Austroads

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Safe System Assessment Framework

Safe System Assessment Framework

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Abstract

This report proposes an assessment framework designed to help road agencies methodically consider Safe System objectives in road infrastructure projects.

The framework considers key crash types that lead to fatal and serious crash outcomes, as well as the risks associated with these crashes (exposure, likelihood and severity). It provides prompts to ensure each pillar of the Safe System are considered. A treatment hierarchy is also provided to help identify the most effective treatments that might be used to minimise death and serious injury.

The framework was developed following a review of literature on Safe System infrastructure and existing risk assessment frameworks. Examples are provided on its application.

Keywords

Safe System, risk assessment, exposure, likelihood, severity, infrastructure, treatment hierarchy

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- Department of State Growth Tasmania
- Department of Transport Northern Territory
- Territory and Municipal Services Directorate, Australian Capital Territory
- Commonwealth Department of Infrastructure and Regional Development
- Australian Local Government Association
- New Zealand Transport Agency.

Summary

The aim of this project was to develop an assessment framework to help road agencies methodically consider Safe System objectives in road infrastructure projects. The Safe System approach involves different elements of the system working together to help eliminate death and serious injury. It involves shared responsibility in reaching this objective, including road users and road managers each taking a role. A key objective for road managers is to ensure that when driver errors do occur, they do not result in high severity outcomes.

The framework will be useful in assessing how closely road design and operation align with the Safe System objectives, and in clarifying which elements need to be modified to achieve closer alignment with Safe System objectives.

Inputs to the development of the framework involved a review of literature (including an assessment of previous attempts at developing such a framework), contact with local and international Safe System experts, inputs from a national workshop involving road safety infrastructure experts, and workshops with the project working group including trials of the proposed framework.

This report provides a summary of the development of the framework. The approach captured within the framework involves identifying the key crash types that result in death and serious injury, and using a risk assessment approach, identifying elements that might contribute to severe outcomes. These key crash types include run-off-road, head-on, intersection, other (including rear end) and vulnerable road user (pedestrian, cyclist and motorcyclist) crashes. The risk elements considered include road user exposure to risk (e.g. traffic volumes), likelihood of a crash, and the likely severity outcome in the event of a crash.

The framework includes all ‘pillars’ of the system, including an assessment of issues relating to the road and travel speeds. It also ensures consideration of other pillars which are typically included less often in infrastructure projects. These include road user issues and vehicle-related issues. Post crash care is also considered.

A treatment hierarchy is presented highlighting examples of Safe System solutions addressing each of the key crash problem types. Case studies are also provided illustrating how the framework might be applied.

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1. Introduction

1.1 Purpose

The aim of this project was to develop an assessment framework to help road agencies methodically consider Safe System objectives in road infrastructure projects. The framework will be useful in assessing how closely road design and operation align with the Safe System objectives, and in clarifying which elements need to be modified to achieve closer alignment with objectives.

The first action item from the Australian *National Road Safety Strategy* (NRSS; Australian Transport Council 2011) is to ensure that all new road projects consider Safe System principles. Details of these principles and the objectives of the Safe System can be found in Appendix A. Essential elements include:

- each pillar of the system working together to help eliminate death and serious injury
- a shared responsibility in addressing these fatal and serious injury outcomes, based on the knowledge that road users will continue to make errors, and road managers are able to minimise the impact of these errors by providing more forgiving infrastructure
- a greater understanding of human tolerances to the forces that occur during different types of crashes.

Although recent NRSS progress reports identify some progress on this action item in individual jurisdictions, clear practical guidance is not available on embedding Safe System principles into the provision of new infrastructure or the upgrading of existing infrastructure. Although the eventual goal of the Safe System approach is clear to most practitioners, the steps required to achieve this need to be clarified.

Several jurisdictions have made practical attempts to implement infrastructure improvements that are consistent with Safe System principles. In some cases, this has entailed developing an assessment framework for proposed improvements. Main Roads Western Australia (MRWA) was perhaps the first to develop such an approach, with the production of the *Towards Zero* framework. This has been used to identify safety issues and the measures to address them for a number of infrastructure projects. Using the knowledge and key learnings from this work, ARRB worked with the Department of Planning, Transport and Infrastructure to develop a similar approach for South Australia. This project builds on this previous work in the development of a comprehensive framework for use in Australia and New Zealand.

1.2 Method

The following method was used to achieve the necessary outcomes for the Safe System assessment framework.

1.2.1 Establishment of Working Group

A working group was established at the outset of the project. This group comprised representatives from the Road Safety Task Force, with strong representation from the roads and roadsides sub-group. There was also representation from local government and the research community at various points in the project.

1.2.2 Literature Review

A literature review was conducted to assess current Australian, New Zealand and overseas approaches to Safe System infrastructure and assessment for road infrastructure projects, as well as developments within international organisations. The literature review was prepared to identify any existing Safe System infrastructure frameworks as well as material that may inform the development of such a framework. Along with a review of published material, this task also involved direct contact with key international experts.

1.2.3 Workshop

A two-day workshop was held in December 2014 involving over 30 professionals from industry, government, the research community and advocacy groups interested in influencing the national agenda relating to road safety infrastructure. A key objective of this workshop was to discuss progress towards implementation of Safe System infrastructure, including the development of the assessment framework.

1.2.4 Framework Development

Based on these earlier tasks, a draft framework was developed and tested on several case studies. The draft framework was peer reviewed and suggested amendments from that review incorporated. The framework was then presented to the project working group, many of whom applied this to current projects and provided feedback. Based on this input the framework was revised, and case studies documented.

1.2.5 Structure of the Report

Following this introduction, Section 2 provides a summary of key points from the literature review, while the full review can be found in Appendix A. Section 3 gives a brief summary from the national workshop. The framework is provided in Section 4 along with an explanation of how to apply it. A template for this framework is provided in Appendix B, while examples showing application can be found in Appendix C.

2. Key Outcomes from the Literature Review

A literature review was conducted to assess approaches to Safe System infrastructure and methods to assess this. The full literature review can be found in Appendix A. The review:

- discusses the origins of the Safe System approach, including the different pillars
- contrasts this approach with the traditional approach taken in road safety, especially in regards to shared responsibility
- stresses the importance of infrastructure in the severity of crash outcomes
- discusses the relationship between speed and infrastructure
- provides information on different types of treatments, including those that move closer to Safe System outcomes (elimination of death and serious injury) and those that act to support safety improvements.

Different frameworks that have been developed and applied within Australia and New Zealand are discussed, including those from Western Australia, South Australia, Victoria and New Zealand. Overseas initiatives are also discussed, including the International Road Assessment Program (iRAP) trigger set and approaches used in Sweden and Canada. There has been limited application of these frameworks, but they do serve to provide useful direction for the development of a framework for use in Australia and New Zealand.

The findings from this review have been used to develop the framework, presented in Section 4.

3. National Workshop

A two-day workshop was held at the ARRB head office in Vermont South, Victoria, in December 2014 involving over 30 professionals from industry, government, the research community and advocacy leaders interested in influencing the national agenda relating to road safety infrastructure.

Challenges facing Australian and New Zealand road agencies were discussed, and are included here given the relevance to the development of the framework. There were four main issues identified:

- **Acceptance of Safe System principles** – this is especially a problem for local government when dealing with political members. The current road blocks against a Safe System are within the organisations themselves and not from the public. At the policy level there is a good understanding for the need for the Safe System approach, but at the planning and implementation level safety is not front and centre for project managers.
- **Translating Safe System in to practice** – there is currently no set manual or treatment book, and no clear understanding of what a Safe System actually looks like. Safe System also currently does not feature heavily in the Austroads guides. Currently known treatments are not completely effective for achieving zero deaths and serious injuries, especially for vulnerable road users and motorcyclists.
- **Capacity** – road agencies and local governments are constantly trying to do more with less, but the focus is also still on efficiency and speed. There is generally a lack of resources and money, as well as competing priorities.
- **Accountability** – there is lack of oversight for project planning and implementation to ensure Safe System is considered and applied.

There is also the need to shift to greater shared responsibility for safety outcomes (including an understanding of the role of road managers), and to adopt proactive rather than reactive funding within the jurisdictions. This includes changes to design polices to include safety features before they need to be retrofitted as safety treatments.

A discussion session was held on the development of a Safe System assessment framework. Different options were presented (based on the literature review presented in Section 2 and Appendix A) and key requirements were discussed.

Some of the key outcomes from the workshop relating to the development and use of the framework were as follows:

- the framework should include all pillars of the Safe System
- it should be scalable, meaning that it can be applied to small projects within local government, and to assessment of major projects or infrastructure types
- it needs to cover the full lifespan of the project
- there is a need to document the process that is used and the reasons that decisions have been made
- there needs to be information on the risks for different road users
- the framework should be able to determine changes before and after options or solutions are applied
- guidance is needed on key concepts, issues and solutions, but information provided should not be too prescriptive (i.e. there must be room for innovation)
- there is a need to describe what is meant by ‘safety performance’ in a Safe System context

- ‘Primary’ or ‘Transformational’ treatments should be presented as a first option. If these cannot be used, the reasons need to be documented, and alternative secondary options provided. There would be preference to next consider treatments that might be a stepping stone, with minimal redundancy of investment, to future Safe System implementation
- links to ANRAM should be made if possible.

4. Safe System Assessment Framework

4.1 Introduction

This section provides an overview of the proposed Safe System assessment framework. The development of this framework was based on the review of literature (including consultation with national and international experts), workshops, and internal discussions within the project team.

As concluded from the literature review and workshop, some of the key objectives of a Safe System framework are 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
- include all pillars of the Safe System.

It envisaged that the framework be applied to all project types, covering the planning, design, operation, maintenance and use of the road network. Examples include assessments of likely safety outcomes from minor safety improvements, new road designs, new sub-divisions, road upgrades, changed speed limits, changed traffic signal phasing, provision of bicycle lanes, etc.

The project focus is 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 will be considered at a number of stages in the process, particularly in 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 proposed framework follows an approach fairly typical in the assessment of risk, including that used in road safety. This is important, as the approach needs to be intuitive to those who use it. The main stages of the framework are as follows:

- identification of objectives
- setting the context
- applying the Safe System matrix
- if required, applying a treatment hierarchy and selection process.

This process is presented graphically in Figure 4.1, with each of these tasks is described in the following sections.

Figure 4.1: Proposed framework

Source: ARRB Group.

4.2 Objectives Identification

The first step is to identify and document the objective of the assessment. The framework can be used for a number of different objectives, e.g.:

- to identify whether a project or solution will produce a Safe System outcome
- to identify the degree of a project's alignment with the Safe System objectives
- to document issues that mean the project will not be aligned (i.e. severe injury risks)
- to suggest solutions that would move the project closer towards, or in full alignment with Safe System objectives.

Thus it is important to note the objective of the assessment. 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.

Another objective which needs to be recognised at the beginning is the scale of the project. For example, the framework could be used to assess:

- an individual location
- a route
- a major highway upgrade/bypass
- an innovative infrastructure design solution
- a generic road type or design (e.g. a staggered T-intersection design).

It should also be noted that the objectives may change once an assessment is commenced. For example a limited assessment at an individual location may require further detail or a review of the broader context once the assessment is conducted.

Finally, the desired depth of assessment needs to be identified. The assessment could be done at high level at the planning stage (key issues only, broad level of alignment, areas for improvement). It could also be carried out in more detail for individual project components (quantitative level of Safe System alignment, identify specific problems and solutions). Where a high degree of precision is required, the subjective assessment proposed in the framework can be replaced by more detailed quantitative information. For example, information could be added using the Australian National Risk Assessment Model (ANRAM; Austroads 2014c) or the Extended Kinetic Energy Management Model (or X-KEMM-X; a brief discussion is in Appendix A.3.2). Having this objective in mind will help to focus the assessment on the overall objectives.

It is important to recognise what final outcome is expected – whether it is an infrastructure solution to a particular crash problem, or the assessment of multiple locations for network-level roll-out – and to keep this in consideration at all steps in the framework process.

Appendix B provides a blank template to assist in completion of the framework, while case studies in Appendix C show how application of the framework can be scaled according to project needs.

4.3 Setting the Context

Once the objectives of the assessment are identified, the context of the project must be defined. Table 4.1 provides a template with prompts to help achieve this.

Table 4.1: Template for setting the project context

Prompts	Comments
What is the reason for the **project**? Is there a specific crash type risk? Is it addressing specific issues such as poor speed limit compliance, road access, congestion, future traffic growth, freight movement, amenity concerns from the community, maintenance/asset renewal, etc.	
What is the **function** of the road? Consider location, roadside land use, area type, speed limit, intersection type, presence of parking, public transport services and vehicle flows. What traffic features exist nearby (e.g. upstream and downstream)? What alternative routes exist?	
What is the **speed** environment? What is the current speed limit? Has it changed recently? Is it similar to other roads of this type? How does it compare to Safe System speeds? What is the acceptability of lowering the speed limit at this location?	
What **road users** are present? Consider the presence of elderly, school children and cyclists. Also note what facilities are available to vulnerable road users (e.g. signalised crossings, bicycle lanes, school zone speed limits, etc.).	
What is the **vehicle** composition? Consider the presence of heavy vehicles (and what type), motorcyclists and other vehicles using the roadway.	

They key intention of these prompts is to 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.

Details for the site or project being assessed should be clearly documented.

4.4 Safe System Matrix

In order to ensure that Safe System elements are considered, or to measure how well a given project (e.g. an intersection, road length, area, treatment type etc.) aligns with Safe System principles, a Safe System matrix has been produced. The purpose of the matrix is to assess different major crash types (those identified as the predominant contributors to fatal and serious crash outcomes) against the exposure to that crash risk, the likelihood of it occurring and the severity of the crash should it occur. The basic structure of the framework is provided in Table 4.2.

Table 4.2: Safe System assessment framework for infrastructure projects

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

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)?

A risk assessment approach has been adopted that includes exposure, likelihood and severity. The Safe System approach has helped practitioners understand that exposure and severity are both important considerations in fatal and serious crash outcomes. However, likelihood (which was perhaps the main issue considered prior to Safe System thinking) has often been overlooked. All elements are important. As indicated below, elimination of exposure or likelihood or severity will mean that fatal and serious outcomes will be eliminated.

Exposure, likelihood and severity (the rows of the matrix) are defined as follows:

- **Road user exposure:** this refers to which road users, in what numbers and for how long are using the road and are thus exposed to a potential crash. The measures of exposure include: AADT, side-road traffic volumes, number of motorcycles, cyclists and pedestrians crossing or walking along the road, length of the road, area and length of time.
- **Crash likelihood:** groups of factors affecting the probability of a crash occurring. They can be elements which moderate opportunity for conflict (e.g. number of conflict points, offset to roadside hazards, separation between opposing traffic). They can also include elements of road user behaviour and/or road environment. Typically, these are the elements which moderate road user error rates. This includes issues such as level of intersection control (e.g. priority/signals/movement ban), speed, sight distance, geometric alignment, driver guidance and warning. and maintenance (change in practice; implications of timing).
- **Crash severity:** groups of factors affecting the probability of severe injury outcomes should a crash occur. Typically, these factors are associated with the amount of kinetic energy and its transfer in the crash, e.g. impact speeds and angles, severity of roadside hazards.

