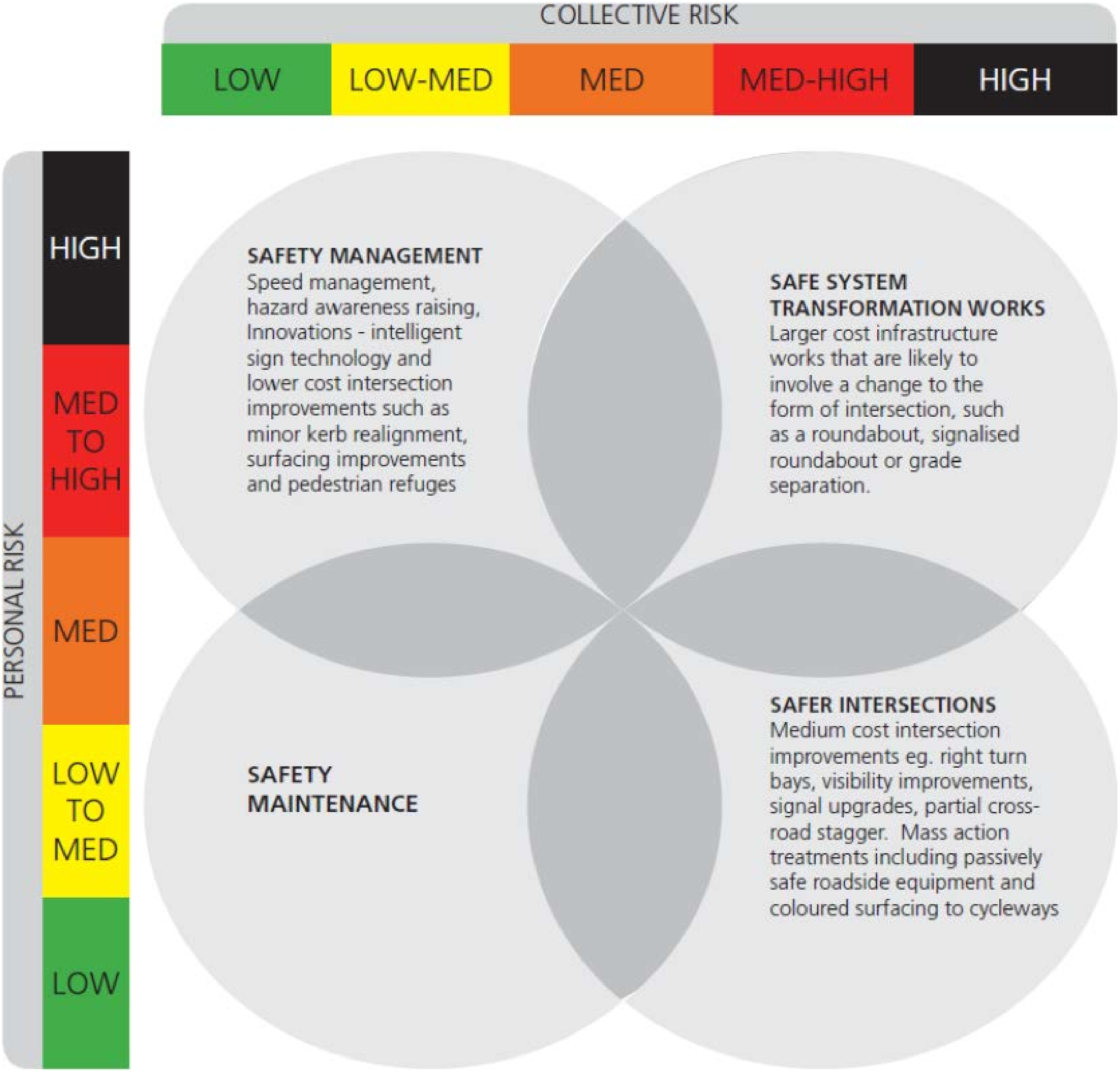
- The use of reported FSI crash data to identify high-risk locations where improvements are most likely to provide benefits of reduced deaths and serious injuries, and a summary of predictive crash risk models
- The use of metrics to catagorise high-risk locations. These include the collective risk metric, which is a measure of the total number of FSI crashes per intersection during a specified period; and the personal risk metric, which is a measure of the risk of death or serious injury to the occupants of each vehicle entering a location
- The use of the level of safety service method to prioritise and map locations (Figure 9.4). This method provides a comparative measure of historic safety performance compared to the expected performance of an individual location.
- The use of the level of safety service method for the identification of best value for money treatments to counter FSI crashes (Figure 9.5).

Figure 9.4: Level of safety service bands

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

Source: NZTA (2013a)

Figure 9.5: Intersection treatment guide



Source: NZTA (2013a)

9.2 Current Safe System tools

9.2.1 Safe System evaluation framework

The Safe System assessment framework was developed by Austroads (2016e) for use by practitioners wishing to include Safe System objectives in the development of all levels of road infrastructure and traffic management projects. The development of this framework was based on a review of literature, workshops, and internal discussions within the project team. Two key objectives of the framework were that it should be capable of assessing a wide variety of project types and be utilised at any stage across the lifespan of a project, and that it include all pillars of the Safe System. It was envisaged that the framework be applied to all project types, covering the planning, design, operation, maintenance and use of the road network.

A treatment hierarchy is provided to guide practitioners to firstly consider those treatments most aligned with Safe System objectives. The hierarchy consists of Primary treatments, Supporting step towards treatments, Supporting treatments and non-safe system treatments as defined in Figure 9.6. 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.

Figure 9.6: Safe System treatment hierarchy

Primary Treatment	• Road planning, design and management considerations that virtually eliminate the potential of fatal and serious injuries occurring in association with the foreseeable crash types
Supporting (step towards)	• Road planning, design and management considerations that improve the overall level of safety associated with foreseeable crash types, but not expected to virtually eliminate the potential of fatal and serious injuries occurring • Improves the ability for a Primary Treatment to be implemented in the future
Supporting Treatment	• Road planning, design and management considerations that improve the overall level of safety associated with foreseeable crash types, but not expected to virtually eliminate the potential of fatal and serious injuries occurring • Does not change the ability for a Primary Treatment to be implemented in the future
Non-Safe System Treatment	• Road planning, design and management considerations that are **not expected to achieve an overall improvement in the level of safety** associated with foreseeable crash types occurring • **Reduces the ability for a Primary Treatment** to be implemented in the future

The framework provides a focus on the assessment of infrastructure, and this means that there is a stronger focus on road and roadside infrastructure and vehicle speeds. However, the road users and vehicle types involved are considered at a number of stages in the process, particularly with respect to limitations on their performance. In many cases road user and vehicle-related changes will be outside the direct control of those applying the framework, but they may be able to influence others who do have the ability to influence these aspects of the system. The same applies to elements relating to post-crash care.

The framework follows a similar approach typical to the assessment of risk, with the main process including:

- Identification of objectives
- Setting the context
- Applying the Safe System matrix
- If required, applying a treatment hierarchy and selection process.

