Development and use of the Austroads Safe System Assessment Framework

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Abstract

Australia adopted the Safe System approach more than a decade ago. The first action item from the Australian National Road Safety Strategy is to ensure that all new road projects consider Safe System principles. Although the main objectives of this approach are clear, there is limited direct guidance on how this can be implemented, especially in the provision of road infrastructure. Austroads has developed a tool to directly address this issue. A framework is presented that assists 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. A treatment hierarchy was also developed to identify effective Safe System infrastructure solutions. The development of both the assessment framework and treatment hierarchy are discussed.

Introduction

Road safety has improved dramatically in Australia in the last few decades. From a high of round 3800 deaths per year numbers have fallen to an average 1250 people per year (average between 2010 and 2014; BITRE 2014; Department of Infrastructure and Regional Development, 2015). However, in recent years the numbers have been relatively stable, and even shown slight increases. When compared to the good road safety performers amongst our OECD peers Australia kills twice as many people per head of population (BITRE 2014).

The Safe System approach was adopted in Australia to provide the framework for a step-change in road safety performance (Australian Transport Council 2005). This approach (see Austroads 2013) recognises that road users inevitably make mistakes that may lead to a crash. In addition, the human body can only withstand certain impact forces before death or serious injury results. A shared approach or responsibility is required to prevent these deaths and serious injuries occuring. More specifically, there is the requirement to move away from blaming the victim, to ensuring that different parts of the 'system' all act together to improve safety, and eventually elimiate death and serious injury. As an example of the shared responsibility, road infrastructure should be forgiving and take into account road user vulnerability to avoid serious injury or death in the event of a crash.

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".

The Safe System comprises four essential components or pillars:

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

It is noted that there is increasing recognition of a fifth pillar within the system that should also be included. The global action plan for the decade of action in road safety also includes post-crash care as a pillar (WHO 2011).

The Safe System approach was introduced in Australia more than 10 years ago, firstly as part of the 2005/06 Road Safety Action Plan (Australian Transport Council 2005). The vision for this strategy is reasonably clear, as summarised above, but the steps required to reach these objectives are less well understood.

In addition, the first action item from the Australian National Road Safety Strategy (Australian Transport Council 2011) is to ensure that all new road projects consider Safe System principles. Although there has been some progress on this action item in individual jurisdictions, clear practical guidance on embedding Safe System principles into the provision of new infrastructure or the upgrading of existing infrastructure is not available.

The aim of this project was to develop an assessment framework to help road agency practitioners 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.

Development of the framework

Development of the framework involved the establishment of a working group, a literature review, engagement with international experts, a stakeholder workshop, framework development, testing and refinement.

The working group was established at the outset of the project and 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.

A literature review was conducted (reported in Austroads 2016) to assess current Australian, New Zealand and overseas approaches to Safe System infrastructure implementation and assessment for road infrastructure projects. The review also attempted to identify any existing Safe System infrastructure frameworks as well as material that may inform the development of such a framework. Some key findings from the review are described below.

Different frameworks have been developed and applied within Australia and New Zealand as well as in some overseas jurisdictions. Most notable in Australia were frameworks developed by Marsh (2012) in Western Australia, and by ARRB Group (reported in Austroads 2016) in South Australia. Overseas initiatives included the International Road Assessment Program (iRAP) trigger set and approaches used in Sweden and Canada (reported in Austroads 2016). More recently, McTiernan and Rensen (2016) provided a framework developed specifically for local roads.

In Western Australia the ‘Towards Zero Framework’ was developed to provide a structured approach to assess projects against Safe System objectives (Marsh 2012). The framework focusses on limiting forces to within human tolerances during a crash. It specifically focusses on fatal and serious injuries, particularly run-off-road and head-on crashes, intersection crashes and crashes involving vulnerable road users. Safe System speeds were taken into account for all these crash types (i.e. the speeds beyond which fatal and serious injury becomes more likely**Error! Reference source not found.**). The framework also recognises the limited funds that road authorities 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 authority expectations (referred to as 'sustainable solutions'). 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.