The matrix columns show the following major crash types:

- run-off-road (also referred to as ‘loss of control’, or ‘off path on curve/straight’)
- head-on (or ‘vehicles from opposing directions’)
- intersection (‘vehicles from adjacent directions’)
- other (this incorporates all same direction, manoeuvring, overtaking, on path and miscellaneous crashes)
- pedestrian
- cyclist
- motorcyclist.

These crash types represent the main crash and road user types that contribute to death and serious injury. They are included as an element of the matrix to help concentrate thinking on crash causes and solutions. They are also provided in this way to ensure that vulnerable road users are directly considered.

Pedestrian, cyclist and motorcyclist crashes are separated to highlight the special focus on vulnerable road users. Note that in some circumstances (depending on the purpose of the assessment) other columns may also be added for specific crash types if these are of high importance (e.g. heavy vehicles).

As already discussed in Section 4.3, the additional Safe System components have been included to help meet the objective that each Safe System pillar be included. Note that post-crash care has been added as a pillar. This forms a pillar of the global road safety action plan through the United Nations (WHO 2011). In the infrastructure context there are sometimes measures that can be taken to facilitate quicker emergency response times, including access to the crash scene, thereby improving safety outcomes.

Examples of how this matrix might be applied are provided in Section 4.5. Depending on the purpose of the assessment, the process may simply require application of this matrix as a way to guide thinking, and document likely Safe System outcomes for a project. However, it is likely that in many cases solutions will be required to improve safety. A draft treatment hierarchy and selection process is outlined in Section 4.6.

4.5 Application of the Framework

The Safe System assessment framework will be best applied by teams of road practitioners with varied types and levels of experience. Training and experience in road safety, road design and traffic management are essential to carry out the analysis. Capabilities and understanding across each of the Safe System pillars is also required. Application of the framework in a team environment will also provide opportunity to improve understanding of the Safe System principles for those less experienced in road safety.

The framework could be applied in different ways. In this section a subjective assessment approach is presented in detail. Depending on the project, it may be possible to apply the framework in a more objective manner, and this option is also discussed.

For this option, each cell in the matrix (Table 4.2) is to be manually assigned a score between zero and four. A score of zero indicates that the system is fully aligned with the Safe System vision for that component of a given crash type. The higher the score, the further the project is from a Safe System condition. Scores should be allocated considering the factors of interest shown in Table 4.2 and the scoring system shown in Table 4.4. It should be noted that some elements can be included in either crash likelihood or severity, as they may affect both in a given situation.

In addition to the score, comments can be added to each of the cells to help identify the specific issues of concern. This is very helpful in determining the key risk factors for each project.

Once there is a score in each cell for the exposure, likelihood and severity rows, the product of each column is calculated and entered in the final row, labelled ‘total’. 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 (with the bold border). 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.

Additional Safe System pillars (i.e. road users, vehicles and post-crash care) are considered in the following rows, where prompts are given to direct the users to consider how the project relates/interacts with road users and vehicles, and vice versa. It also gives the user the opportunity to consider additional actions, such as automated enforcement or regulatory restrictions on vehicle access.

The outcomes from this assessment should be recorded, and added to the content on objectives and context to form the assessment report. Examples of such reports are provided in Appendix C.

The full Safe System assessment framework template is provided in Table 4.3.

Table 4.3: Safe System matrix for safe roads and roadsides and safe speeds

	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	**/448**

Additional Safe System components

Pillar	Prompts	Comments
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)?	

Note that no scoring system is ideal and there will always be cases that produce anomalous results. In addition, the same weighting has been given to different types of crashes. Thirdly, the scores produced are not directly associated with a specific level of crash risk. For this reason care should be taken when comparing scores for different variations, and particularly when comparing scores between different sites.

Table 4.4: Safe System matrix scoring system

Road user exposure	Crash likelihood	Crash severity
0 = there is no exposure to a certain crash type. This might mean there is no side flow or intersecting roads, no cyclists, no pedestrians, or motorcyclists).	0 = there is only minimal chance that a given crash type can occur for an individual road user given the infrastructure in place. Only extreme behaviour or substantial vehicle failure could lead to a crash. This may mean, for example, that two traffic streams do not cross at grade, or that pedestrians do not cross the road.	0 = should a crash occur, there is only minimal chance that it will result in a fatality or serious injury to the relevant road user involved. This might mean that kinetic energies transferred during the crash are low enough not to cause a fatal or serious injury (FSI), or that excessive kinetic energies are effectively redirected/dissipated before being transferred to the road user. Users may refer to Safe System-critical impact speeds for different crash types, while considering impact angles, and types of roadside hazards/barriers present.
1 = volumes of vehicles that may be involved in a particular crash type are particularly low, and therefore exposure is low. For run-of-road, head-on, intersection and 'other' crash types, AADT is < 1 000 per day. For cyclist, pedestrian and motorcycle crash types, volumes are < 10 units per day.	1 = it is highly unlikely that a given crash type will occur.	1 = should a crash occur, it is highly unlikely that it will result in a fatality or serious injury to any road user involved. Kinetic energies must be fairly low during a crash, or the majority is effectively dissipated before reaching the road user.
2 = volumes of vehicles that may be involved in a particular crash type are moderate, and therefore exposure is moderate. For run-of-road, head-on, intersection and 'other' crash types, AADT is between 1 000 and 5 000 per day. For cyclist, pedestrian and motorcycle crash types, volumes are 10–50 units per day.	2 = it is unlikely that a given crash type will occur.	2 = should a crash occur, it is unlikely that it will result in a fatality or serious injury to any road user involved. Kinetic energies are moderate, and the majority of the time they are effectively dissipated before reaching the road user.
3 = volumes of vehicles that may be involved in a particular crash type are high, and therefore exposure is high. For run-of-road, head-on, intersection and 'other' crash types, AADT is between 5 000 and 10 000 per day. For cyclist, pedestrian and motorcycle crash types, volumes are 50–100 units per day.	3 = it is likely that a given crash type will occur.	3 = should a crash occur, it is likely that it will result in a fatality or serious injury to any road user involved. Kinetic energies are moderate, but are not effectively dissipated and therefore may or may not result in an FSI.
4 = volumes of vehicles that may be involved in a particular crash type are very high, or the road is very long, and therefore exposure is very high. For run-of-road, head-on, intersection and 'other' crash types, AADT is > 10 000 per day. For cyclist, pedestrian and motorcycle crash types, volumes are > 100 units per day.	4 = the likelihood of individual road user errors leading to a crash is high given the infrastructure in place (e.g. high approach speed to a sharp curve, priority movement control, filtering right turn across several opposing lanes, high speed).	4 = should a crash occur, it is highly likely that it will result in a fatality or serious injury to any road user involved. Kinetic energies are high enough to cause an FSI crash, and it is unlikely that the forces will be dissipated before reaching the road user.

Depending on the purpose of the assessment, the process could finish at this point. This would provide detail on the level of Safe System alignment, as well as the risks that inform this assessment. However, if various options are to be tested, the process should be repeated for each of these options.

If the purpose of the assessment is to find solutions, a further step is required. Section 4.6 provides advice on treatment selection options that might be applied.

Where a more objective assessment is required, a more quantitative approach could be used. For example, the Extended Kinetic Energy Management Model (X-KEMM-X) model could be applied to determine the probability of a severe outcome for intersections. Similarly, Australian National Risk Assessment Model (ANRAM) elements could be applied to calculate crash risk or an estimate of severe crashes. ANRAM provides estimates of likelihood and severity for the different crash types. Together with exposure, the values derived from this assessment could be provided in the matrix and a calculation of risk made.

It should be noted that although a subjective scoring system is easy to apply, it can lead to issues when comparing sites, especially when these have been assessed by different individuals or teams. For this reason, the assessment framework should not be used as a method of directly comparing different sites but rather is better suited to comparing options at a single site, identifying sources of risk and identifying solutions.

As already highlighted, when applied using subjective assessment, the scoring system produces results that indicate increasing or decreasing risk (i.e. the higher the score, the higher the risk) but this score does not correspond directly to a crash rate or frequency. Changes in score indicate only a likely change in risk, and not the exact magnitude of that change. Put another way, the scoring system should not be interpreted as a linear scale in which, for example, twice the score means twice the risk. For this reason, ‘banding’ of scores might be a useful approach. For example, a range of low scores might indicate good compliance with Safe System objectives, while high scores might represent poor compliance. The exact banding would need to be determined based on wider use of the framework and comparisons with actual safety performance. Replacing a subjective assessment with a more objective approach (e.g. ANRAM) is likely to provide a more useful metric to determine actual change in crash risk.

4.6 Treatment Hierarchy and Selection

The Safe System assessment matrix described in Section 4.4 will provide information on the key risk types. This will inform decisions on appropriate treatments that might be used to address this risk. This section provides information on key treatment types that can be used to address this risk.

It is intended that if high levels of risk were identified for one or more crash types, the solutions for that crash type should be reviewed (e.g. for run-off-road). The information is provided in order of priority. Implementation of Safe System involves first consideration of solutions which eliminate occurrence of fatal and serious injuries (primary solutions). In some situations, such options will not be feasible due to project constraints dictated by budget, site, conflicting road user needs, or the environment. If so, the next safest project-feasible solution needs to be identified (supporting solutions). This process requires a clear Safe System-based hierarchy of solutions, as suggested in Table 4.5 to Table 4.11. If carried out as part of context-sensitive design, the solution hierarchy of will result in the net Safe System gain compared to simple selection of standard-compliant solutions. The reasons why options have been selected (particularly those that are not primary solutions) should be documented.

Highest priority amongst the supporting solutions are treatments that might act as stepping stones, with minimal redundancy of investment, to future implementation of Safe System solutions. For example, a wide central painted median with audio-tactile lines may be installed with adequate width to allow future application of wire rope barrier.

The options provided in Table 4.5 to Table 4.11 have been produced based on a number of recent Austroads projects as well as two Safe System infrastructure national round-table workshops (see Section 3 and Turner et al. 2009). The information presented in these tables is provided for indicative purposes, and careful thought should be given to the selection of treatments. Certain specific types of infrastructure, and the way that this is applied might mean that the location within the hierarchy might vary. Many treatment types have not been fully evaluated to determine their influence on fatal and serious crash outcomes. Over time, and with the improvement in knowledge on effective treatments, this list is expected to evolve. Further details on each of these treatments can be found in the Austroads Road Safety Engineering Toolkit website (www.engtoolkit.com.au).

For each treatment an indication is provided on how safety is influenced, whether this be by reducing exposure (indicated with an E), likelihood (L) and/or severity (S). This information can be coupled with the outputs from the assessment process to help identify appropriate treatments. For example, if the assessment for likelihood identifies that risks are high, then those treatments that operate through reductions in crash likelihood would be more appropriate.

Where high risks are present for more than one crash type (as is often the case), combinations of one or more of these treatments should be considered. In addition, combinations of supporting treatments, particularly in association with lower speeds, may be adequate to fully address specific crash risks.

Table 4.5: Run-off-road (to left or right) treatments

Hierarchy	Treatment	Influence (E = exposure L = likelihood S = severity)
Safe System options ('primary' or 'transformational' treatments)	• Flexible roadside and median barriers (or equally/better performing future equivalent) • Very high quality compacted roadside surface, very gentle to flat side slopes and exceptionally wide run-off areas • Very low speed environment/speed limit.	S S L, S
Supporting treatments which move towards better Safe System alignment (compatible with future implementation of Safe System options)	• Wide run-off areas, with well-maintained shallow drainage and gentle side slopes • Wide sealed shoulders with audio-tactile edgeline • Lower speed limit.	S L L, S
Supporting treatments (does not affect future implementation of Safe System options)	• Non-flexible safety barrier • 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
Other considerations	• Speed enforcement • Rest area provision • Lane marking compatible with in-vehicle lane-keeping technology.	L, S L L

Table 4.6: Head-on treatments

Hierarchy	Treatment	Influence (E = exposure L = likelihood S = severity)
Safe System options ('primary' or 'transformational' treatments)	• One-way traffic • Flexible median barrier • Very wide median • Very low speed environment/speed limit.	L S S L, S
Supporting treatments (compatible with future implementation of Safe System options)	• Wide median • Painted median/wide centrelines.	L L
Supporting treatments (does not affect future implementation of Safe System options)	• 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
Other considerations	• Speed enforcement • Rest area provision • Lane marking compatible with vehicle-lane-keeping technology.	L, S L L

Table 4.7: Intersection treatments

Hierarchy	Treatment	Influence (E = exposure L = likelihood S = severity)
Safe System options ('primary' or 'transformational' treatments)	• Grade separation • Close intersection • 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 site 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.	L, S

Table 4.8: 'Other' crash type treatments

Hierarchy	Treatment	Influence (E = exposure L = likelihood S = severity)
Safe System options ('primary' or 'transformational' treatments)	• Low speed environment.	L, S
Supporting treatments (compatible with future implementation of Safe System options)	• Reduce speed environment/speed limit.	L, S
Supporting treatments (does not affect future implementation of Safe System options)	• Variable message signs/managed freeway systems • Skid resistance improvement • Turning lanes • Overtaking lanes • Improved sight distance/conspicuity • Improved delineation.	L L L L L L
Other considerations	• Speed enforcement.	L, S

Table 4.9: Pedestrian 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

Table 4.10: Cyclist 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 • 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

Table 4.11: Motorcyclist 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)	• Shared motorcycle/bus/taxi lane (e.g. on freeways).	L
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.	L L L S
Other considerations	• Speed enforcement • Enforcement of other regulations.	L, S L

Once treatment options have been selected, the reason for this selection should be documented. Where Safe System solutions were not able to be used, the reason for this should also be recorded. A new assessment should be undertaken to determine the effect of the new treatments, and the results of this recorded (e.g. change in score). As previously discussed, the assessment can be used on several options to determine the solutions that bring the best results in terms of eliminating death and serious injury within project limitations.

5. Discussion

An assessment framework will be an important tool to help road agencies methodically consider Safe System objectives in road infrastructure projects. The framework developed through this project has been tested on a variety of projects, and been found to produce results that not only identify compatibility with Safe System objectives, but also assist practitioners in assessing key elements of the Safe System. This includes a focus on the key crash types that result in fatal and serious outcomes and the mechanisms by which these crashes result in serious injury outcomes (i.e. exposure, likelihood and severity). It also ensures that a broader perspective is taken when assessing projects, and that opportunities are sought to address issues relating to road users, vehicles and post-crash care.

The provision of a treatment hierarchy is also an important tool for practitioners. This provides a useful approach whereby the most effective treatment options are considered first. These will not be available for use in many cases, but it is important that a systematic approach be taken to the selection of treatments and that this process be documented.

It is important that the framework developed through this project be implemented in road agency operations. One effective way to make sure this happens is to provide updates to relevant Austroads Guides with information on the framework. These updates should either include details of the assessment framework, or provide cross-reference to this detail. There are many opportunities to reference the framework from within current Guides.

The framework and treatment hierarchy are likely to evolve and improve over time. As these tools are applied to projects, more case studies will become available. As more evidence is gathered on effective treatments and risk, the guidance provided will be improved. As with any new approach, it is likely that the tools will undergo a rapid evolution and it will be important to coordinate any new knowledge to ensure that all practitioners have access to this.