Before the framework is applied, the objectives of the assessment must first be identified. It could be to assess the level of Safe System alignment only, identify Safe System-relevant issues, develop solutions, or to develop and compare alternative project options (or all of these). In some cases the assessment may need to be broken down into smaller sections or elements which are more manageable.

Secondly, the desired depth of the assessment needs to be identified. This could be done at high level at the planning stage or a more detailed level for individual project components. Where a higher level of precision is required, subjective assessment could be replaced by more detailed quantitative assessment methods.

The context of the project being assessed is also important and its consideration help ensure that each pillar in the Safe System is considered as part of the assessment. Even though the focus of the framework is to assess infrastructure-related projects, there are many ways that professionals may be able to influence safety outcomes besides infrastructure-specific changes.

In order to consider all Safe System elements and also allow measurement of how well a given project aligns with Safe System objectives, a matrix (known as the Safe System assessment framework) was produced (Table 9.2). The purpose of the matrix is to assess different crash types identified as the predominant contributors to fatal and serious injury outcomes. Each crash types is assessed against the exposure of the crash risk, the likelihood of it occurring and the severity of the crash should it occur.

Table 9.2: The Safe System assessment framework

	Run-off-road	Head-on	Intersection	Other	Pedestrian	Cyclist	Motorcyclist
Exposure	AADT; length of road segment	AADT; length of road segment	AADT for each approach; intersection size	AADT; length of road segment	AADT; pedestrian numbers; crossing width; length of road segment	AADT; cyclist numbers; pedestrians	AADT; motorcycle numbers; length of road segment
Likelihood	Speed; geometry; shoulders; barriers; hazard offset; guidance and delineation	Geometry; separation; guidance and delineation; speed	Type of control; speed; design, visibility; conflict points	Speed; sight distance; number of lanes; surface friction	Design of facilities; separation; number of conflicting directions; speed	Design of facilities; separation; speed	Design of facilities; separation; speed
Severity	Speed; roadside features and design (e.g. flexible barriers)	Speed	Impact angles; speed	Speed	Speed	Speed	Speed

Additional Safe System components	
Pillar	**Prompts**
Road user	Are road users likely to be alert and compliant? Are there factors that might influence this? What are the expected compliance and enforcement levels (alcohol/drugs, speed, road rules, and driving hours)? What is the likelihood of driver fatigue? Can enforcement of these issues be conducted safety? Are there special road uses (e.g. entertainment precincts, elderly, children, on-road activities, motorcyclist route), distraction by environmental factors (e.g. commerce, tourism), or risk-taking behaviours?
Vehicle	What level of alignment is there with the ideal of safer vehicles? Are there factors which might attract large numbers of unsafe vehicles? Is the percentage of heavy vehicles too high for the proposed/existing road design? Is this route used by recreational motorcyclists? Are there enforcement resources in the area to detect non-roadworthy, overloaded or unregistered vehicles and thus remove them from the network? Can enforcement of these issues be conducted safety? Has vehicle breakdown been catered for?
Post-crash care	Are there issues that might influence safe and efficient post-crash care in the event of a severe injury (e.g. congestion, access stopping space)? Do emergency and medical services operate as efficiently and rapidly as possible? Are other road users and emergency response teams protected during a crash event? Are drivers provided the correct information to address travelling speeds on the approach and adjacent to the incident? Is there reliable information available via radio, VMS etc. Is there provision for e-safety (i.e. safety systems based on modern information and communication technologies, C-ITS)?

Source: Austroads 2016e

The Safe System assessment framework is best applied by teams of road practitioners, with training and experience in road safety, road design and traffic management being essential to carry out the analysis. The framework can be applied in different ways. As an example, a subjective assessment approach is demonstrated in Table 9.3. Using the scoring system provided in Austroads (2016e), a score is placed in each cell for the exposure, likelihood and severity rows, and the product of each column is calculated and entered in the final row. The purpose of this multiplicative approach is that if a score of zero has been given for any component of a crash type (i.e. exposure, likelihood or severity), that crash type receives a total of zero and is eliminated from the score (as it has reached a Safe System). The sum of the infrastructure total scores for each crash type is then added to the final cell on the right hand side. This score is out of a possible 448 and represents the safer speeds and safer roads and roadsides pillars. The closer the score is to zero, the more the project in question is in alignment with Safe System principles.

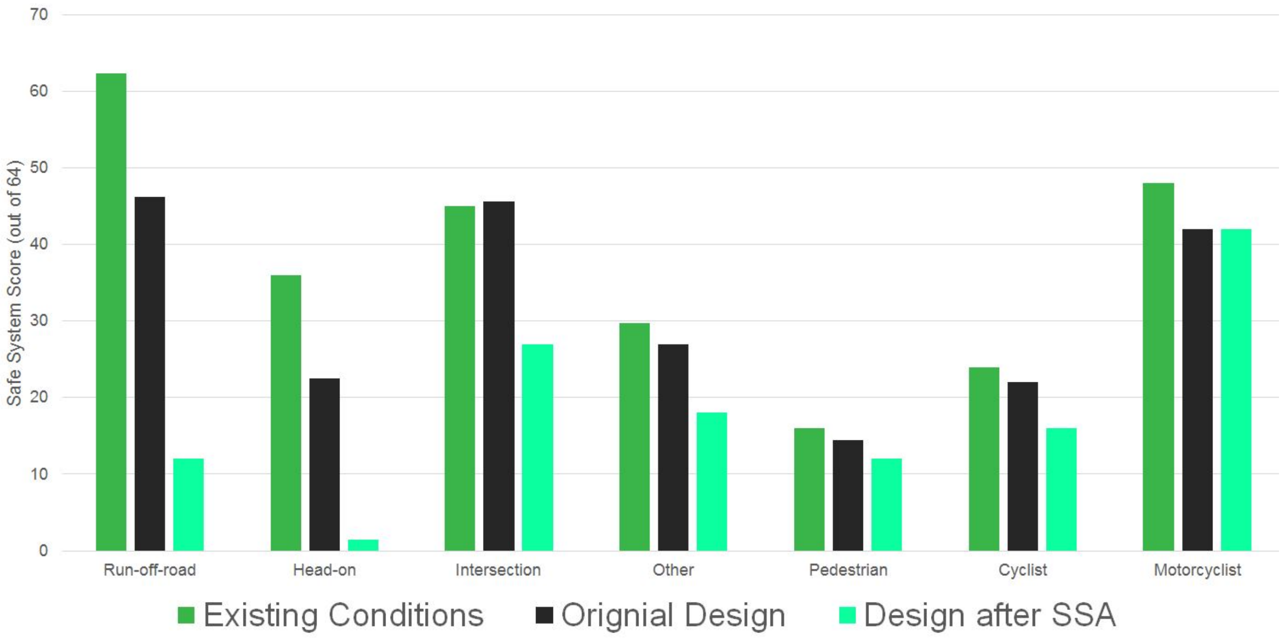
Table 9.3: Example of a subjective assessment using the Safe System assessment framework

	Run-off-road	Head-on	Intersection	Other	Pedestrian	Cyclist	Motorcyclist	
Exposure	$/_{4}$	$/_{4}$	$/_{4}$	$/_{4}$	$/_{4}$	$/_{4}$	$/_{4}$	
Likelihood	$/_{4}$	$/_{4}$	$/_{4}$	$/_{4}$	$/_{4}$	$/_{4}$	$/_{4}$	
Severity	$/_{4}$	$/_{4}$	$/_{4}$	$/_{4}$	$/_{4}$	$/_{4}$	$/_{4}$	
Product	$/_{64}$	$/_{64}$	$/_{64}$	$/_{64}$	$/_{64}$	$/_{64}$	$/_{64}$	$/_{\mathbf{448}}$

Source: Austroads (2016e)

VicRoads have been using Safe System Assessments (SSA) to assess and develop major projects. Figure 9.7 highlights the additional safety performance (in terms of a Safe System Assessment score) for 14 potential major projects in Victoria with a combined value of $3.8 billion if constructed. It can be seen that use of the SSA as a tool has resulted in solutions better aligned with harm minimisation objectives over original design plans.