As identified in the previous section, the subjective application of the framework means that comparisons between locations should not be made, and the results cannot be linked to actual crash rates or frequency. Trials using objective assessment (e.g. outputs from ANRAM) should be undertaken and clear guidance produced to demonstrate this process.

Although the framework has been designed to be simple and quick to apply, there are likely to be training needs. Indeed, the framework has been identified as a useful mechanism with which to make practitioners aware of some of the key Safe System concepts as they relate to road infrastructure. Training material (e.g. user guide and presentation material) should be developed, including examples that demonstrate the wide range of applications. This training should include how to apply the framework for a quick assessment through to more detailed applications, including linkage to objective data where available.

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Appendix A Literature Review

A literature review was conducted to assess current Australian, New Zealand and overseas approaches to Safe System infrastructure and assessment for road infrastructure projects, as well as developments within international organisations. The literature review was conducted with the help of the expert librarians in the MG Lay Library, Australia's premier road and transport collection housed at ARRB. Databases examined included ATRI, the Road Research Register (Australia), TRID (US and Europe) and TRANSPORT (OECD).

In addition, direct contact was made with key national and international experts. This helped to identify unpublished works, including work in progress. The team's professional networks were utilised to access the existing material. The networking included representatives from PIARC, the iRAP Global Technical Committee and individual country experts.

The literature review was prepared to identify any existing Safe System infrastructure frameworks as well as material that may inform the development of such a framework. It was presented in a format that allowed direct input to workshop discussion (Section 3). Note that the literature task was completed in November 2014 and so does not include material beyond that point in time. Some significant work has been conducted in the last year on Safe System infrastructure. Although not available for inclusion in the literature review, the recent findings were in many cases included in the development of the framework.

A.1 Understanding the Safe System Approach

The Safe System approach has been adopted by road agencies around the world and has significantly changed the way road safety is managed and delivered in Australia and New Zealand. This approach recognises that road users are human beings that inevitably make errors that may lead to a crash. The human body can only withstand a certain level of kinetic energy before a crash will result in death or serious injury. Road infrastructure should therefore be forgiving and take into account this vulnerability to avoid serious injury or death in the event of a crash.

A Safe System comprises four essential components which together reflect a holistic view of road safety:

- safe roads and roadsides
- safe speeds
- safe vehicles
- alert and compliant road users (safe road use).

The Safe System approach is based primarily on 'Vision Zero' and 'Sustainable Safety' developed in Sweden and the Netherlands respectively. Vision Zero states that any fatal or serious injuries that occur within the road system are unacceptable, and human tolerances must be taken into account when designing road infrastructure. The foundation of the Sustainable Safety approach is designing a road transport network based on the following concepts:

- Functionality: roads should be physically and visually different to demonstrate their differing functions (such as arterial roads designed for travel over long distances, and local roads are designed for access to properties).
- Homogeneity: there should be minimal interaction between vehicles travelling at different speeds, in different directions and between vehicles of different mass or type.
- Predictability: roads should be 'self-explaining' (i.e. predictable), and the function and road rules should be clear to all users.

- Forgivingness: roads and roadsides should be forgiving in the event of a crash and accommodate road user error.
- State awareness: the road user should be able to measure their own capability of performing the driving task.

In Australia, the Safe System approach is outlined in a number of Federal and state-based documents. The *National Road Safety Strategy 2011–2020* (Australian Transport Council 2011) defines the Safe System key principles as follows:

> a road safety approach which holds that people will continue to make mistakes and that roads, vehicles and speeds should be designed to reduce the risk of crashes and to protect people in the event of a crash.

A.1.1 Safe System versus the Traditional Approach

Historically the aim of road safety was to address the worst crash sites (or 'blackspots') first. This was typically a reactive approach based on individual sites' crash histories. Road safety practitioners then progressed to consider proactive programs and treatments based on potential crash risks, which could be determined from traffic and infrastructure characteristics. This represented the initial shift towards Safe System thinking. The current challenge for road safety practitioners and road agencies is that the Safe System challenges them to respond differently to road safety issues. For example, consider the comparison between the 'old' road safety paradigm and the Safe System approach as shown in Table A 1.

Table A 1: Comparison between traditional and Safe System approaches

Issue	Traditional approach	Safe System approach
Understanding of critical speeds at which FSI crashes occur for different crash types	Information on biomechanical tolerances was available, but was not core to understanding of how to address risk.	Biomechanical tolerances are core to the vision of eliminating FSI crashes.
Road user error	Human error was often seen as the excuse for inaction, and energy was focused toward improving driver behaviour rather than infrastructure.	A 'forgiving' road and roadside is core to the Safe System. FSI crashes should not occur as a result of driver error. Vehicle and infrastructure improvements should be used to reduce impact forces (should a crash occur) to below human tolerances, and therefore reduce crash severity.
Shared responsibility	The focus was on driver education to address road user error, which consequently lowered the responsibility of road managers.	Road managers/designers share the responsibility for safe travel outcomes by accommodating road user error.
Design requirements	Treatment types were often selected based on high BCRs rather than eliminating death and serious injury.	It is paramount that new infrastructure assists in eliminating death and serious injury. This also includes speed management and separation of road users travelling in different directions or of different mass.
Crash severities addressed	Total crashes (of all severities) was often used to identify problem sites.	FSI crashes should be the main aim and starting point in site identification. Minor and non-injury crashes may be useful to provide additional information, but are not the core focus.

Source: Adapted from Austroads (2013a).

There are three highly relevant research studies relating to this.

Kimber (2003)

Kimber (2003) noted that the traditional approach placed too much emphasis on driver contribution to crashes as a result of researchers collecting data on-site for post-crash assessments (Figure A 1). This resulted on a strong focus on driver behaviour which also contributed to:

- potentially effective infrastructure interventions being overlooked
- a high level of concentration, for many years, on measures to change driver behaviour to eliminate crashes, rather than focussing on re-engineering other parts of the road, vehicle or driver system
- a misguided focus on driver behaviour and error that still remains dominant in today's thinking across international communities.

Kimber (2003) suggested, in contrast, that it is an unforgiving road and vehicle system that plays in combination with driver error to cause serious casualty crashes (Figure A 2). When the road and vehicle environment allow it, routine driver errors can translate into collisions, which sometimes result in serious injury or death. A much more useful means of identifying actions to reduce serious casualty outcomes is to focus more on the infrastructure and vehicle safety levels rather than driver error.

Figure A 1: Traditional thought on relative factor contributions to crashes

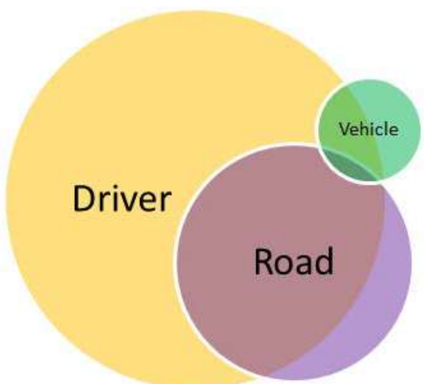
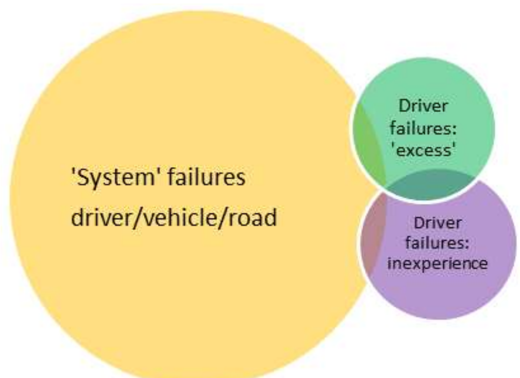


Figure A 2: Reclassification into failure of the driver/vehicle/road system, driver failure from 'excess' and driver failure from inexperience



Source: Adapted from Kimber (2003).

It is not helpful to assume all driver error can be eliminated. Human error is human nature and is to be expected. The system needs to be forgiving of these errors, so that they do not lead to casualty crashes. It is important to remember that the four pillars in the Safe System (safer roads and roadsides, vehicles, speeds and road users) are all important. Therefore, attention must be given to making roads and roadsides, vehicles and speeds more forgiving, as well as continuing to work towards achieving greater levels of road user compliance with the road rules. When a road user makes a mistake that is not illegal (e.g. an error of judgement or not paying due care and attention), the system must compensate and provide adequate protection to all road users.

Stigson et al. (2008)

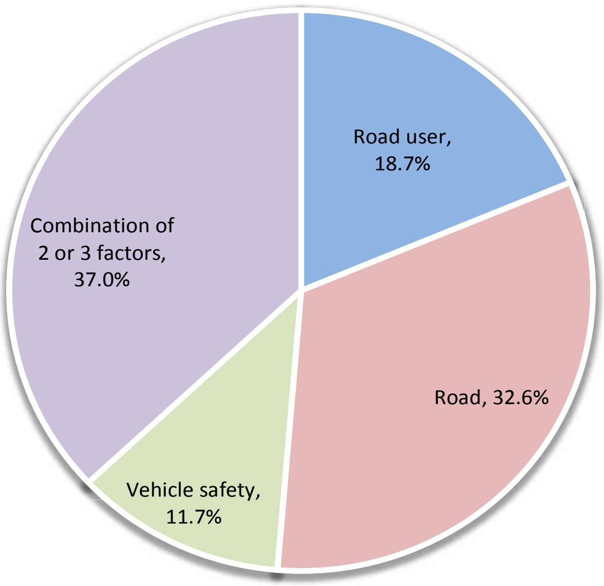
Stigson et al. (2008) determined which factors (road user, road or vehicle) were involved in vehicle occupant fatality crashes in Sweden in 2004. Many of the crashes studied occurred when there were at least two or all three components interacting at once (85 out of 230 cases). Noncompliance by a road user, the vehicle and the road/roadside individually resulted in a fatal crash in 43, 27 and 75 cases respectively (Table A 2 and Figure A 3). In other words, the road environment corresponded with the most fatal outcomes. This again challenges the traditional thinking on relative factor contributions to crashes (Figure A 1).

Table A 2: Role of the road, vehicles and road user in fatal crashes in Sweden (2004)

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 Programme (EuroRAP) rating)	75 (32.6%)
Vehicle safety (European New Car Assessment Programme (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: Adapted from Stigson (2008).

Figure A 3: Role of each pillar in fatal crashes (Sweden)



It should be noted that Stigson et al. (2008) categorised crashes based on factors that contributed to the crash outcome, and not simply crash causation. This identified that there were strong interactions between the three pillars of a Safe System (road user, road and vehicle), but also that the road and roadside were the most strongly linked to fatal crash outcomes. Put another way, in the event of a crash occurring, regardless of how that crash was caused, infrastructure can have a significant impact on the severity outcome.

Elvik et al. (2009)

Elvik et al. (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. In other words, it was thought that around 37% of fatalities and 63% of serious injuries are not the result of road users breaking road rules. This implies that:

- it is routine human error that results in crashes, and these are part of human existence
- 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.

Austroads (2014a)

A recent study by Austroads (2014a) found that a surprisingly small number of error types accounted for the majority of crashes. The most common was overcorrection after straying onto the unsealed shoulder. Understandably, a relatively small selection of treatment types (applied in the appropriate place) would have significantly reduced the crash severity. These included sealed shoulders, roadside barriers and centreline wire rope safety barriers (WRSB). Forty cases from the CASR crash database were randomly selected for analysis, provided they were at least injury crashes (i.e. no property-only crashes), on rural high speed roads, did not involve a medical condition or drugs/alcohol, and occurred less than 10 years ago. Table A 3 shows the frequency of critical errors made by drivers, and Table A 4 shows the frequency of the infrastructure countermeasures that could be effective in protecting drivers from these errors.

Table A 3: Frequency of critical errors

Error	Frequency
Change into occupied lane	1
Drove off road	2
Evasive manoeuvre (animal on road)	1
Fail to give way to approaching traffic	1
Failed to stop	1
Failed to appreciate stationary vehicle	1
Failed to give way	5
Failure to monitor speed of other traffic	1
Fell asleep	4
Lane excursion	4
Left sealed surface	1
Loss of traction/overcorrection on unsealed surface	3
None – vehicle component failure	1
Overcorrection after straying into opposite lane	1
Overcorrection after straying onto unsealed shoulder	8
Panic braking	1
Rolled vehicle	1
Simultaneous overtaking	1

Source: Austroads (2014a).

Table A 4: Frequency of infrastructure countermeasures to protect drivers

Infrastructure countermeasure	Frequency
Centreline WRSB	9
Clear zone	6
Divided road	7
Fence road reserve	1
Geometry changes	1
Heavy vehicle lanes	3
Overtaking provision	1
Restricted access	1
Roundabout	4
Roadside barrier	11
Sealed shoulder	11
Sealed surface	2
Slip lane geometry	1

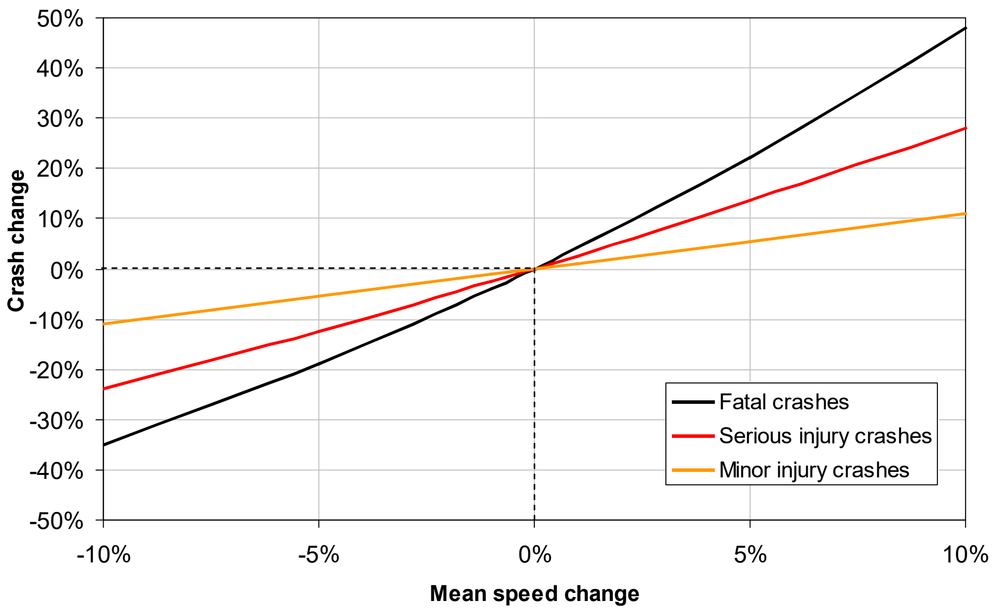
A.1.2 Speed and Safety

Speeding is often quoted as being one of the main causes of crashes and it is thought to contribute to approximately one-third of all fatal crashes worldwide (OECD 2006). This is similar to New Zealand with travelling too fast for the conditions being a crash factor for more than 30% of fatal and almost 17% of severe crashes (fatal and serious injury crashes together) on urban roads (NZ Crash Analysis System database). On top of this, it is often suggested that these figures underestimate the true extent of the problem, particularly in rural areas (e.g. Kloeden et al. 2001).