Figure 9.7: Typical Victorian major project Safe System Assessment outcomes



Source: personal communication Wayne Moon, VicRoads

Applying the Safe System Assessment Framework

The following provides a brief indication of how the framework can be applied. It is recommended that the Safe System Framework Guide (Austroads 2016e) be consulted for more detailed information and application examples.

In this case, hypothetical treatments for the intersection of Terrara Road with Burwood Highway are considered. The figures below show a baseline a baseline assessment of the intersection using the framework.

Source: ©nearmap (2015), 'Vic', map data, nearmap, Sydney, NSW.

	ROR	HO	INT	OTHER	PED	CYC	M/C	
Exposure	High volume × $^{4}/_{4}$	High volume × $^{4}/_{4}$	High vol. on Burwood Hwy × Moderate vol. on Terrara Rd – $^{4}/_{4}$	High volume × $^{4}/_{4}$	Low pedestrian volumes ✓ $^{1}/_{4}$	Low cyclist volumes ✓ $^{1}/_{4}$	Low motorcyclist volumes ✓ $^{1}/_{4}$	
Likelihood	Steep grade × Deceleration lane ✓ Presence of intersection × No shoulders × Moderate clear zone – No barriers × $^{3}/_{4}$	Divided, wide/raised median ✓ Intersection movements/conflict points minimal for HO crash ✓ $^{1}/_{4}$	% turning movements × No. of lanes and conflict points × High speed × Poor sight distance × Protected turn lanes ✓ $^{3}/_{4}$	High no. of lanes × Protected turn lanes ✓ Short decel. lanes × Buses stopping × $^{3}/_{4}$	Service lane with footpath ✓ No crossing facilities at intersection × Many lanes to cross × $^{4}/_{4}$	Service lane – some separation ✓ No crossing facilities at intersection × $^{4}/_{4}$	No delineation × Well surfaced ✓ Straight road ✓ $^{3}/_{4}$	
Severity	High speed × No barriers × Steep grade × Poles and trees to hit × $^{3}/_{4}$	High speed × Low speed in side road ✓ $^{3}/_{4}$	High speed × Bad conflict angles × $^{4}/_{4}$	High speed × $^{3}/_{4}$	High speed × No crossing facilities × $^{4}/_{4}$	High speed × $^{4}/_{4}$	High speed × Some roadside hazards × $^{4}/_{4}$	**Total**
Product	$4*3*3={}^{36}/_{64}$	$4*1*3={}^{12}/_{64}$	$4*3*4={}^{48}/_{64}$	$4*3*3={}^{36}/_{64}$	$1*4*4={}^{16}/_{64}$	$1*4*4={}^{16}/_{64}$	$1*3*4={}^{12}/_{64}$	$^{176}/_{448}$

Additional Safe System components	Prompts	Comments
Road user	Are road users likely to be alert and compliant, or are there factors that might influence this? What are the expected compliance and enforcement levels (alcohol/drugs, speed, road rules, and driving hours) and what is the likelihood of driver fatigue? Are there special road uses (e.g. entertainment precincts, elderly, children, on-road activities), distraction by environmental factors (e.g. commerce, tourism), or risk-taking behaviours?	• Elderly drivers – slower reaction times, lower level of control, fatigue, frailty • Downhill may cause tendency to speed in eastbound direction.
Vehicle	What level of alignment is there with the ideal of safer vehicles? Are there factors which might attract large numbers of unsafe vehicles? Is the percentage of heavy vehicles too high for the proposed/existing road design? Are there enforcement resources in the area to detect non-roadworthy, overloaded or unregistered vehicles and thus remove them from the network?	• No vehicle enforcement • Moderate % of heavy vehicles.
Post-crash care	Are there issues that might influence safe and efficient post-crash care in the event of a severe injury? Do emergency and medical services operate as efficiently and rapidly as possible? Are other road users and emergency response teams protected during a crash event? Are drivers provided the correct information to address travelling speeds on the approach and adjacent to the incident? Is there provision for e-safety (i.e. safety systems based on modern information and communication technologies, C-ITS)?	• Medians may be used for emergency stops • Service lanes can be used by emergency services • Close to emergency facilities (less than 10 km).

In an alternative scenario, closure of the median with left in / left out access is considered.

Source: ©nearmap (2015), 'VIC', map data, nearmap, Sydney, NSW.

	ROR	HO	INT	OTHER	PED	CYC	M/C	
Exposure	High volume × $^4/_4$	High volume × $^4/_4$	High vol. on Burwood Hwy × Low vol. on Terrara Rd ✓ $^1/_4$	High volume × Low vol. on Terrara Rd ✓ $^3/_4$	Low pedestrian volumes ✓ $^1/_4$	Low cyclist volumes ✓ $^1/_4$	Low motorcyclist volumes ✓ $^1/_4$	
Likelihood	Steep grade × Deceleration lane ✓ No intersection ✓ No shoulders × Moderate clear zone – No barriers × $^2/_4$	Divided, wide/raised median ✓ Divided, wide/raised median ✓ No intersection movements/conflict points that could result in HO crash ✓ $^0/_4$	No turning movements ✓ High speed × Protected turn lanes ✓ $^1/_4$	No. of lanes × Protected turn lanes ✓ Decel. lanes no longer needed ✓ Buses stopping × $^2/_4$	Service lane with footpath ✓ No crossing facilities at intersection × $^4/_4$	Service lane – some separation ✓ No crossing facilities at intersection × $^4/_4$	No delineation required ✓ Good sight distance ✓ Well surfaced ✓ Straight road ✓ $^2/_4$	
Severity	High speed × No barriers × Moderate clear zone – $^3/_4$	High speed × Low speed in side road ✓ $^3/_4$	High speed × Few conflict angles ✓ $^3/_4$	High speed × $^3/_4$	High speed × $^4/_4$	High speed × $^4/_4$	High speed × Some roadside hazards × $^4/_4$	**Total**
Total	$4*2*3={}^{24}/_{64}$	$4*0*3={}^{0}/_{64}$	$1*1*3={}^{3}/_{64}$	$3*2*3={}^{18}/_{64}$	$1*4*4={}^{16}/_{64}$	$1*4*4={}^{16}/_{64}$	$1*2*4={}^{8}/_{64}$	$^{85}/_{448}$

A comparison of the baseline and the median closure options is as follows (signalised option considerations not presented here):

	ROR	HO	INT	OTHER	PED	CYC	M/C	
Baseline	$^{36}/_{64}$	$^{12}/_{64}$	$^{48}/_{64}$	$^{36}/_{64}$	$^{16}/_{64}$	$^{16}/_{64}$	$^{12}/_{64}$	$^{176}/_{448}$
Signalised	$^{36}/_{64}$	$^{0}/_{64}$	$^{24}/_{64}$	$^{32}/_{64}$	$^{8}/_{64}$	$^{16}/_{64}$	$^{12}/_{64}$	$^{128}/_{448}$
Left-in left-out	$^{24}/_{64}$	$^{0}/_{64}$	$^{3}/_{64}$	$^{18}/_{64}$	$^{16}/_{64}$	$^{16}/_{64}$	$^{8}/_{64}$	$^{85}/_{448}$

It is clear that none of the options would produce Safe System outcomes. The left in, left out option comes closest with a score of 85 and substantial improvement over the baseline assessment. Further opportunities to align the intersection with the Safe System could be explored in relation to pedestrian and cyclist safety and most opportunity lies with measures that would mitigate crash severity.

9.2.2 Safe System Intersection Design Tool

As discussed in previous sections, impact speed and impact angle are important factors that affect the energy transfer and ultimately the risk of severe outcomes in a crash. X-KEMM-X applies these concepts to intersection design (Jurewicz and Sobhani 2016). The model allows the direct relationship between intersection geometry and serious and fatal injury crash outcomes to be analysed.

An outline of how the model calculates FSI outcomes for an intersection design are included in Appendix B.

9.1 Examples of commencing the transition towards the Safe System

Some current activities are worth noting in the context of providing practitioners with support to commence the transition towards a Safe System. The experience with the installation of wide centerline on the Bruce Highway in Queensland, the adoption of ROSMA in Main Roads WA, the mobilisation of Safe System activity in Victoria and knowledge and capacity building in New Zealand are significant developments for those jurisdictions and lessons can be learnt from their experiences.

9.1.1 Wide Centreline treatment on the Bruce Highway

The Bruce Highway in Queensland is a strategically important highway that carries high volumes of traffic with correspondingly high levels of severe injury crashes, including a high proportion of head-on crashes. Bobbermen (2016) documented a pragmatic process that led to the rapid implementation over 2 years of wide centerline treatment on 500 km of road that has been associated with approximately 50 less fatalities following implementation.

Using a Systemic Approach to incrementally improve safety, Bobbermen (2016) outlined the shift of focus away from a project based approach to that of network planning and programming tied to corresponding strategic design stereotypes. Six key learnings from the experience based on the financial and variable pre-existing asset condition that existed at the time are highlighted and briefly outlined below:

1. Use a Network-wide Strategy - greater strategic control is exercised through a total road network strategy to maximise the beneficial outcome and to not leave the safety solution to chance through many decisions on many projects
2. Set Realistic Network-wide Intervention and Construction Standards – the development and application of a) A network-wide intervention standard (which is the trigger for enhancement work) and b) A network-wide construction standard (the completed construction standard for new work).
3. Balance Crash Risk - Balancing the crash risk of significant components meant that a calculated and risk assessed reduction in shoulder width and lane width made space available for a wide centreline to facilitate quick retrofitting to existing narrow asset formations.
4. Prioritise for Delivery Efficiency - Delivery efficiency can be gained through both “economy of location” by bundling projects in the same vicinity or “economy of scale” by bundling work of similar type over a larger area.This includes elements of prioritising for delivery efficiency (elevating slightly lower BCR projects to bundle project work and avoid conducting marginally higher BCR projects at isolated sites) and controlling for scope creep
5. Consider Risk Compensatory Influences – consider the mechanisms in road design features that may result in motorists changing their behaviour on the basis of perceived risk levels – provision of overtaking lanes, effect of 250 mm less lane width with applied ATLM and proximity to oncoming traffic
6. Focused Management of the Road System – effort is required to ensure integration of various disciplines (asset, planning, design, delivery and safety management) to achieve a successful engineering plan, understand the complexity of decision making, maintaining the adopted standards between projects and network-wide planning and maintaining a single line of accountability for safety outcomes.

Bruce Highway, Queensland

Several centreline treatment types have been used in Queensland. These include audio-tactile line marking (ATLM) along significant lengths of highway, wide medians and MWRSB along the Bruce Highway between Cooray and Curra (TMR 2014).

In 2011, the Queensland Department of Transportation and Main Roads installed 56 km of continuous, 1.0 m wide painted median with ATLM along the Bruce Highway, at a cost of approximately $33,000 per km (Whittaker 2012). The implementation of a wide median was achieved by narrowing the traffic lanes. Previously, the speed limit along this section was reduced from 100 km/h to 90 km/h. Whittaker (2012) concluded that these treatments had been effective in reducing head-on and loss of control over centreline crashes by 75%. Fatal and severe injury crashes were also reduced. The benefit-cost ratio for the treatments was calculated to be 18.5, making them an extremely low cost treatment for reducing crashes.

Bobbermen (2016) has reported on the success of the Bruce Highway treatment indicating:

- The rapid completion of 500 km of safety treatment in about 2 years
- A saving of approximately 50 lives in the short period from 2013 - 2015
- Delivery of a step change in reducing the number of fatalities by 50%
- Saving significantly more than $5b in total program costs when compared to standard treatments.

9.1.2 Road Safety Management (ROSMA) framework

While many road agencies have created specialist road safety programs, ROSMA stands out as an approach to integrate Safe System principles into core business activities of a road agency in a sustainable manner. Developed by Main Roads Western Australia, the system provides a focus on the reduction of killed and serious injury crashes. Projects are captured through the corporate enterprise project management system are reviewed through a gated process at each stage in the project life cycle. These submissions are assessed by a team for alignment with Safe System principles and the activity can only proceed if approved.

The ROSMA system aligns with ISO39001 for Road Traffic Safety and uses the risk methodology used by the New Zealand Transport Authority. The process essentially consists of three steps as outlined in Figure 9.7. A suite of tools has been developed to assist staff with decision making. Most importantly ROSMA sets targets in terms of KSI crash reduction, at a project level which are aligned with state and national road safety commitments.

Figure 9.8: The three steps involved in the ROSMA process

Source: MRWA

Importantly, the approach also contains a commitment to the change management amongst staff required in relation to adopting the Safe System approach and education, workshops and capacity building underpin the corporate processes involved.

Further information on ROSMA can be found at: http://apps.mainroads.wa.gov.au/ar-2015/online/our_operational_performance/road_safety.html

9.1.3 Commencing the transition towards the Safe System in Victoria - SSRIP

The Safe System Road Infrastructure Program (SSRIP) is a partnership between the Transport Accident Commission (TAC) and VicRoads to deliver safer roads infrastructure throughout Victoria. The TAC has committed $1.4 billion to the program over 10 years, with VicRoads responsible for managing the projects. The investment includes:

- 41% of the investment on new Safe System treatments, like continuous wire-rope barrier and innovative intersection design
- 37% for conventional treatments at known high-risk crash locations (e.g. partial barrier, fully controlled right turn arrow)
- 10% to develop safe cycling and pedestrian infrastructure.