Elvik (2009) conducted a speed study across a number of countries involving 115 studies. As part of this analysis, 526 estimates were made of the change in casualty rate as a result of a change in the posted speed limit. This work provided strong support for a Power Model – that a small reduction in mean speed can result in a considerable reduction in fatal and injury crashes. This change was magnified on rural roads (Figure A 4) compared to urban roads (Figure A 5) due to higher speeds.

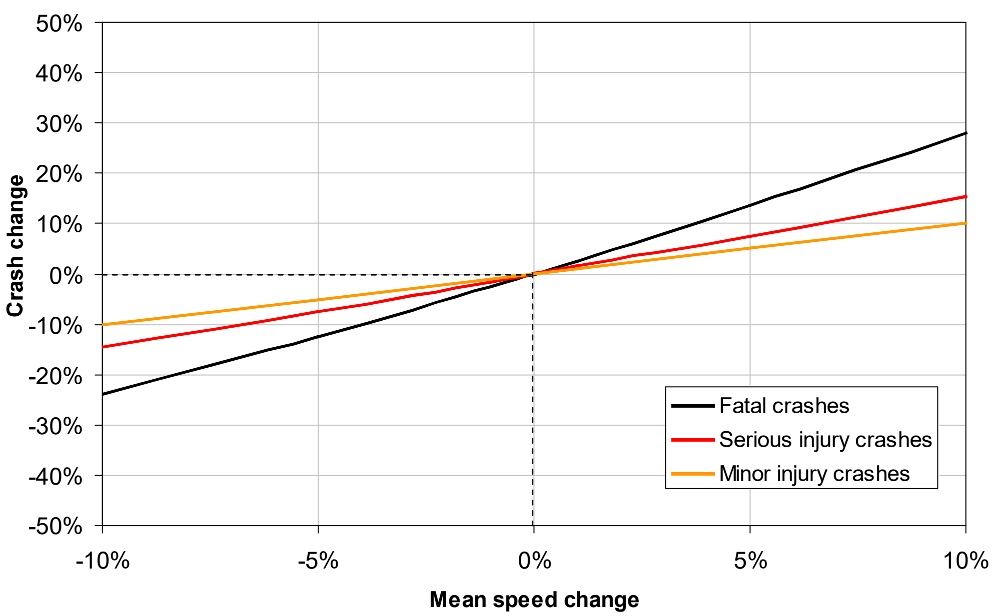
It should be noted, however, that the Power Model exponent has reduced over time (particularly for fatal crashes), i.e. that a decrease in mean speed has a smaller impact on safety than previously. Elvik (2009) reasoned that this was probably due to improved safety devices.

Figure A 4: Mean speed changes versus expected crash changes for rural roads and freeways



Source: Based on Elvik (2009).

Figure A 5: Mean speed changes versus expected crash changes for urban and residential roads



Source: Based on Elvik (2009).

Elvik (2013) has since reanalysed the data used in the 2009 study. This study suggests an exponential model is more appropriate, which produces slightly bigger fatal and injury crash reduction estimates, than a Power Model. It also suggests that the impact of safety should be dependent on the initial mean speed instead of a simple division between ‘high’ and ‘low’ speed roads as shown in Figure A 4 and Figure A 5.

Elvik (2004) has also established a strong direct causal link between speed and crash risk. In a presentation to the Royal Statistical Society, he concluded that:

> There is a very strong statistical relationship between speed and road safety. It is difficult to think of any other risk factor that has a more powerful impact on crashes or injuries than speed.
>
> The statistical relationship between speed and road safety is very consistent. When speed goes down, the number of crashes or injured road users also goes down in 95% of the cases. When speed goes up, the number of crashes or injured road users goes up in 71% of the cases.
>
> The causal direction between speed and road safety is clear. Most of the evidence reviewed in this report comes from before-and-after studies, in which there can be no doubt about the fact that the cause comes before the effect in time. (p.4).

A.1.3 Safe System Speeds

As mentioned previously, there are limits to the biomechanical tolerances of the human body under different crash scenarios. Speed management is at the core of the Safe System approach. A Safe System speed is defined as the maximum survivable speed upon impact where the chance of death is less than 10%. This speed changes depending on the angle of impact and the road user type. Fildes et al. (2005) researched these tolerances and the findings are presented in Table A 5.

Safe System speeds have been challenged by a number of other studies (Richards 2010; Rosen & Sander 2009) and so the speeds highlighted in Table A 5 should be treated as indicative.

Table A 5: Safe System speeds

Crash type	Impact speed
Car/pedestrian/cyclist	20–30 km/h
Car/motorcyclist	20–30 km/h
Car/tree or pole	30–40 km/h
Car/car (side impact, intersections)	50 km/h
Car/car (head-on)	70 km/h

Source: Fildes et al. (2005).

Speeds of 30 km/h are the maximum any vulnerable or unprotected road user (particularly pedestrians) can withstand without sustaining death or serious injuries. Although this speed is fairly common on local roads in Europe, it is uncommon in Australia and New Zealand. Where higher speeds are desirable, additional and appropriate infrastructure would be required to ensure casualty crashes are avoided (e.g. separation).

Speeds over 50 km/h dramatically increases the chances of death and serious injury in the event of a crash between two vehicles at an intersection. Design is one way to manage speeds; for example, roundabouts can geometrically constrain vehicles to lower speeds and more favourable conflict angles.

Casualties as a result of head-on crashes can be significantly reduced if speeds are 70 km/h or lower given current vehicle design and safety features. If higher speeds are required in either a rural or an urban environment, frontal and side-impact vehicle-to-vehicle conflicts, and vulnerable road user-to-vehicle conflicts need to be separated to prevent these potentially high severity crashes from occurring.

Although these harm minimisation speeds are now well known, current speed limit setting practice is generally higher due to motorists' highly optimistic assessments of risk and their expectations based on the road layout. Austroads (2005) states that although many jurisdictions will accept the principles of a Safe System, the practical implementation of such a system will be harder to achieve.

Typical speed limits currently used on higher volume urban roads in Australia and New Zealand are provided in Table A 6 and Table A 7.

Table A 6: Summary of typical urban speed limits in Australia

Speed limits (km/h)	Typical application/ road function	Key features
40	Strip shopping centres	• May be applied on roads within a strip shopping centre during times of high crash risk to pedestrians.
	Urban roads outside of schools (part-time)	• On roads otherwise speed limited 50, 60, 70 and 80 km/h.
50	Residential streets and collector roads	• Default urban speed limit. • Undivided arterial roads within a commercial or industrial roadside environment.
60	Urban arterial roads	• Generally undivided roads within a residential road environment. • Divided arterial roads within a commercial or industrial environment.
	Rural roads outside of schools (part-time)	• On roads otherwise speed zoned 80 km/h or more.
70	Urban arterial roads	• Generally divided roads within a residential road environment. • Undivided arterial roads within a partially developed roadside environment with low levels of direct access.
80	Urban arterial roads	• Divided arterial roads within a residential environment with service roads or minimal direct access to main roadway. • Undivided arterial roads within a sparse roadside environment with very low levels of direct access.

Source: Adapted from Austroads (2014d).

Table A 7: Summary of typical urban speed limits in New Zealand

Speed limits (km/h)	Typical application/ road function	Key features
40	Strip shopping	• Physical treatments may be necessary to constrain vehicle speeds.
	Outside schools (part-time)	• On local roads may need to be supported with physical treatments to constrain vehicle speeds.
50	All types of road	• Default urban speed limit.
	Holiday periods	• Generally used when there are large differences between the level of activity between holiday and non-holiday periods.
60	Urban arterial roads	• On divided roads that have full roadside development, and where the road geometry and its environment can safely accommodate higher vehicle operating speeds.
70	Urban arterial roads	• Roads on the outskirts of urban development or within a large urban area or where there is partial abutting roadside development.
	Rural arterial roads	• On roads through small country towns.
80	Urban arterial roads	• On arterial roads through rural land within a large urban traffic area.
	Rural roads	• On roads passing through sparse areas of development (i.e. small townships or hamlets) or in urban fringes.

Source: Adapted from Austroads (2014d).

For more information on speed limits and speed limit setting, see Austroads (2014b; 2014d; 2008).

There has been much research into how current speed limits can be reconciled with Safe System speeds. For example, Austroads (2010) provides a procedure on how to achieve Safe System speeds through speed limit setting and infrastructure. It involves four key steps:

1. Identify what the speed limit is expected to be given the road class and function.

   This is generally in line with Table A 6 or Table A 7. Although these speeds do not typically reflect the more recent understanding of survivability for different crash types, these speeds represent the high end of a possible speed limit and will give an indication of driver expectations given the current environment.

2. Identify the Safe System speed that is applicable for the location.

   This step involves determining the appropriate Safe System speed whilst taking into account the road use and function (Table A 5). In other words, consideration must be made as to whether there are vulnerable road users present, unprotected roadside hazards, intersections, or no separation between traffic streams. Note there may be a significant difference in the selected speeds for the first and second steps.

3. Carry out a Safe System analysis to the Safe System speed limit with road infrastructure.

   This involves the assessment of current and/or future road infrastructure that could be implemented to minimize key crash types, or the impact of a lower speed limit. Supporting treatments should be considered where all crashes cannot be eliminated to provide incremental improvements to safety.

4. Manage driver perceptions of the road environment and traffic speeds as deemed necessary.

   This step involves managing driver perceptions and any disparity between the posted speed limit and desired speeds. Additional features may be required to assist with this (e.g. narrower traffic lanes, gateway treatments).

This approach has been further developed to produce a model guideline for speed limit setting (Austroads 2014b). This model promotes a route-based approach to speed zoning and minimising the frequency of speed limit changes.

A.1.4 Safe System Treatments

The main focus of this project is to develop a framework for the selection of infrastructure solutions to achieve a Safe System. An important part of this framework will be to advise on treatment selection, and to ensure it is the best application for the situation to move towards Safe System objectives.

Hierarchy of control

A hierarchy of hazard control ensures that the more effective risk controls are prioritised first. The higher within the hierarchy, the less the treatment is dependent on changes in human behaviour to achieve safety outcomes. The standard hierarchy of control that is often applied to a workplace or worksite is as follows (Rose 2005):

- eliminate – design out the hazard
- engineering controls – isolate or guard others from exposure to the hazard
- administrative controls – training/behaviour change
- personal protective equipment – a last resort.

In a road context, the objective is to separate different road users from potential higher energy transfers than they can withstand (for instance, separation of pedestrians and vehicles travelling over 30 km/h), and if that is not possible, rely more heavily on behaviour change. Marsh (2012) defines what a Safe System hierarchy of control would potentially look like:

1. Lower impact energies than human tolerances at potential conflict points.

   This comes back to ensuring that impacts occur at the Safe System speeds identified for different crash types (Table A 5).

2. Design a self-explaining road so that the road 'talks' to road users.

   Features of the road should influence the road user both consciously and subconsciously so that they naturally drive and act in a safe manner. This is particularly important for locations of high risk. For example, audio tactile edge lines can alert a driver to their own distraction or fatigue.

3. Ensure road infrastructure provides opportunities for road users to recover from error or non-compliance.

   This allows for drivers to avoid crashes as a result of distraction or fatigue. A 10 metre clear zone is often considered adequate.

4. Lower the crash risk to an 'acceptable' level.

   Design roads to reduce driver distraction and fatigue from happening in the first place. For example, roads should be predictable and not 'surprise' drivers (e.g. a concealed driveway).

Primary and supporting treatments

Turner et al. (2009) present a framework for Safe System infrastructure solutions based on major crash types. The treatments listed in Table A 8 are considered to be those that have the potential to achieve the Safe System objectives of near-zero deaths and serious injuries, and are termed *primary treatments*.

In some cases primary treatments cannot be utilised, and so the nearest relevant treatment is considered. Many such solutions, or s*upporting treatments* (Turner et al. 2009) reduce the likelihood of a crash, but do not fully reduce the consequence or severity of a crash should one occur. They therefore cannot completely eliminate FSI crashes altogether, but can improve safety nevertheless. An example of a supporting treatment is the use of audio-tactile edge lines, which reduce the occurrence of run-off-road crashes. They also reduce the likelihood of collisions with roadside barriers. It is important to note that supporting treatments also includes educational campaigns, signage and interim speed limits, as demonstrated in Table A 8. Many of these supporting treatments will eventually require replacement with alternative treatments to achieve a full Safe System. In the meantime, vehicle design and technology is required in addition to achieve these outcomes.

Table A 8: Safe System infrastructure

Crash type	Example of primary Safe System treatments*	Example of supporting treatments
Run-off-road	• Centre and edge barrier systems (particularly wire-rope barriers) • Clear zone provision.	• Concentration on high crash locations • Lower interim speed limits • Improved education of public • Improved shoulder provision, audio-tactile edge lines, delineation.
Intersection	• Grade separation • Roundabouts • Intersection platforms • Time separation between flows with fully-controlled turning phases.	• Restrictions in use of particular intersections (through route guidance, closing of intersections, restricting movements at intersections) • ITS systems used to warn road users (e.g. vehicle activated speed limit signs).
Head-on	• Median barriers/carriageway duplication.	• Vehicle design improvements • Shoulder sealing • Increased separation between opposing traffic flows (i.e. wider medians) • Provision of overtaking lanes • Audio-tactile centrelines • Improved skid resistance • Vehicle activated warning signs at curves • Provision of rest areas • Improved delineation.

Pedestrian	• Grade separation • Raised pedestrian crossings (wombat crossings) and other relevant traffic calming.	• Lower interim speed limits • Pedestrian signals • Pedestrian fencing • Medians/refuge islands • Electronic warning signs • Improved lighting • Improved skid resistance • Parking restrictions.
Motorcyclist/ cyclist	• Separation from other road users.	• Improved road surface • Improved clear zones • Improved curve alignment • Protected right turns (fully controlled) • Fixed speed cameras • Lower interim speed limits • On-road cycle lanes.

** Speed management is a relevant treatment consideration for all these crash types.*

Source: Adapted from Turner et al. (2009).

Austroads (2013b) examined ways of improving the performance of Safe System infrastructure. This identified current primary infrastructure solutions to include:

- traffic signals
- roundabouts
- flexible median barriers on divided and undivided roads
- flexible roadside barriers.

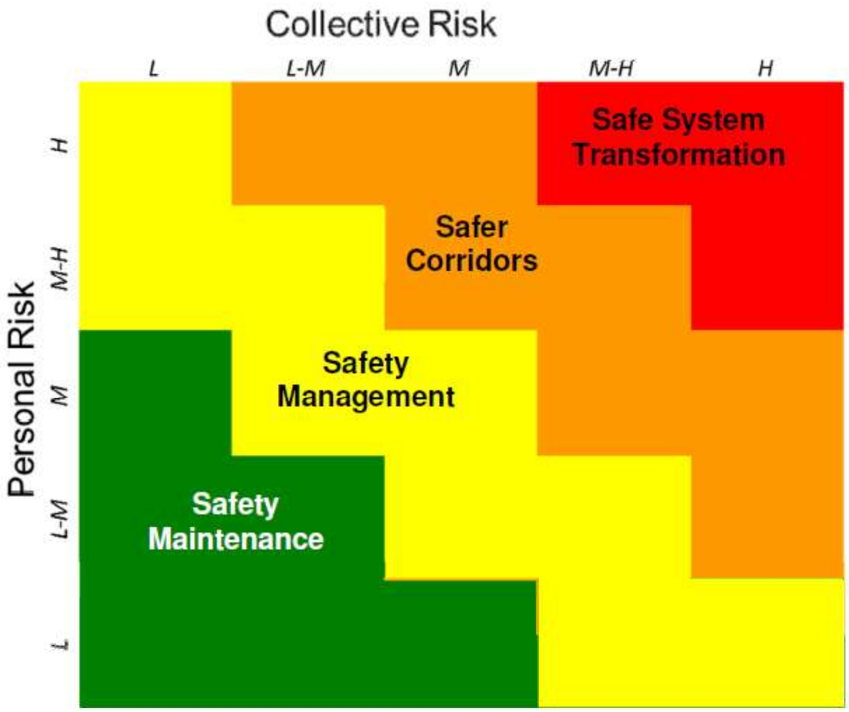
The project identifies ways to improve these infrastructure solutions to achieve better Safe System results. There is a similar Austroads project which is specifically looking at understanding and improving Safe System intersection performance.

Network-level investment frameworks

Collective risk, also referred to as the crash density, is defined as the level of risk for all road users combined (e.g. average annual number of FSI crashes per kilometre). These data are fairly easy to obtain and are readily available from crash databases supplied by road or transport agencies. Personal (or individual) crash risk is the measure of the likelihood of an individual road user being involved in a crash as they travel a particular road. This is often reported as per 100 million vehicle kilometres travelled (VKT). Personal crash risk is more complicated to calculate, as the average annual daily traffic (AADT) needs to be collected for an individual stretch of road. Crash rates can be alternatively estimated based on design elements for a section of road, namely the relationships between design elements and crash outcomes.

Figure A 6 shows different treatment approaches for different categories of collective and personal risk.

Figure A 6: Collective and personal risk matrix with respective treatment categories



Source: Tate and Brodie (2014).

Treatment types can be categorised into four groups based on this collective and personal risk:

- ***Safe System Transformation Works*** consist of major upgrades or the provision of an alternative safer route. This is most suitable for higher volume roads with constrained design and/or poor alignment (thus high collective and personal risk). These are typically rural/outer-metropolitan highways.
- ***Safer Corridors*** are most effective at locations such as inner-metropolitan arterials where a lot of road safety investment has already occurred. These areas usually have low personal risk, but collective risk is high due to high traffic volumes and mixed road use (e.g. pedestrians, public transport, cyclists). A blackspot approach or other road safety intervention would be recommended, or other strategic reassessment of route functions.
- ***Safety Management*** is appropriate for road sections where low traffic volumes and road design contribute to unsafe travel for a small proportion of road users of that section (i.e. high individual risk but low collective risk). This is most common on rural roads and local roads. There may be no crash history as a result. There will be a low economic return on investment in a Safe System transformation (e.g. road duplication), so the framework proposes a low-cost approach for the section.
- ***Safety Maintenance*** is best suited where both personal and collective risk are low, and there is no major evidence of an apparent serious safety issue.

A.2 Existing Frameworks within Australasia

This section provides information on assessment frameworks used in Australia and New Zealand. The information was current as of November 2014 and it should be noted that new approaches may have been developed since that time. In several cases this information has been gathered from unpublished sources.

A.2.1 Western Australia

Marsh (2012) developed a comprehensive framework that has now been used for several years in Western Australia. A Safe System Working Group was established in 2007 for a new highway to work towards achieving zero deaths for the first five years of its operation. As part of this, a ‘Towards Zero Framework’ was developed to provide a structured approach to assess the project against Safe System objectives.

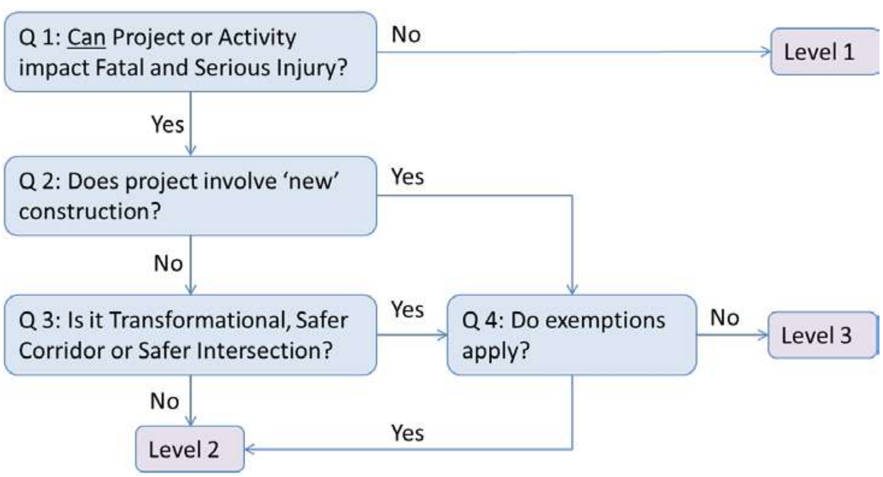
A key feature of the framework is that it focusses on limiting forces beyond human tolerances during a crash. It specifically focusses on fatal and serious injuries, particularly in run-off-road and head-on crashes, intersection crashes and crashes involving vulnerable road users. The Safe System speeds were taken into account for all these crash types (Table A 5). Emphasis is also placed on the level of personal and collective risk for treatment selection (Appendix A.1.4).

Before a Safe System review takes place, the project is assessed to determine its appropriate level of review. There are three levels under which a project can fall:

- Level 1: projects that could not be expected to affect the frequency/density of FSI crashes (e.g. installation of fibre optic cable) – no Safe System review is required.
- Level 2: projects where existing personal and collective risk indicates Safety Maintenance and/or Safety Management is required (Figure A 6) – A Safe System Review internal to the project is required.
- Level 3: projects where personal and collective risk indicates a Safe System Transformation and/or Safer Corridor/Safer Intersection is required (Figure A 6), or the project involves road building – a Safe System Reference Group must be formed to undertake the Safe System Review. The purpose of the Reference Group is to provide advice to Main Roads for the design of sustainable infrastructure to ensure a safe road network for all users.

Guidance is provided to determine the Safe System Review Level (Figure A 7), and then how to conduct the reviews at Levels 2 and 3, as well as the objectives and expectations of the Safe System Reference Group. Treatment selection is also guided through an effectiveness scale for different scenarios.

Figure A 7: Main Roads WA assessment flowchart



Source: MRWA (unpublished).

The framework also recognises the limited funds that road agencies often have for these projects, and as a result provides a hierarchy of control for treatments. At the top end, this involves targeting the prevention of death or serious injury (e.g. through road and roadside infrastructure), while still considering other demands such as managing community and road agency expectations (referred to as ‘sustainable solutions’) (Marsh 2012). Second-order treatments are those that provide real-time risk reduction or the provision of pre-crash warning (e.g. ITS and audio-tactile road markings). The lowest level of the hierarchy is general risk reduction, including other road and roadside treatments, enforcement and driver/community education.

The framework has since been utilised for a number of projects, with some interesting outcomes as a result. Traditional treatments have sometimes been replaced with others which better fit with Safe System outcomes (e.g. wire rope barriers, replacing proposed signalised intersections with a roundabout, using horizontal deflection on the approach to a pedestrian crossing, use of ITS). One project identified that the process of using the framework can lead to reduced costs while improving safety outcomes. For example, construction costs were significantly reduced for one project due to less earthwork requirements due to the use of barriers instead of a wide clear zone. The treatment also had a lower environmental impact as more existing vegetation was retained.

A.2.2 South Australia

South Australia has also developed a Safe System framework. The key objective of this tool is to ensure that projects deliver safety outcomes to minimise fatal and serious injury crashes, with the aspiration of reducing these crashes to as near to zero as possible. The framework was developed to be used at various stages in a project's design and implementation (e.g. planning new roads, upgrades, assessing existing infrastructure) and for projects of different sizes (from large capital projects to individual site assessments). Experiences were drawn from the Western Australia framework (outlined in Appendix A.2.1) before a framework was developed and a trial was undertaken.

The framework comprises a checklist that embeds Safe System principles and core to this understanding are the different biomechanical tolerances of road users in certain situations. This is based on a combination of selecting the desired speed environment (based on road function), the existing or predicted future speed environment, and the infrastructure provided.

All four pillars of the Safe System (road and roadside, vehicle, road user and speed) need to collaborate to ensure that a Safe System outcome is achieved. With current technology, there is no definite guarantee that the number of deaths and serious injuries will be reduced to zero, however a Safe System is the best current available approach to achieve as close to this as possible.

The South Australian approach to achieving a Safe System follows a four-step process:

1. consider the function of the road in light of Safe System principles
2. undertake a risk assessment using the Safe System framework
3. identify solutions or options
4. revise plans and operating strategies and document the decisions made.

Step one involves determining the intended function of the road based on the likely road users. Critical impact speeds (as previously mentioned in Table A 5) were used to ensure that when crashes occur they will not result in serious injury or death to any road users (vehicle occupants or others). If higher speeds than these were required, certain measures were then necessary to accommodate these speeds (e.g. infrastructure improvements to separate road users, protection from hazards).

Once this is determined, the Safe System Framework is applied. This framework considers the planning, design, construction, operation and maintenance issues and how they relate to Safe System outcomes. It combines the Safe System pillars with the traditional Haddon matrix (Haddon 1968; 1980) (Table A 9).

Table A 9: Safe System assessment framework (South Australia)

	Before crash	During crash	After crash
Safe people			
Safe speeds			
Safe roads and roadsides			
Safe vehicles			

The Haddon matrix is a systematic framework for road safety based on a disease model. It comprises infrastructure, vehicle and users in pre-crash, in-crash and post-crash stages. Central to this approach, similar to the Safe Systems approach, is the understanding that the exchange of kinetic energy in a crash leads to injury, which needs to be managed to ensure that human tolerances are not exceeded. However, it did not directly address the institutional management needed to produce the target objectives.

Once the issues have been identified, there is a requirement to document the solutions selected to mitigate these issues. The same framework is used to provide possible treatments to address the safety issues identified.

Based on the steps outlined above, the initial plans will need to be revised and revisited to reflect the Safe System principles. This will most likely be an iterative process until the project meets the Safe System requirements. It is imperative that any changes made to plans are assessed for negative consequences, and that the cost implications are monitored. Where Safe System requirements cannot be met, it is important that the reasons for this are documented.

A.2.3 Victoria

Safe System speed and infrastructure matrix

As part of an investigation into the safety effectiveness of staggered rural T-intersections for VicRoads, ARRB applied a draft Safe System assessment framework adopted from the MRWA and SA models. The framework highlights the need to focus on the human-road-vehicle relationship throughout an assessment, and also recommends the use of an independent assessment panel to review key decisions.

This strategy consists of four steps as outlined below. These steps may need to be repeated a number of times throughout the planning, design and construction phases until the project meets the desired Safe System objectives:

1. Consider the Safe System principles before reviewing the project. This includes determining the maximum survivable impact speeds and the need to reduce impact forces to below human tolerance levels. Factors such as road users (presence, regulation, enforcement), travel speeds, road infrastructure (both proposed and existing) and vehicle types on the road should be considered in this assessment.
2. Undertake an alignment assessment using the Safe System matrix. The matrix looks at the proposed/existing infrastructure and/or solutions in the context of each pillar (safer people, safer speeds, safer roads and safer vehicles). This is categorised into key road crash types, and the level of Safe System alignment (i.e. ideal, high, moderate and low aligning solutions). This promotes identification of specific gaps and assists in the development of solutions.
3. Identify solutions/options. The gaps identified in Step 2 between Safe System and the proposed/existing conditions are systematically assessed for treatment and/or speed options. The approach to Safe System implementation identified previously in Figure A 6 can be used to assist in this process.
4. Revise plans and operating strategies.

MUARC Visionary Research Model

The Monash University Accident Research Centre (MUARC) has developed a Visionary Research Model (VRM), which conceptualises how the road system would look and operate if it were to fully satisfy the Safe System objectives of zero death and serious injuries, and then works backwards to define the boundaries of its design and operation in order to achieve that (Corben et al. 2004).

The initial model development was restricted to the single scenario of a pedestrian potentially being struck by a vehicle. The model describes five ‘layers of protection’, starting close to the victim (i.e. the pedestrian) and moving concentrically outwards. The layers are described as follows:

1. The first layer is immediately around the pedestrian, and focusses on minimising injury risk and maximising biomechanical tolerances of the pedestrian. This varies greatly with age, health, etc., and there are few practical methods for achieving this with the current level of technology.

2. The second layer also looks at injury risk, but attempts to manage the transfer of kinetic energy between the car and pedestrian. Research shows that the most promising results come from front-of-car designs with energy absorbing features. For pedestrians, there is the option of protective clothing/helmets. Another option is to develop energy-absorbing road surfaces.
3. The third layer aims to reduce injury risk by minimising the kinetic energy of the car at the point of impact. This is related to travel speeds, which has the greatest potential to reduce kinetic energy. New in-vehicle technologies can assist with achieving lower speeds at the time of a crash, as well as improved sight distances, skid resistant road surfaces, traffic calming infrastructure and narrower roads/wider footpaths (visually promoting slower driving behaviour).
4. The fourth layer looks at reducing crash risk, as opposed to injury risk (the focus of layers 1, 2 and 3). This is for a given level of exposure. Similar countermeasures can be used as identified in Layer 3. Infrastructure improvements, traffic calming and lower speed limits can help pedestrians with gap acceptance, and these will lower injury risk as well as crash risk. Education and behaviour change initiatives for pedestrians can also help lower crash risk.
5. The fifth and outer-most layer also addresses crash risk through reducing exposure levels. This can be achieved by reducing exposure of pedestrians to crashes, vehicle volumes, pedestrian volumes or a combination. This could be done through disincentives to use private vehicles, incentives to use public transport, review of road function classifications or changes in traffic management through ITS and traffic signals to discourage drivers from entering high pedestrian volume zones.

This style of model is very rigorous and is helpful in identifying possible solutions to achieve a Safe System, but also offers the opportunity to quantify the effects of any implementation. It also challenges practitioners to consider innovative solutions, whilst maintaining an evidence-based approach.

A.2.4 New Zealand

New Zealand has not developed a Safe System framework as yet, but there exists a ‘safety management philosophy’ which reflects the Safer Journeys strategy and therefore Safe System principles and visions (Tate & Brodie 2014). One of the key actions within the Safer Journeys Action Plan was to target high risk rural roads. As a result, this management scheme has first been applied to New Zealand’s state highways.

Tate and Brodie’s paper looks at different ways to calculate collective and personal risk in order to identify high risk and determine an appropriate management philosophy.

KiwiRAP is used for its risk mapping and star rating capabilities. This takes into account both historical crash data and proactive measures to locate high risk sites or corridors. The KiwiRAP star rating also links levels of service with road network classifications to give an idea of traffic volumes and density.

In order to select suitable sub-sections for treatment (as KiwiRAP can identify quite large lengths of road as ‘high risk’), a ‘sliding window’ method is used. This routine looks at crashes within a certain defined window length (e.g. 5 km). The window is then moved along the route by a defined offset length (e.g. 1 km), and crashes that fall within the window are reported at each increment.

Treatment selection is done as per the treatment types demonstrated in Appendix A.1.4 and Figure A 6. Once the appropriate treatment philosophy is selected, the *High Risk Rural Roads* guide (NZTA 2011) provides a range of possible treatment types aimed at addressing head-on, run-off-road and intersection crashes, as well as crashes involving vulnerable road users (Table A 10).