A specialist SSRIP and a Safe System Design Team in Network Design Services has been assembled within VicRoads to assist with the design, innovation, funding, capacity building, cultural change and delivery required to transition towards Safe System solutions over large parts of the road network. Some ambitious and transformational treatments have been implemented or are planned that are fully aligned with Safe System harm minimisation principles. As an example, 20 of the State's most high risk sections of road will be improved with the application of continuous lengths of flexible barrier systems even in the presence of clear zones or wide central medians. Innovative intersection designs are being worked on and internal guidance documents and supplements are being updated or created to reflect the Safe System approach.

Operationalising the Safe System in VicRoads

An important indicator of the cultural change occurring in Victoria is reflected in an email circulated to all VicRoads staff from the Chief Executive, John Merritt in November 2016. The message called upon all staff to adopt and implement outcomes on all VicRoads infrastructure projects and across all business areas to achieve a meaningful transition towards the Safe System to reduce serious injury and fatal accidents. A copy of the Austroads Safe Systems Framework report was attached to the email.

We need to live and breathe Safe System, for the sake of the community that is depending on us.

At our last Safe System Governance Committee meeting, we discussed the importance of considering Safe System Principles for all projects. It is most pleasing to see many projects such as Princess Hwy West, Punt Road, Hoddle Street, Outer Suburban Arterial Roads (OSARs) and South Gippsland Highway Re-alignment are already embracing this Safe System mindset shift at the different stages of project implementation, some already making it real on the ground. A couple of specific ways they are leading this is through the application of continuous safety barrier to largely achieve safer roadsides which is critical to address our high rate of run off road crashes on country roads.

In line with numerous key initiatives, being the State Government's 2016 Toward Zero vision, the National Road Safety Strategy 2011 - 2020, and VicRoads Corporate Plan it is vitally important that ALL VicRoads infrastructure projects, including those already under construction, now consider how they can adopt and implement outcomes to achieve a meaningful transition towards Safe System to reduce serious injury and fatal accidents. Within all our day to day work we have influence and power to shape and change things for the better. This includes most parts of our business like Strategic Planning, Pipeline Planning, Development, Delivery, Road Design, Major Projects, Statutory Planning, Traffic Management, and so on with all parts of our business striving to achieve this no matter what phase the project is at.

VicRoads is very fortunate to have two dedicated areas that can assist you to realise this objective across your projects, the SSRIP team in Footscray and the Safe System Design Team in Network Design Services. Both teams have been working closely with many Regions and Projects already, helping projects understand what they can do to ensure their projects align towards Safe System. I encourage you to make use of their expertise in helping shape your projects. A very useful tool to understand how your project aligns with Safe System and what other things you could consider to increase that alignment, is the Austroads - Safe System Assessment Framework. I am asking all projects to utilise this framework during project development and delivery with PRC focusing on understanding how projects are considering such.

Safe System is a new emerging area for both Victoria (and the world) and it is important that VicRoads continues to lead in this space. We can do this across all our projects irrespective of whether it is part of the SSRIP or not. Where possible, I encourage Safe System dialogue in our community interactions and correspondence. Some Regions and Projects are making considerable gains in receiving community support already by leading in this way. With contemporary and visionary leadership we can make Towards Zero real.

John Merritt
Chief Executive
VicRoads

More information on the SSRIP program can be found at: https://www.towardszero.vic.gov.au/safe-roads/why-safe-roads-matter

9.1.4 The difference between life and death

As part of the New Zealand *Safer Journeys* road safety strategy, resource material and toolkits has underpinned extensive activity to build up knowledge and understanding of the Safe System (https://www.nzta.govt.nz/safety/). While not unique, many of the resources support "mature" discussions with the community and professionals regarding harm minimization principles, perceptions of risk and the nature of the road safety problem.

Safety resources have been made available for local government, engineers and planners, in recognition of the vital role they play in developing a safe road system:

- Safe System for system designers
- Safer journeys for engineers
- Safer journeys for planners
- Safer journeys for coroners
- Safer Speeds Programme
- Planning to improve road safety
- Road safety information and tools
- Crash Analysis System (CAS).

The difference between life and death

An information brochure and a 20 minute DVD video have been created to explain the Safe System approach to road safety and what it means for everyone to play their part. This video has been used widely to educate people, including engineers, about the Safe System (NZTA 2014):

Source: https://www.youtube.com/watch?v=mFcLUCtUAzc

Consequently Tasmania has also made a 10 minute video via their Road Safety Advisory Council (StateGrowth 2015):

Source: https://www.youtube.com/watch?v=P6UvGEMqaS8

Another supporting development has been the formation of the Safe Roads Alliance between NZTA and various consulting organisations to deliver improvements to the State Highway Network over six years based on funding of approximately $100 m per year (plus $20 m per annum in minor works). The Alliance will deliver on the Safe Roads and Roadsides programme that will improve 90 high-risk rural highways across the country.

Explicit in the outcomes of the program is an expectation that the improvements will make roads more forgiving of human error, helping to reduce the occurrence of crashes in the first place and limiting their severity when they do happen. Safety improvement projects will generally include a combination of the following engineering treatments with a specific focus on road departure and head-on crash types:

- side barriers
- median barriers
- rumble strips
- curve reduction
- wide centrelines
- improved road markings and signs.
- More information on the Safe Roads Alliance can be found at: https://www.nzta.govt.nz/safety/our-vision-vision-of-a-safe-road-system/safe-roads-alliance/

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Resources

Melba Highway median wire rope safety barrier: http://www.tac.vic.gov.au/about-the-tac/media-room/news-and-events/current-media-releases/saving-lives-melba-highway-wire-rope-barrier

Wire rope safety barriers and the motorcyclist “cheese cutter” effect myth: https://www.towardszero.vic.gov.au/making-progress/articles/flexible-barriers-how-they-work-and-the-cheese-cutter-myth

National Road Safety Partnership Program: http://www.nrspp.org.au/

Safe System Road Infrastructure Program: https://www.towardszero.vic.gov.au/safe-roads/why-safe-roads-matter

New Zealand Transport Agency Safer Journeys: https://www.nzta.govt.nz/safety/

New Zealand Transport Agency Safe System video: https://www.youtube.com/watch?v=mFcLUCtUAzc

Tasmania Road Safety Advisory Council Safe System video: https://www.youtube.com/watch?v=P6UvGEMqaS8

New Zealand Transport Agency Safe Roads Alliance: https://www.nzta.govt.nz/safety/our-vision-vision-of-a-safe-road-system/safe-roads-alliance/

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National Road Safety Strategy: http://roadsafety.gov.au/nrss/safe-system.aspx

Appendix A Learnings from the Netherlands

A.1 A European inspired design guide in Australia

Five internationally recognised factors are highlighted as being important, which must be balanced in the design of cycling infrastructure in order to meet the needs of all cyclists. These factors are:

- **Directness** – this is important in both distance and time. Stops or loss of priority at intersections, hills, detours, sharp corners, poor sight lines, shared paths and rough surfaces all impact on directness. Indirect routes and delays will influence cyclists to undertake measures that may increase safety risks in order to save time. Improving directness improves attractiveness of the cycling route, travel times and safety.
- **Safety and perceived safety** – the safety of cyclists primarily depends on the masses and speeds that cyclists are exposed to. Perceived safety is also important for less confident cyclists, who feel less safe when mixing with higher speed traffic. Both safety and perceived safety are improved when cyclists are provided with exclusive space and where conflicts with motorised vehicles are avoided. Where separation is not provided, it is important that vehicle speeds are kept at or below 30 km/h.
- **Comfort** – it is important to design facilities that are comfortable for cyclists of all ages and levels of experience to ride on. Comfort is affected by several factors: vehicle nuisance should be kept to a minimum; bicyclists are sensitive to rough pavement and so road surfaces should be kept generally smoother than is acceptable for motorised vehicles; cyclists should be able to maintain reasonable speeds; bends should be avoided in order to aid directness of travel; bicycles rely on human-power and so steep grades should be avoided; cyclists are exposed to the elements and good facility design should provide a level of protection.
- **Attractiveness** – the attractiveness to cyclists relates to factors of safety (including perceived safety), security and quality of the facility. The provision of no bicycle infrastructure can be a major barrier for cyclists. Cycling infrastructure that promotes these factors will generally attract all types of cyclists.
- **Coherence** – cohesion is relevant to the broader cycling network. An appropriate density of cycling network, with links to public transport, is needed. It is also important that facility connectivity be maintained throughout the cycling network.

A.2 Midblock

Midblock roads are divided by vehicle operating speeds and the road function, such as whether access is required and the volumes of vehicular traffic that are to be expected (Table A 1). For local roads with vehicle operating speeds up to 30 km/h, vehicle and bicycle speeds may be similar and under these circumstances, mixed vehicle/bicycle traffic is deemed appropriate. On local roads where vehicle speeds are very low, it also may be appropriate to mix all road users, including pedestrians. In some circumstances, such as alongside arterial roads, cycling tracks may also be used to serve the function of limited vehicle access to properties, thereby removing the need for regular access along the arterial road (Figure A 1). In this circumstance, vehicle operating speeds should be 30 km/h or below. The use of on-road bicycle tracks with vehicle access can also be used to highlight primary cycling routes on local roads (Figure A 2). However, with all of these treatments, it is suggested that cycling tracks should be reverted back to bicycle-only use before major intersections.

Table A 1: Selection of urban road bicycle facilities based on road function

<table>
<tr><th>Road function</th><th colspan="2">Vehicle operating speed (km/h)</th><th>Cycle tracks appropriate?</th><th>Explanation</th></tr>
<tr><td rowspan="2">Local access road with or without parking</td><td colspan="2" rowspan="2">Up to 30 km/h</td><td>No</td><td>Mixed traffic is appropriate. Cycle tracks with limited vehicle access may be appropriate.</td></tr>
<tr><td rowspan="2">Maybe</td><td>Bicycle lanes/cycle tracks may be appropriate on primary bicycle route.</td></tr>
<tr><td rowspan="3">Collector /distributor road</td><td rowspan="2">Up to 50 km/h</td><td>No kerbside parking</td><td>Bicycle lanes with on kerbside parking are most appropriate.</td></tr>
<tr><td>With kerbside parking</td><td>Yes</td><td>Bicycle lanes <u>not</u> preferred due to door zone conflicts.</td></tr>
<tr><td colspan="2" rowspan="2">More than 50 km/h</td><td rowspan="2">Yes</td><td rowspan="2">Bicycle lanes <u>not</u> preferred due to high speed difference.</td></tr>
<tr><td>Arterial road</td></tr>
<tr><td>Urban motorway</td><td colspan="2">More than 70 km/h</td><td>No</td><td>High quality parallel off-road bicycle path with grade separated, signalised or priority crossings at intersections is appropriate</td></tr>
</table>

Source: TMR (2015)

Figure A 1: A one-way cycling track with combined local road access in the Netherlands

Source: TMR (2015)

Figure A 2: On-road bicycle tracks with vehicle access in the Netherlands

Source: TMR (2015)

Along collector and distributor roads with vehicle operating speeds of up to 50 km/h, it is recommended that the use of cycling lanes should be limited to roads where kerbside parking is prohibited. Along roads where kerbside parking is allowed, the use of cycling lanes is not appropriate due to the significant risk of "dooring" crashes. An alternative along these roads is to shift bicycle traffic to a cycling track on the kerbside and have the parking lane in between the cycling track and the traffic lanes (Figure A 3). There are many advantages to this design that include greater perceived safety and reduced stress on cyclists, reduced conflicts between cyclists and vehicles entering parking spaces, reduced movement of vehicles into the cycling track and the effect of visually narrowing the road, thereby encouraging reduced vehicle speeds. Where substantial physical separation between the cycling lane and traffic lane is not deemed necessary, this design can be implemented with little extra cost and space requirements compared to having a cycling lane combined with kerbside parking. This type of design is now being implemented in many capital cities around Australia.

Figure A 3: A comparison of kerside parking combined with a cycling lane (left, Brisbane) and a kerbside cycling track combined with a parking lane next to the traffic lane (right, the Netherlands). In both examples, the combined width requirement for parking and bicycle facilities is 4.0 metres

Source: TMR (2015)

Where vehicle operating speeds are higher than 50 km/h, such as along some collector and distributor roads and arterial roads, it is recommended that bicycle lanes are not used due to the high speed difference between vehicle and bicycle traffic. Instead, physically separated cycling tracks are prefered. There are a number of ways these can be implemented, such as one- and two-direction tracks and with or without vehicle parking alongside, and with different track and separation widths being appropriate for different situations. However the cycling track is implemented, bicycle priority must be continued through side-street intersections and property access points. The design must also ensure that vehicles are not allowed access along the cycling track and ideally, vehicle movements over the track to access properties and side-streets should be restricted as much as is practical. Along roads where where vehicle operating speeds are greater than 70 km/h, on-road cycling facilities are not appropriate and instead bicyclists should be provided with high quality parallel off-road paths.

A.3 Intersections

There are three main requirements for bicycle traffic at intersections: directness; safety; and comfort. Several design options are detailed in the report, each applicable to intersections between roads of different functionality. The designs, however, all maintain some key concepts, which are detailed below.

Firstly, where bicycle and motor vehicle streams intersect, speeds should be kept at or below 30 km/h through appropriate design. This can be achieved through reduced motor vehicle turning radii and with vertical and horizontal deflection of vehicle traffic. It is important to remember that low speeds need to be maintained through the entire intersection to allow for the safe crossing of cyclists. These measures are also beneficial for pedestrians and in many situations, the safety of both can be catered for though similar designs; for example, combined raised pedestrian and bicycle crossings. The ability to implement these treatments will be dependent on the need to accommodate larger heavy vehicles in the street – coordination with network planners and network operators is required.