Table A 10: Examples of treatments

Key crash type	Safe System transformation treatments	Safer corridor treatments	Safety maintenance treatments
Head-on	• Median barriers • Safe System speeds.	• Marked median treatments • ATP markings • Improved delineation • Active warning signs • Harm reduction speeds.	• Increased intervention levels • Increased skid resistance • Hazard removal.
Run-off-road	• Roadside barriers • Clear zones • Safe System speeds.	• Wider shoulders • ATP markings • Improved delineation • Harm reduction speeds.	• Increased intervention levels • Increased skid resistance • Planting policies • Hazard removal.
Intersections	• Grade-separated interchanges and overpasses • Roundabouts • Safe System speeds.	• Wider shoulders and separated turning facilities • Improved delineation • Active warning signs • Harm reduction speeds.	• Increased intervention levels • Increased skid resistance • Hazard removal • Improved sight visibility.
Vulnerable road users	• Separated off-road facilities • Safe System speeds.	• Wider shoulders and separated turning facilities • Improved delineation • Harm reduction speeds.	• Improved sight visibility • Reduce pinch points • Consistent shoulder width and surface quality.

Source: Tate and Brodie (2014).

A.2.5 International Road Assessment Program (iRAP) Trigger Set

The International Road Assessment Program (iRAP) commenced development of an approach whereby safety infrastructure could be rated to determine whether Safe System objectives would be achieved. The iRAP trigger set is a list of criteria required to achieve Safe System compliance (or a Risk Factor of zero) for various crash types and different road users. For example, a head-on crash for vehicle occupants can be mitigated by ensuring speeds are below 70 km/h, median barriers are in place or the roads are on-way only (Table A 11).

Table A 11: iRAP trigger set for vehicle occupants

Crash type	Safe System compliance (Risk factor = 0)
Run-off driver and passenger side	• Speeds <= 50 km/h (Note: > 10 m clear zones and wire rope barriers approach 0 but currently are not considered full Safe System compliant for reducing fatal and serious outcomes)
Head-on loss of control	• Speeds <= 70 km/h • Median barrier in place (concrete, metal and wire-rope all considered compliant for reducing head-on risk to Safe System levels (note the severity of hitting the barrier is captured in run-off risk) • One-way roads.
Head-on overtaking	• Median barriers or flexi-posts present • Median present (that is divided carriageway) • One-way road.
Intersection	• Speeds <= 50 km/h • No intersection present or side road entering flow onto road being assessed reduced to zero (e.g. turn in only at three leg intersection).
Property access	• Speeds <= 50 km/h • No property access present.

Source: Personal communication, Rob McInerney, iRAP.

A.3 Existing International Frameworks

A.3.1 Sweden

The Swedish Transport Administration (STA) has a highly-developed approach to treating its urban and rural road networks. The approach has the express, long-term view of eradicating death and serious injury from Swedish roads. This is the fundamental goal of Sweden’s Vision Zero, a road safety vision which, together with the Dutch equivalent (Sustainable Safety), form the foundation of Australasia's Safe System road safety vision.

The approach uses a judiciously defined combination of infrastructure and speed limit setting that recognises the performance limits of humans and of vehicle fleets. It has reached a decidedly advanced state and is highly ambitious in its aspiration.

Sweden’s strategy for addressing rural road safety involves raising the infrastructure quality along major rural corridors and routes to Vision Zero standards by investing where speed limits exceed 80 km/h and no physical separation exists between opposing vehicles or from roadside hazards. Under these conditions, continuous mid- and side-barriers are provided, rather than relying on painted centres lines, medians or standard clear zones. The primary criterion for prioritisation of investment in Vision Zero infrastructure is exposure, as indicated by vehicle kilometres travelled (VKT). The STA aims to maximise the proportion of total VKT occurring on ‘Vision Zero’ roads and, so, transform its road network to meet the ultimate vision of no deaths or serious injuries.

The Swedish approach differs uniquely from others in that, instead of aiming to treat the highest risk segments of a rural route (as indicated by any of the collective or individual risk metrics), it defines how the network should ‘look and operate’ to achieve Vision Zero performance. Various combinations of speed and infrastructure have been defined for each urban and rural road class, with the express purpose of achieving Vision Zero performance. The framework uses the speed limit as a primary determinant of the need for various forms of infrastructure.

A similar approach is used for urban and semi-urban roads. For high-speed urban situations, such as on 100 or 90 km/h motorways, continuous mid- and side-barriers are required to satisfy Vision Zero design requirements. Hazard-free clear zone requirements apply in the vicinity of intersections. For vulnerable road users – pedestrians and cyclists, in particular complete separation along and across urban roads zoned 60 km/h or above is required to meet Vision Zero principles (there is no provision in the Swedish speed limit setting system for 50 km/h limits but there is for 40 km/h limits).

In essence, the Swedish approach focuses on:

- Five predominant crash types accounting for a major proportion of Sweden’s traffic deaths and serious injuries, namely:
  - head-on
  - run-off-road
  - intersection
  - pedestrian
  - cyclist.
- The range of road classes that categorise travel according to each road’s transport function and the types of environments through which traffic passes.
- The need for improved infrastructure, better-matched speed limits or both, in order to address the potential deaths or serious injuries due to:
  - inadequate separation between opposing directions of traffic
  - hazardous roadsides

- the potential for high-speed/severe-angle collisions at intersections
- inadequate separation of vulnerable road users (pedestrians and cyclists) from vehicular traffic or high travel speeds.

- Exposure is the principal prioritisation criterion for investment in a range of treatment philosophies needed to address infrastructure deficiencies and/or mismatched speed limits.
- The treatment philosophies aim to meet Vision Zero performance, and where this is not possible in the short-term, two alternative treatment philosophies ('approved' and 'partially approved') have been defined to reduce deaths and serious injury resulting from the key crash types. These alternative treatment philosophies are less ambitious than the Vision Zero form but, nevertheless, enable worthwhile progress to be made.
- There are numerous combinations of treatment form for the various combinations of:
  - road class
  - urban or rural setting
  - road cross-section
  - intersection type
  - presence of vulnerable road users
  - speed limit.

In summary, Sweden has defined how all its major classes of roads should 'look and operate' in order to achieve Vision Zero objectives, 'towards Vision Zero' objectives or simply improve safety. Definitions include rural roads ranging from motorways, though duplicated four-lane highways to undivided two-lane rural roads of various speed limit settings. For each commonly occurring combination of rural road class and speed limit, the required infrastructure to address head-on, run-off-road, intersection and vulnerable road user collisions and so achieve Vision Zero performance is specified. In addition, less ambitious combinations of speed limit and infrastructure are also specified. For rural routes, the following treatment package from Sweden has been defined to achieve Vision Zero outcomes:

- continuous median- or mid-barrier separation of opposing directions
- continuous side-barriers with minimum breaks, no hazardous breaks and no hazardous barrier terminations
- intersections that are either grade-separated, controlled by roundabouts or have geometric features that prevent 90-degree collisions at speeds greater than 50 km/h.

In addition, the Swedish approach specifies full separation for pedestrians and cyclists along and across highways. However, the practical relevance in Australasia of this aspect of Sweden's approach will be mainly within and on approach to townships along a given route.

The implementation of these treatment philosophies follows a route-based approach, in which the STA aims to achieve the simple philosophy of maximising the exposure of road users to Vision Zero infrastructure with properly-matched speed limits.

The STA has a relatively small set of highly focussed key performance indicators (KPIs), chosen because of their scientifically-robust relationship to road safety outcomes.

With respect to infrastructure investment, the applicable KPIs are:

- percentage of traffic on state roads over 80 km/h with physical separation of opposing directions
- percentage of safe routes for pedestrians, cyclists and moped riders for municipal roads shared with cars
- percentage of municipalities with good maintenance of bike paths.

Relevance to Defining a Safe System Framework

The relevance of the Swedish practice to this study, which seeks to define a Safe System framework, is that Sweden focuses on the following attributes of the road-transport system in assessing whether Vision Zero principles are likely to be met:

- speed limit
- foreseeable key crash types, with special attention to vulnerable road users
- presence or absence of Vision Zero infrastructure features to separate effectively the foreseeable crash types.

Where incompatible combinations of these attributes exist (i.e. that do not meet Vision Zero principles), infrastructure and/or speed limit solutions are required to bring about Vision Zero performance. The incompatible combinations and their Vision Zero solutions are categorised according to:

- environment type (urban or rural)
- road function (motorway, arterial, local etc.)
- road cross-section (divided, undivided, number of lanes).

Only defined forms of infrastructure are approved to address the risks of death or serious injury for the key crash types for each of the major classes of urban and rural roads. In situations where the required infrastructure cannot be provided by 2025, lower speed limits will apply, in order to deliver Vision Zero performance.

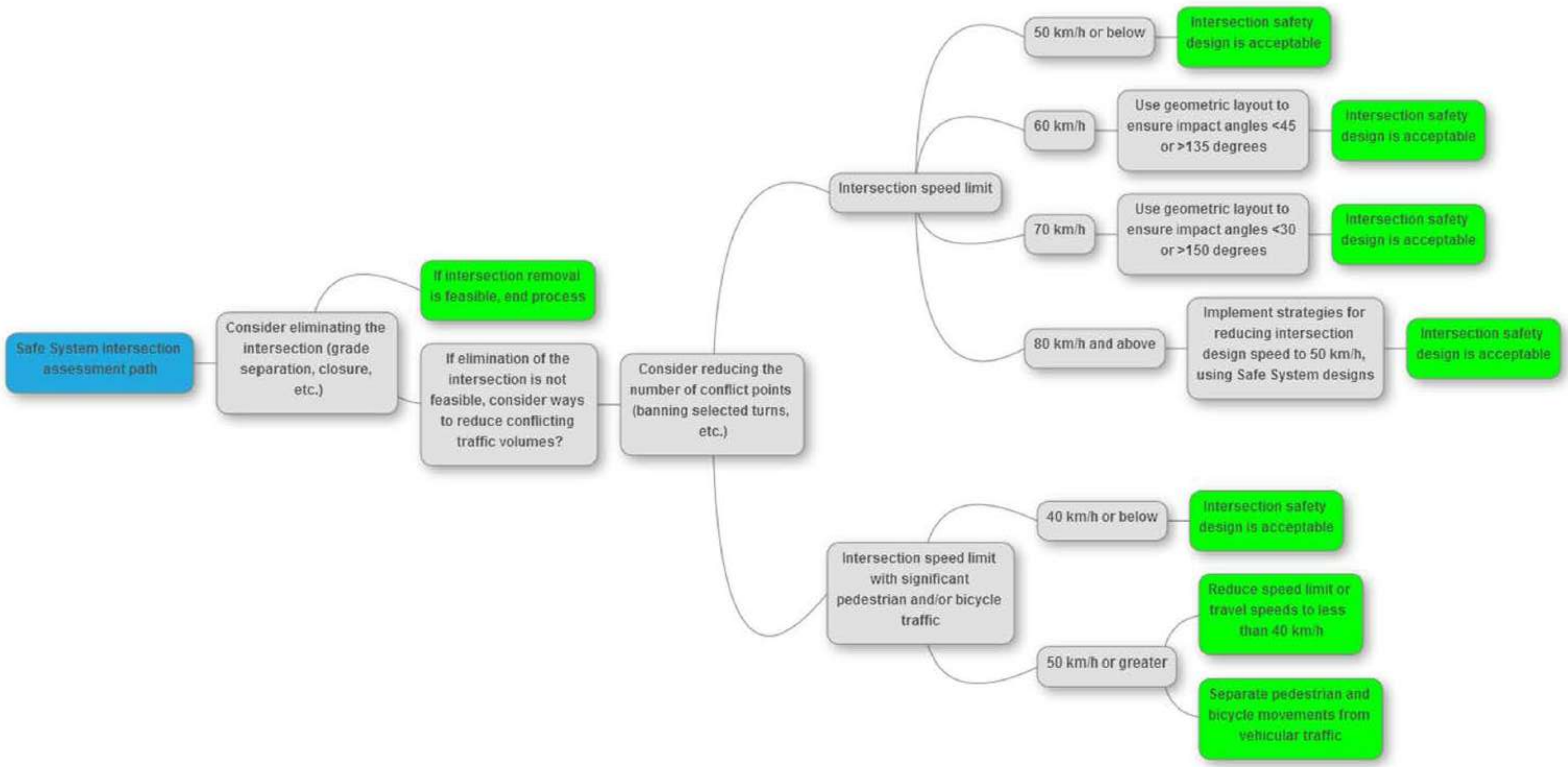
A.3.2 Canada

The Capital Region Intersection Safety Partnership (CRISP) commissioned a pilot project with MUARC to look at engineering applications of the Safe System approach (Huculak 2014). The aim of the project was to highlight differences between the traditional approach and the Safe System approach to intersection design for 'poorly performing' intersections in Canada (within CRISP partner jurisdictions).

The Kinetic Energy Management Model (KEMM), developed by MUARC, was used to evaluate the transfer of kinetic energy exchange during a crash. It determined the amount of energy occupants will receive and the chance of this causing serious injury or death. This determined which intersection geometries performed better in terms of risk, and which geometries were therefore Safe System compliant. KEMM uses the same five layers of protection as discussed in Appendix A.2.3.

The Safe System Intersection Assessment Path provides a step-by-step guide to achieving Safe System outcomes (for intersection applications only) by first reducing the risk of crashes, and then reducing the kinetic forces during a crash (Figure A 8).

Figure A 8: Safe System intersection assessment path



Source: Huculak (2014).

A.3.3 USA

A number of US states have adopted the Vision Zero approach. Utah, New York, Minnesota and Washington DC have made changes to their law enforcement, legislation and infrastructure with the aim of reducing fatal and serious crashes to zero. As a part of this, each state has released action plans and strategies for how to do this. These include:

- City of New York's *Vision Zero Action Plan* (City of New York 2014)
- Utah's *Strategic Highway Safety Plan* (Utah Safety Leadership Committee 2013)
- Minnesota's *Strategic Highway Safety Plan* (Minnesota Department of Transportation 2007).

Since adoption, these states have had significant success – Utah has reduced its annual death toll from 373 in 2000 to 243 in 2011, Minnesota from 657 in 2002 to 494 in 2006 and New York from 381 in 2000 to 249 in 2011.

However, none of the states is known to have adopted the Safe System approach, and subsequently there are currently no Safe System assessment frameworks available from the US.

A.3.4 Other Hierarchies of Control

Western Samoa Road switch safety review

The Western Samoa Road Switch Safety Review follows a similar structure to the Victorian assessment (discussed in Appendix A.2.3), with Safe System elements considered for each pillar (safer people, safer speeds, safer roads and safer vehicles) and for different activities. These activities include understanding crashes and risk, education and information supporting road users, enforcement of road rules and admittance to the system (Figure A 9).

Figure A 9: Western Samoa Road switch safety review

		Safe System Elements			
		1. Safe People	2. Safe Speed	3. Safe Roads and Roadsides	4. Safe Vehicles
Activity	A. Understanding Crashes & Risk	• Review crash data • Identify hazards of switching driving sides • Expert review and report	• Reduce town and rural speed limits • Village entry treatments (speed humps)	• Mark direction arrows (every 150 m) • Change all road signs/lines accordingly (regulatory, warning, advisory etc.) • New bus bays • Village entry treatments • New pedestrian facilities (esp. at schools)	• Assess buses • Review affect of LHD vehicles on RHD roads (esp. rural curves and overtaking)
	B. Education & Information supporting road users	• Switch Day media promotion – TV, radio, press • TV & radio discussion panels • Switch test track • School Switch Education. Program • Tourist awareness campaign • Awareness campaign targeting teachers and key village matais	• Enhanced speed zone signing	• 'Look' stencilling • Clock tower roundabout campaign	• Cheaper late model vehicles available (long lead-in time)
	C. Enforcement of road rules	• Introduce random breath testing and license checks	• Enhanced speed enforcement campaign	• Enhanced enforcement campaign • Police leave cancelled	• Vehicle inspection and registration checks
	D. Admittance to the system	• Consider license retesting (did not occur)			• Bus modifications

Source: ARRB Group.

Appendix B Template for Assessment

Background

[insert text on background to project, including photo and/or map of location]

Objectives identification

[insert text on the objectives of the assessment]

Setting the context

Prompt	Comment
What is the reason for the **project**? Is there a specific crash type risk? Is it addressing specific issues such as poor speed limit compliance, road access, congestion, future traffic growth, freight movement, amenity concerns from the community, etc.	
What is the **function** of the road? Consider location, roadside land use, area type, speed limit, intersection type, presence of parking, public transport services and vehicle flows. What traffic features exist nearby (e.g. upstream and downstream)?	
What is the **speed** environment? What is the current speed limit? Has it changed recently? Is it similar to other roads of this type? How does it compare to Safe System speeds? What is the acceptability of lowering the speed limit at this location?	
What **road users** are present? Consider the presence of elderly, school children and cyclists. Also note what facilities are available to vulnerable road users (e.g. signalised crossings, bicycle lanes, school zone speed limits, etc.).	
What is the **vehicle** composition? Consider the presence of heavy vehicles (and what type), motorcyclists and other vehicles using the roadway.	

Safe System matrix

	Run-off-road	Head-on	Intersection	Other	Pedestrian	Cyclist	Motorcyclist
Exposure							
Likelihood							
Severity							

Additional Safe System components

Pillar	Prompts
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? Can enforcement of these issues be conducted safety? 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?
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? 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? 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)?

Appendix C Case Study Examples

The examples provided in this Appendix are for illustration purposes only. They are designed to demonstrate applications of the framework. They do not represent final design options, and in some cases provide details on options that have been superseded. The assessments made were produced by individuals, and do not necessarily represent ARRB, Austroads, or road agency policy or practice.

C.1 Intersection Analysis: Burwood Highway and Terrara Road, Vermont South

Background

The intersection of Burwood Highway and Terrara Road in Vermont South was selected for framework analysis, as it has very recently been modified by VicRoads. It was originally a priority controlled intersection on a major urban arterial (80 km/h) with U-turn facilities in both directions (Figure C 1). The intersection was then modified to a partially signalised intersection with a fully controlled right-turn signal into Terrara Road, a separate U-turn facility for those travelling east on Burwood Highway, and no right turn out of Terrara Road (Figure C 2). The partial signalisation was a treatment of a black spot problem associated with a high number of turners crossing right into Terrara Road, a collector road. An additional (hypothetical) scenario was also assessed, to investigate the effectiveness of closing the median at the intersection and only allowing left-in/left-out movements into Terrara Road (Figure C 3).

In the following sections, the three scenarios (baseline; signalised; and closed median) are assessed using the Safe System assessment framework.

C.1.1 Baseline: Uncontrolled Intersection and U-turn Facility

Figure C 1: Aerial of Burwood Highway and Terrara Road intersection, before signalisation

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

Objectives identification

The objective of this assessment was to identify how well the current intersection aligns with Safe System objectives, and to allow comparison with other treatment options. This is the assessment of an individual location, looking at a specific road design and operational issues.

Setting the context

Prompts	Comments
What is the function of the road? Consider location, roadside land use, area type, speed limit, intersection type, presence of parking, public transport services and vehicle flows. What traffic features exist nearby (e.g. upstream and downstream)?	• Major arterial (Burwood Highway), high speed environment (80 km/h), high flows (> 10 000 vpd) • Unsignalised T-intersection with collector road (Terrara Road) • U-turn facilities for both east and west directions • Residential land use, urban, parking available in service lanes • Bus service on Burwood Highway with stops near the intersection.
What road users are present? Consider the presence of elderly, school children and cyclists. Also note what facilities are available to vulnerable road users (e.g. signalised crossings, bicycle lanes, school zone speed limits, etc.).	• Elderly drivers due to presence of retirement village in vicinity • Some specialised vehicles (due to tip nearby) • No school children present • Low volumes of cyclists (who regularly use the service lane) and pedestrians.
What is the vehicle composition? Consider the presence of heavy vehicles (and what type), motorcyclists and other vehicles using the roadway.	• Moderate proportion of heavy vehicles, although it is expected that larger vehicles would use Eastlink for east-west travel • Low volumes of motorcyclists.
What is the reason for the project? Is there a specific crash type risk? Is it addressing specific issues such as poor speed limit compliance, road access, congestion, future traffic growth, freight movement, amenity concerns from the community, etc.	• High number of intersection casualty crashes • Some issues with speed limit compliance (especially travelling east on Burwood Highway as it is downhill).

Safe System matrix

	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	$4 * 3 * 3 = {}^{36}/_{64}$	$4 * 1 * 3 = {}^{12}/_{64}$	$4 * 3 * 4 = {}^{48}/_{64}$	$4 * 3 * 3 = {}^{36}/_{64}$	$1 * 4 * 4 = {}^{16}/_{64}$	$1 * 4 * 4 = {}^{16}/_{64}$	$1 * 3 * 4 = {}^{12}/_{64}$	$^{\mathbf{176}}/_{\mathbf{448}}$

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).

C.1.2 After: Signalised Intersection and U-turn Facility

Figure C 2: Aerial of Burwood Highway and Terrara Road intersection, after signalised intersection implementation

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

Objectives identification

The objective of this case study is to identify how well the installed signalised intersection design aligns with Safe System objectives. This is the assessment of an individual location, looking at a specific road design and operational issues. Differences from baseline to the before case are highlighted in red.

Setting the context

Prompts	Comments
What is the reason for the project? Is there a specific crash type problem? Is it addressing specific issues such as poor speed limit compliance, road access, congestion, future traffic growth, freight movement, amenity concerns from the community, etc.	To assess the level of improvement in Safe System alignment compared to the original design
What is the function of the road? Consider location, roadside land use, area type, speed limit, intersection type, presence of parking, public transport services and vehicle flows.	Major arterial (Burwood Highway), high speed environment (80 km/h), high flows (> 10 000 vpd) Signalised T-intersection with local road (Terrara Road) with restricted turning movements U-turn facility for east direction only Residential use, urban, parking available in service lanes Bus service on Burwood Highway.
What road users are present? Consider the presence of elderly, school children and cyclists. Also note what facilities are available to vulnerable road users (e.g. signalised crossings, bicycle lanes, school zone speed limits, etc.).	Elderly drivers due to presence of retirement village in vicinity Some specialised vehicles (due to tip nearby) No school children present Low volumes of cyclists (who regularly use the service lane) and pedestrians.
What is the vehicle composition? Consider the presence of heavy vehicles (and what type), motorcyclists and other vehicles using the roadway.	Moderate proportion of heavy vehicles, although it is expected that larger vehicles would use Eastlink for east-west travel Low volumes of motorcyclists.

Safe System matrix

	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 Terarra 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 ✓ No intersection movements/conflict points that could result in HO crash ✓ $^0/_4$	% 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 ✓ Extended decel. lanes ✓ Need to stop at signals × Buses stopping × $^4/_4$	Service lane with footpath ✓ No crossing facility across Terrara Rd (low speed) × Zebra crossing ✓ $^2/_4$	Service lane – some separation ✓ No bicycle crossing facilities at intersection × $^4/_4$	No delineation × Well surfaced ✓ Straight road ✓ $^3/_4$	
Severity	High speed × No barriers × Steep grade × Poles and trees – $^3/_4$	High speed × Low speed in side road ✓ $^3/_4$	High speed × Reduced conflict angles ✓ $^2/_4$	High speed × Visible intersection ✓ Resurfaced ✓ $^2/_4$	High speed × $^4/_4$	High speed × $^4/_4$	High speed × Some roadside hazards × $^4/_4$	**Total**
Product	$4 * 3 * 3 = {}^{36}/_{64}$	$4 * 0 * 3 = {}^{0}/_{64}$	$4 * 3 * 2 = {}^{24}/_{64}$	$4 * 4 * 2 = {}^{32}/_{64}$	$1 * 2 * 4 = {}^{8}/_{64}$	$1 * 4 * 4 = {}^{16}/_{64}$	$1 * 3 * 4 = {}^{12}/_{64}$	$^{128}/_{448}$

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.
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 – however there is scope to install red light cameras at the intersection if an issue is detected in future • 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).

C.1.3 Alternative Design: Left-in, Left-out Intersection Only

Figure C 3: Aerial of Burwood Highway and Terrara Road intersection, hypothetical intersection closure

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

Objectives identification

The objective of this case study is to identify how a hypothetical intersection closure would with Safe System objectives. This is the assessment of an individual location, looking at a specific design issues. Note that alternative high quality intersections are located to either side of this location, and so the impact on the local road network is expected to be minimal.

Setting the context

Prompts	Comments
What is the reason for the project? Is there a certain crash type problem? Is it addressing specific issues such as poor speed limit compliance, road access, congestion, future traffic growth, freight movement, amenity concerns from the community, etc.	• To assess the level of improvement in Safe System alignment compared to the original design.
What is the function of the road? Consider location, roadside land use, area type, speed limit, intersection type, presence of parking, public transport services and vehicle flows.	• Major arterial (Burwood Highway), high speed environment (80 km/h), high flows (> 10 000 vpd) • Left-in/left-out intersection with local road (Terrara Road) • No U-turn facility • Residential use, urban, parking available in service lanes • Alternative turning facilities exist in close proximity • Bus service on Burwood Highway.
What road users are present? Consider the presence of elderly, school children and cyclists. Also note what facilities are available to vulnerable road users (e.g. signalised crossings, bicycle lanes, school zone speed limits, etc.).	• Elderly drivers (due to presence of retirement village in vicinity) • Some specialised vehicles (due to tip nearby) • No school children present • Low volumes of cyclists (who regularly use the service lane) and pedestrians.
What is the vehicle composition? Consider the presence of heavy vehicles (and what type), motorcyclists and other vehicles using the roadway.	• Some proportion of heavy vehicles, although it is expected that larger vehicles would use Eastlink for east-west travel • Low volumes of motorcyclists.

Safe System matrix

	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	$4 * 2 * 3 = {}^{24}/_{64}$	$4 * 0 * 3 = {}^{0}/_{64}$	$1 * 1 * 3 = {}^{3}/_{64}$	$3 * 2 * 3 = {}^{18}/_{64}$	$1 * 4 * 4 = {}^{16}/_{64}$	$1 * 4 * 4 = {}^{16}/_{64}$	$1 * 2 * 4 = {}^{8}/_{64}$	$^{85}/_{448}$

C.1.4 Comparison of Options

The three options (baseline, partial signalisation and left-in, left-out) are summarised in Table C 1.

Table C 1: Comparison of options

	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. The partial signalisation option offers a substantial safety improvement over the baseline situation, but does not produce as substantial a result.

Each of the alternative options have other opportunities for improvements in safety. This is particularly the case for run-off-road and ‘other’ (rear-end and lane changing) crashes. Further intersection treatment solutions would also be required under the partial signalisation option. Further treatment options could be selected from the treatment hierarchy (Section 4.6) to improve safety. As an example, all treatments still have moderate potential for fatal and serious injury due to run-off-road crashes. Safety could be greatly improved through the provision of roadside protection.

C.2 Length Analysis: Beaconsfield Parade

Beach Road between Princess Street in Albert Park and Nepean Highway in Beaumaris is an arterial road, oriented in a north-westerly and south-easterly direction. Beach Road within the subject area is also known as Beaconsfield Parade, Jacka Boulevard, Marine Parade and Ormond-Esplanade.

The two-way traffic volume along Beach Road ranges between 20 000 annual average daily traffic (AADT) in Albert Park to 36 000 AADT in the suburb of St. Kilda. The posted speed limit in both directions is 60 km/h. Land use along Beach Road is residential/commercial on one side and beach frontage/commercial on the other.

In the following sections, the scenarios assessed are the baseline scenario and the treatment option scenario incorporating the following:

- introduce a buffer of approximately 0.7 m between parked vehicles and the existing on-road bicycle lane
- signalise the intersection of Beaconsfield Parade/Victoria Parade and retire the Pedestrian Operated Signal (POS) just west of this intersection.

C.2.1 Baseline: Uncontrolled Intersection and U-turn Facilities

Objectives identification

The objective of this assessment was to identify how well the current length of Beach Road aligns with Safe System objectives, and to allow comparison with other treatment options. This is the assessment of a length, looking at a specific road design and operational issues.

Setting the context

Prompt	Comment
What is the reason for the project? Is there a specific crash type problem? Is it addressing specific issues such as poor speed limit compliance, road access, congestion, future traffic growth, freight movement, amenity concerns from the community, etc.	• High number of bicycle casualty crashes e.g. car dooring • Some safety issues with the median openings.
What is the function of the road? Consider location, roadside land use, area type, speed limit, intersection type, presence of parking, public transport services and vehicle flows. What traffic features exist nearby (e.g. upstream and downstream)?	• Arterial (Beach Rd), speed 60 km/h, high flows (> 20 000 vpd) • Unsignalised T-intersections with open medians • 13 open medians along the approximately 6.5 km length • Residential land use, urban, parking available on side road • High bike volumes on road and off road path provided.
What road users are present? Consider the presence of elderly, school children and cyclists. Also note what facilities are available to vulnerable road users (e.g. signalised crossings, bicycle lanes, school zone speed limits, etc.).	• Cyclists using the on and off road facilities • High bicycle volumes • No school children present • Clear way north west bound in the morning peak.
What is the vehicle composition? Consider the presence of heavy vehicles (and what type), motorcyclists and other vehicles using the roadway.	• Moderate proportion of heavy vehicles • High volumes of motorcyclists during weekends.