Secondly, staging motor vehicle movements at an intersection can reduce the cognitive load on drivers. This allows drivers to deal with other motor vehicle traffic before dealing with bicycle traffic, instead of forcing drivers to deal with all other traffic at the same time. Staging can generally be achieved by moving the bicycle crossing facilities further from the intersection, allowing turning vehicles to stop out of the way of through traffic before entering the bicycle crossing. Such designs also facilitate less extreme viewing angles for both drivers and cyclists, enabling better lines of sight between each other and avoiding circumstances where the cyclist is within the driver's blind-spot, or vice versa, when approaching the critical point of conflict.

Thirdly, where motor vehicle speeds and/or volumes make safe interactions unfeasible, full segregation is required. This can be in the form of an underpass or overpass. Ideally, it is preferential if motor vehicle traffic is vertically deviated, allowing bicycle traffic to pass through the intersection with no impedance.

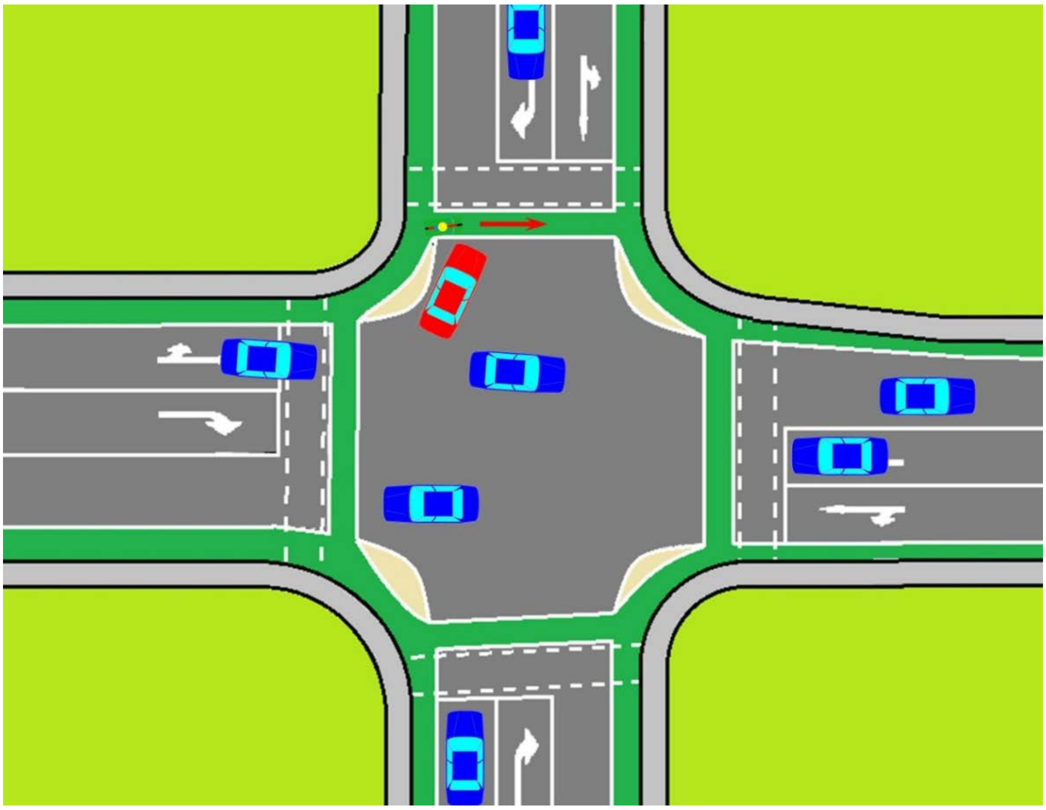
A.4 Major intersections

At major intersections such as signalised intersections, it is important that lines of sight between drivers and cyclists are maintained and that speeds are kept low where conflicts can occur. Such measures can be achieved within a similar footprint to conventional intersections by maintaining kerbside cycling tracks through the intersection and by using blister islands or other means to reduce the turning radii for left turning vehicles. Where heavy vehicle movements need to be considered, blister islands can be made mountable. Shifting the crossing point further away from the intersection can allow for turning vehicle storage (Figure A 4). This, as previously discussed, helps to maintain through traffic flow while allowing turning vehicles to deal with bicycle traffic separately from motor vehicle traffic. These design philosophies are shown in Figure A 5 and Figure A 6. As shown in Figure A 5, the red turning vehicle can stop after the completion of the left turn but before entering the bicycle crossing. At the same time, appropriate lines of sight between the driver and cyclist are maintained. As shown in Figure A 6, left turn speeds are also reduced through this design, as corner radii are reduced by the protective blister islands to a point where high speed cornering is no longer possible.

Figure A 4: A two-way cycling track alongside Brisbane Road, Mooloolaba, Queensland. The cycling track has been deviated back from the intersection to allow space for turning vehicles to stop before entering the crossing

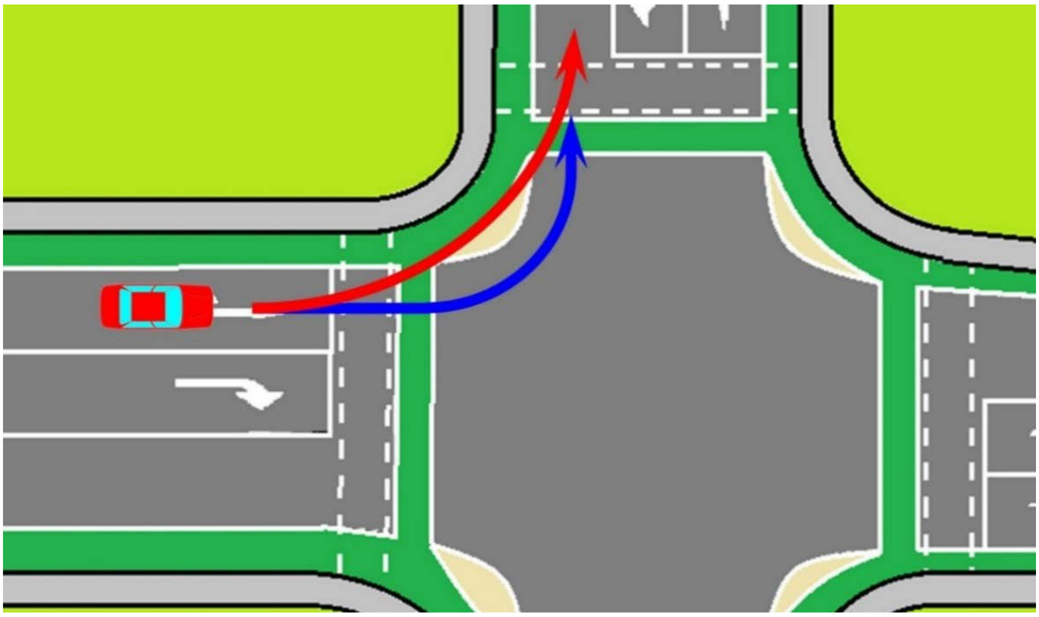
Source: TMR

Figure A 5: A Dutch approach to major intersection design that reduces vehicle speeds and deviates bicycle crossing points to where they can be better managed



Source: Image adapted from TMR (2015)

Figure A 6: A comparison of vehicle turning radii associated with conventional intersection design (red line) and the Dutch approach to intersection design (blue line). The smaller radius of the blue line reduces cornering speeds to appropriate levels



Source: Image adapted from TMR (2015)

A.5 Roundabouts

As at major intersections, cyclists can be adequately designed for at roundabouts by reducing speeds and shifting the bicycle crossing point further away from the intersection itself. A number of roundabout designs are described within the TMR (2015) report. These include the use of both one- and two-way cycling tracks. Low speed entry/exit design is also promoted as it helps to reduce motor vehicle speeds through the intersection. Raised bicycle crossings can also help to reduce vehicle speeds at the points of conflict by means of vertical deflection. An example of bicycle friendly roundabout design is shown in Figure A 7.