Safe System matrix

	ROR	HO	INT	OTHER	PED	CYC	M/C	
Exposure	High volume × $^4/_4$	High volume, on a section there is no median but peed × $^1/_4$	High vol. on Beach Rd Few intersections, LED, × $^4/_4$	High volume × $^4/_4$	Median pedestrian volumes, crossing illegally ✓ $^3/_4$	High cyclist volumes ✓ $^4/_4$	High motorcyclist volumes ✓ $^4/_4$	
Likelihood	Flat ✓ Deceleration lane ✓ Presence of intersection × No shoulders × Morning clearway × 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 × Medium speed × Protected turn lanes ✓ $^3/_4$	High no. of lanes × Protected turn lanes ✓ Short decel. lanes × Buses stopping × $^3/_4$	Footpath provided ✓ No crossing facilities at intersection × Many lanes to cross × $^4/_4$	Service lane – some separation ✓ $^4/_4$	Well surfaced ✓ Straight road ✓ $^3/_4$	
Severity	Medium speed × No barriers × Poles and trees to hit × $^4/_4$	Medium speed × Low speed in side road ✓ $^1/_4$	Medium speed × $^3/_4$	Medium speed × $^3/_4$	Medium speed × Some crossing facilities × $^4/_4$	High speed × $^4/_4$	High speed × Some roadside hazards × $^4/_4$	**Total**
Product	$4 * 3 * 4 = {}^{48}/_{64}$	$1 * 1 * 1 = {}^{1}/_{64}$	$4 * 3 * 3 = {}^{36}/_{64}$	$4 * 3 * 3 = {}^{36}/_{64}$	$3 * 4 * 4 = {}^{48}/_{64}$	$4 * 4 * 4 = {}^{64}/_{64}$	$48 * 3 * 4 = {}^{12}/_{64}$	$\mathbf{{}^{245}/_{448}}$

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?	• Drivers may be distracted by the beachfront views and related activity (e.g. wind surfing) • Pedestrians crossing mid-block to access beach front facilities.
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?	• Parking enforcement creates high in-and-out movement along Beach Rd • 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)?	• The wide medians may be used for emergency stops • Three lanes in each direction • Close to emergency facilities (less than 10 km).

C.2.2 After: Signalised Intersection and Closure of Medians

Objectives identification

The objective of this case study is to identify how well the proposed installation of a signalised intersection at Victoria Ave and other treatments along the length (e.g. closure of medians) aligns with Safe System objectives. This is the assessment of a length, looking at a specific road design and operational issues. Differences from baseline to the before case are highlighted in red.

Setting the context

Prompts	Comments
What is the reason for the project? Is there a specific crash type problem? Is it addressing specific issues such as poor speed limit compliance, road access, congestion, future traffic growth, freight movement, amenity concerns from the community, etc.	• To assess the level of improvement in Safe System alignment compared to the original design.
What is the function of the road? Consider location, roadside land use, area type, speed limit, intersection type, presence of parking, public transport services and vehicle flows.	• Arterial (Beach Rd), speed 60 km/h, high flows (> 20 000 vpd) • Signalised T-intersection with local road (Victoria Ave) • Removing pedestrian crossing west of Victoria Ave • Closing of medians to prevent conflict with turning traffic • Residential use, urban, parking available side of the road • Bus service on Beach Rd.
What road users are present? Consider the presence of elderly, school children and cyclists. Also note what facilities are available to vulnerable road users (e.g. signalised crossings, bicycle lanes, school zone speed limits, etc.).	• Cyclists using the on and off-road facilities • High bicycle volumes • The bicycle lanes are provided with a 700 mm buffer to prevent car dooring • No school children present • Clear way north west bound in the morning peak.
What is the vehicle composition? Consider the presence of heavy vehicles (and what type), motorcyclists and other vehicles using the roadway.	• Moderate proportion of heavy vehicles • High volumes of motorcyclists during weekends.

Safe System matrix

	ROR	HO	INT	OTHER	PED	CYC	M/C	
Exposure	High volume × $^{4}/_{4}$	High volume, on a section there is no median but low speed × $^{1}/_{4}$	High vol. on Beach Rd Few intersections, LED, × $^{4}/_{4}$	High volume × $^{4}/_{4}$	Median pedestrian volumes, crossing illegally ✓ $^{3}/_{4}$	High cyclist volumes ✓ 700 mm buffer provided Note it is not clear from the matrix if this should still be a score of 4. $^{3}/_{4}$	High motorcyclist volumes ✓ $^{4}/_{4}$	
Likelihood	Flat ✓ Deceleration lane ✓ Presence of intersection × No shoulders × Morning clearway × No barriers × $^{3}/_{4}$	Divided, wide/raised median ✓ Intersection movements/conflict points minimal for HO crash ✓ $^{1}/_{4}$	% turning movements ✓ Medians closure ✓ Introduction of a signalised intersection – no raised approaches × No. of lanes and conflict points × Moderate speed × Good sight distance Protected turn lanes ✓ $^{4}/_{4}$	High no. of lanes × Protected turn lanes ✓ Introduction of median closure Buses stopping × $^{3}/_{4}$	Footpath provided ✓ No crossing facilities at intersection × Many lanes to cross × $^{4}/_{4}$	Service lane – some separation ✓ Car dooring is somehow eliminated due to the buffer zone Median closure are preventing turning movement traffic Kerb outstands for side streets $^{2}/_{4}$	Well surfaced ✓ Straight road ✓ $^{3}/_{4}$	
Severity	Medium speed × No barriers × Poles and trees to hit × $^{4}/_{4}$	Medium speed × Low speed in side road ✓ $^{1}/_{4}$	Medium speed × $^{3}/_{4}$	Medium speed × $^{3}/_{4}$	Medium speed × Some crossing facilities × $^{4}/_{4}$	Medium speed × $^{4}/_{4}$	High speed × Some roadside hazards × $^{4}/_{4}$	**Total**
Product Beach Rd	$4 * 3 * 4 = {}^{48}/_{64}$	$1 * 1 * 1 = {}^{4}/_{64}$	$4 * 4 * 3 = {}^{48}/_{64}$	$4 * 3 * 3 = {}^{36}/_{64}$	$3 * 4 * 4 = {}^{48}/_{64}$	$3 * 2 * 4 = {}^{24}/_{64}$	$4 * 3 * 4 = {}^{12}/_{64}$	$\mathbf{{}^{220}/_{448}}$

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?	• The number of cyclists is high and car dooring exposure • Provision of buffer zone • Pedestrians crossing mid block.
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?	• Parking enforcement, creates high in and out movement along Beach Rd • 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)?	• The wide medians may be used for emergency stops • Three lanes in each direction • Close to emergency facilities (less than 10 km).

C.2.3 Comparison of Options

The three options (baseline, partial signalisation and left-in, left-out) are summarised in Table C 2.

Table C 2: Comparison of options

	ROR	HO	INT	OTHER	PED	CYC	M/C	
Baseline Beach Rd	$4*3*4 = {}^{48}/_{64}$	$1*1*1 = {}^{1}/_{64}$	$4*3*3 = {}^{36}/_{64}$	$4*3*3 = {}^{36}/_{64}$	$3*4*4 = {}^{48}/_{64}$	$4*4*4 = {}^{64}/_{64}$	$48*3*4 = {}^{12}/_{64}$	${}^{245}/_{448}$
Product Beach Rd	$4*3*4 = {}^{48}/_{64}$	$1*1*1 = {}^{4}/_{64}$	$4*4*3 = {}^{48}/_{64}$	$4*3*3 = {}^{36}/_{64}$	$3*4*4 = {}^{48}/_{64}$	$3*2*4 = {}^{24}/_{64}$	$4*3*4 = {}^{12}/_{64}$	${}^{\mathbf{220}}/_{448}$

It is clear that the proposed option does produce Safe System outcomes. Introduction of a traffic signalised intersection with no additional Safe System enhancements suggest the overall project is marginally beneficial from a Safe System perspective.

Provision of buffer zones and the kerb outstands improves the situation only slightly.

C.3 Paraburdoo – Tom Price Road (SLK 0-48.9)

C.3.1 Existing Situation

Traffic data: 120 vehicles per day (vpd), 27.5% heavy vehicles (2014).

Crashes per million vehicle km: 102.7 (approx. 3 times greater than Pilbara average of 31.1).

A summary of the key accident types by section are summarised as follows:

- eleven reported crashes, seven (64%) were hit animal of which six (55%) involved cattle and one a kangaroo. Seven (58%) crashes occurred during hours of darkness, with no street lights, although it is noted that five of these involved animals
- two crashes required hospitalisation
- one crash required medical treatment
- eight crashes involved property damage
- three (27%) reported crashes occurred on curves.

The carriageway is typically 6 m wide with unsealed shoulders and has no line marking. The posted speed is 110 km/h. The section is typically rural in nature. The horizontal and vertical geometry of the road suited the posted speed.

The general delineation and definition of the road and the edge of seal is poor at night and particularly during dusk. The road has a number of sweeping bends along its entire length and although guide posts are in place, the general definition of the bends is poor at night when forward visibility is restricted.

Tracking for road trains on some of the bends required encroachment over the centre of the road resulting in potential conflict with opposing traffic. Typical movements are shown on Figure C 4, which indicates that even on a straight section vehicles are tracking to the road edge when passing.

Figure C 4: Paraburdoo Road – typical traffic

Cattle were encountered during the night-time inspection and presented a significant hazard to traffic. This is supported by the crash data.

There are a number of culverts along the road within the clear zone which are potentially hazardous for errant vehicles running off the road.

There are a number of floodways along this section of the road and the overtaking sight distance could be impacted by the vertical geometry of the road at some locations.

The edge of the seal is breaking up at some locations and requires repair, particularly at the pull-in location at SLK 0 on the north side of Paraburdoo Road. Loose material is also being dragged onto the carriageway as the pull-in is not sealed (Figure C 5).

Figure C 5: Paraburdoo Road – pull-in area at SLK 0

Prompt	Comment
What is the reason for the project? Is there a specific crash type problem? Is it addressing specific issues such as poor speed limit compliance, road access, congestion, future traffic growth, freight movement, amenity concerns from the community, etc.	• Road requiring general rehabilitation • High number of animal-related crashes.
What is the function of the road? Consider location, roadside land use, area type, speed limit, intersection type, presence of parking, public transport services and vehicle flows. What traffic features exist nearby (e.g. upstream and downstream)?	• Rural road with relatively low flows and a moderate level of heavy vehicles • Speed limit 110 km/h • Relatively featureless with minor intersections.
What road users are present? Consider the presence of elderly, school children and cyclists. Also note what facilities are available to vulnerable road users (e.g. signalised crossings, bicycle lanes, school zone speed limits, etc.).	• Tourist traffic going towards the national parks • Heavy vehicles servicing local centres such as Tom Price – some traffic running between various mine sites.
What is the vehicle composition? Consider the presence of heavy vehicles (and what type), motorcyclists and other vehicles using the roadway.	• Moderate proportion of heavy vehicles • Some recreational vehicles.

Safe System matrix

	ROR	HO	INT	OTHER	PED	CYC	M/C	
Exposure	L volume ✓ $^1/_4$	Low volume ✓ $^1/_4$	Not applicable $^0/_4$	Low volume $^1/_4$	Very pedestrian volumes ✓ $^0/_4$	Very Low cyclist volumes ✓ $^0/_4$	Very Low motorcyclist volumes ✓ $^0/_4$	
Likelihood	No shoulders × No barriers × Poor/no delineation (edgeline) × Curves × $^3/_4$	Poor/no delineation (centreline) × Narrow pavement × $^3/_4$	Not applicable $^0/_4$	Animals on Road × $^3/_4$	No Shoulder × No lighting × $^3/_4$	No Shoulder × No lighting × $^3/_4$	Mix of vehicles – some heavies × $^3/_4$	
Severity	High speed × No barriers × Culvers × Floodways × $^3/_4$	High speed × $^3/_4$	Not applicable $^0/_4$	High speed × $^3/_4$	High speed × $^4/_4$	High speed × $^4/_4$	High speed × Some roadside hazards × $^4/_4$	**Total**
Product	$1 * 3 * 3 = {}^9/_{64}$	$1 * 3 * 3 = {}^9/_{64}$	$0 = {}^0/_{64}$	$1 * 3 * 3 = {}^9/_{64}$	$0 * 3 * 4 = {}^0/_{64}$	$0 * 3 * 4 = {}^0/_{64}$	$0 * 3 * 4 = {}^0/_{64}$	$\mathbf{^{27}/_{448}}$

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?	• Given the nature and length of the road drivers could be fatigued.
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)?	• Remoteness from emergency services?

C.3.2 Suggested Measures

Pavement marking – centreline and edge lines along the entire length of the road together with raised reflective pavement markers through each bend, with the required road widening on bends in the first instance.

Widening on bends – widen the lanes at bends as a first stage upgrade to accommodate the tracking requirements of the design vehicle when travelling in opposite directions at the design speed.

Sealing of shoulders – seal the shoulders to a minimum of 1.0 m on each side of the road as a future stage.

Cattle within road reserve – install appropriate fencing along the entire route.

Prompt	Comment
What is the reason for the project? Is there a specific crash type problem? Is it addressing specific issues such as poor speed limit compliance, road access, congestion, future traffic growth, freight movement, amenity concerns from the community, etc.	• Road requiring general rehabilitation • High number of animal-related crashes • Fencing along roadside.
What is the function of the road? Consider location, roadside land use, area type, speed limit, intersection type, presence of parking, public transport services and vehicle flows.	• Rural road with relatively low flows and a moderate level of heavy vehicles • Speed limit 110 km/h • Relatively featureless with minor intersections.
What road users are present? Consider the presence of elderly, school children and cyclists. Also note what facilities are available to vulnerable road users (e.g. signalised crossings, bicycle lanes, school zone speed limits, etc.).	• Tourist traffic going towards the national parks • Heavy vehicles servicing local centres such as Tom Price – some traffic running between various mine sites.
What is the vehicle composition? Consider the presence of heavy vehicles (and what type), motorcyclists and other vehicles using the roadway.	• Moderate proportion of heavy vehicles • Widen shoulders and lane widths at bends • Some recreational vehicles.

Safe System matrix

	ROR	HO	INT	OTHER	PED	CYC	M/C	
Exposure	L volume ✓ $^{1}/_{4}$	Low volume ✓ $^{1}/_{4}$	Not applicable $^{0}/_{4}$	Low volume $^{1}/_{4}$	Very pedestrian volumes ✓ $^{0}/_{4}$	Very Low cyclist volumes ✓ $^{0}/_{4}$	Very Low motorcyclist volumes ✓ $^{0}/_{4}$	
Likelihood	No shoulders × No barriers × Improved delineation (edgeline) ✓ Sealed Shoulders✓ Curves × $^{2}/_{4}$	Improve delineation (centreline) ✓ Wider pavement (sealed shoulders) ✓ $^{2}/_{4}$	Not applicable $^{0}/_{4}$	Animals on Road × Fencing along road ✓ $^{2}/_{4}$	Sealed Shoulder ✓ No lighting × $^{2}/_{4}$	Sealed Shoulder ✓ No lighting × $^{2}/_{4}$	Mix of vehicles – some heavies × $^{3}/_{4}$	
Severity	High speed × No barriers × Culvers × Floodways × $^{3}/_{4}$	High speed × $^{3}/_{4}$	Not applicable $^{0}/_{4}$	High speed × $^{3}/_{4}$	High speed × $^{4}/_{4}$	High speed × $^{4}/_{4}$	High speed × Some roadside hazards × $^{4}/_{4}$	**Total**
Product	$1 * 2 * 3 = {}^{6}/_{64}$	$1 * 2 * 3 = {}^{6}/_{64}$	$0 = {}^{0}/_{64}$	$1 * 2 * 3 = {}^{6}/_{64}$	$0 * 3 * 4 = {}^{0}/_{64}$	$0 * 3 * 4 = {}^{0}/_{64}$	$0 * 3 * 4 = {}^{0}/_{64}$	$^{\mathbf{18}}/_{\mathbf{448}}$

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?	• Given the nature and length of the road drivers could be fatigued • Sealed shoulders.
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)?	• Remoteness from emergency services?

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