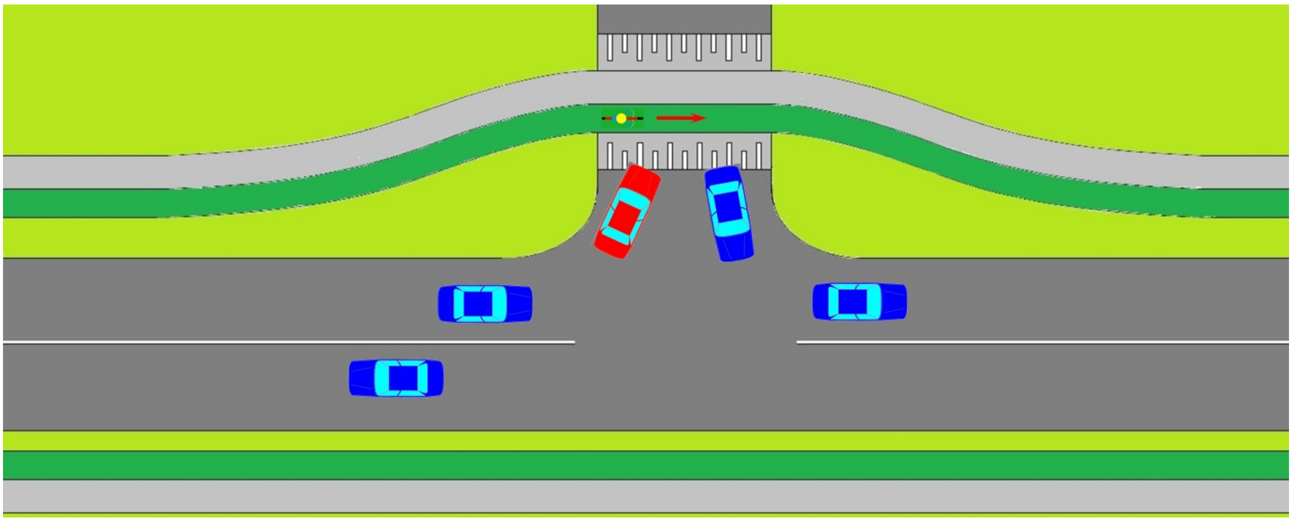
Figure A 7: A radial roundabout design with separated cycling tracks, and bicycle crossings that allow for staging of motor vehicles

Source: TMR (2015)

A.6 Minor intersections

At minor intersections with side-streets and access points, it is recommended that the intersection be designed to achieve safe speeds for all road users, ensure all road users are aware of the crossing and ensure that all road users are aware of the priority that applies. As previously discussed, these design objectives can be achieved through the use of tight turning radii and shifting the point of the crossing further away from the intersection (Figure A 8 and Figure A 9). Vertical deflection at the crossing and localised narrowing of the side-street traffic lanes on approach to the intersection can be used to further reduce motor vehicle speeds. Surface treatments can also be used to visually signify the presence of the crossing. Mountable treatments can be used to accommodate heavy vehicle access through tighter turning radii. It is noted that where two-way cycling tracks are used, a higher level of safety features is required than where only one-way tracks are used.

Figure A 8: Side-street intersection incorporating appropriate cycling track crossing



Source: Image adapted from TMR (2015)

Figure A 9: An example of a raised cycling track crossing at a minor road intersection in Queensland

Source: TMR (2015)

Appendix B Intersection Design Using X-KEMM-X

An outline of the method for assessing an intersection design using X-KEMM-X is as follows:

Step 1: Draw a conflict point diagram for the intersection. This diagram shows all the crossings of conflicting traffic movements, including pedestrians.

Step 2: Measure conflict angles and indicate the assumed impact speed of the two vehicles involved in each conflict point. Impact speeds were based on approach speeds given by speed limits, or as determined by any speed management solutions which were part of the design.

Step 3: Compute delta-V for each vehicle involved in the conflict using Equation 1.

Step 4: Estimate the probability of an FSI outcome in a crash for each vehicle at each conflict point based on the impact location (i.e. near side, far side, front or rear) for each vehicle involved in the crash. An assumption is to always consider the worst case scenario; therefore, for any angle crash the bullet vehicle (i.e. the hitting vehicle) will impact the target vehicle (i.e. the other vehicle) from the side rather than the front or rear. This is because for an angle crash there is a possibility that the target vehicle is impacted from the front/rear or side, and the side impact is more severe than the front or rear impact. For head-on and rear-end crashes, the assumption is that the target vehicle is impacted from the front and rear respectively, since the possibility of side impact for these type of crashes was very low. For all these crash types (i.e. angle, head-on and rear-end crash types), the bullet vehicle is assumed to be impacted on the front.

Step 5: After estimating the probability of each vehicle's occupants sustaining an FSI outcome, the overall FSI probability for the crash event is estimated using the union of these two probabilities.

Calculating the probability of an FSI crash outcome requires some assumptions to be made in order to obtain a quantitative calculation output. The direction of the vehicle, mass of the vehicle, impact angles and speeds all need to be determined which may all be quite different in real life for each situation.

Another important assumption is that both vehicles were of equal mass, which in reality is not the case due to the diverse manufacturers and types of vehicles on the road. However, making this assumption helped to establish a reliable relative comparison among different intersection designs. Further research could involve modelling mass ratios based on actual crash data. Other procedural assumptions in X-KEMM-X include:

- There was no lane change within the intersection/roundabout, affecting the angles
- Any left turning lanes turn into the closest lane
- Any right turning lanes also exit into the closest lane
- If there are multiple turning lanes, then the exit lanes are adjacent to one another
- All legal movements that can be made are developed in the model
- No illegal turn movements are made
- If one lane allows multiple movements, i.e. right turn or straight from the same lane, a rear-end crash is included (this is due to the change in speed and movement)
- Turning speeds were 30 km/h for right-turn, and 15 km/h for left-turn
- Impact speeds may be lower if driver reaction and braking took place before impact – no such action was assumed due to lack of information about distribution of speed dissipation in the majority of collisions.

These assumptions were made in order to reduce confusion and provide a consistent conflict diagram across all intersection designs. In reality, there would be multiple additional possible conflicts due to rear-ends and lane changing; however, including these would make this analysis almost impossible to undertake. Also, these crash types are far less severe by their nature.

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