Work in South Australia built upon the approach developed in Western Australia. However, key differences included the addition of all Safe System pillars. Prompts for the assessment of Safe Vehicles and Safe Road Users were added to those of Safe Roads and Safe Speeds. In addition the 'fifth pillar' of post-crash care was also added. This reflected the UN Decade of Action pillar on this topic (WHO, 2011) and also older appreciation of this issue, including that from the Haddon Matrix (Haddon 1968; 1980) which considered issues following a crash to be of importance in understanding and addressing crash risk.

The South Australian 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. Key crash types that result in the majority of death and serious injury were included in this framework.

One other key finding from the literature review was the notion that there are different categories of infrastructure treatments, including those that are likely to largely eliminate death and serious injury (termed Primary, Safe System or Transformational treatments) while others made smaller steps to improving safety outcomes (termed supporting treatments) (Turner et al. 2009; Tate and Brodie 2014). Often the Primary treatments are overlooked (typically due to higher cost) in favour of lesser treatments, but these should actually be considered as first choice options even though there application will not always be possible.

The findings from the literature review were presented to a national workshop involving over 30 professionals from industry, government, the research community and advocacy leaders interested in influencing the national agenda relating to road safety infrastructure. The need for an assessment framework was discussed. Some of the key outcomes from the workshop were that the framework:

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

In addition, it was considered that the '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

The assessment framework

Based on the literature review and input from the workshop a draft framework was developed. The proposed framework followed an approach fairly typical in the assessment of risk, including that used in road safety (e.g. Austroads 2006), analysing exposure, likelihood and severity for key crash types. This is important, as the approach needs to be intuitive and reasonably familiar to those who use it. The main stages of the framework are as follows:

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

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
- all of the above.

Another objective which needs to be recognised before commencement is the scale of the assessment. For example, the framework could be used to assess an individual location, a route, a major highway upgrade/bypass, an innovative infrastructure design solution, or a generic road type or design (e.g. a staggered T-intersection design). In some cases the assessment may need to be broken down into smaller sections or elements which are more manageable.

It should also be noted that these two objectives may change once an assessment has 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 conducted 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, such information could be added using the Australian National Risk Assessment Model (ANRAM; Austroads, 2014).

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.

Once the objectives of the assessment are identified, the context of the project must be defined. Table 1 provides a template with prompts to help achieve this.

Table 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.

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 2. The content of each cell has been sourced from recent literature reviews and statistical modelling of severe crash risk factors (safety performance functions, crash rate analysis) conducted for Austroads and individual jurisdictions (e.g. Austroads 2010; Austroads 2012; Austroads 2014; Austroads 2015a)

Table 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. Yet, preventing crash, or minimising its probability, have been recognized early by the Safe System thinkers (e.g. Wegman and Aarts, 2006). The frameworks highlights how 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 road 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 road maintenance (change in practice, implications of timing).
- Crash severity: groups of infrastructure or operational 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 to those involved 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 (see e.g. Austroads 2015b). 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, 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.

It is suggested that each of the cells relating to the key crash types in Table 2 be given a rating out of four for each of the key risk types (exposure, likelihood and severity). A zero indicates the safest or 'Safe System' state, while a four indicates the highest risk. Guidance is provided in Austroads (2016) on this rating process. Scores are then multiplied for each column, with a possible total of 64 for each crash type. Scoring in this manner identifies how close to Safe System outcomes the design is (i.e. how close to zero), and where the remaining crash risk lies. The score can also be used as a baseline to compare alternative project/treatment options.

The treatment hierarchy

An important part of this framework was provision of advice on treatment selection, and to ensure the best solutions are considered to help move towards Safe System objectives. Information on infrastructure treatment options and effectiveness is widespread (e.g. Austroads 2012; Elvik et al; 2009). Turner et al. (2009) present an early framework for Safe System infrastructure solutions based on major crash types. As already discussed, treatments that have the potential to achieve the Safe System objectives of near-zero deaths and serious injuries (termed Primary Treatments) are most desirable. 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 on effective solutions for each crash type is provided in order of priority based on Safe System effectiveness, i.e. consideration of solutions which eliminate occurrence of fatal and serious injuries first.

In some situations, such options will not be feasible due to project constraints (e.g. budget, conflicting road user needs, environment etc.). If so, the next safest solution needs to be identified. If all possible Safe System solutions are ruled out, the next highest priority are the supporting solutions 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.

Example treatment options are provided in full in Austroads (2016), while those options applicable to run-off-road crashes are provided in Table 3. These options were produced based on a number of recent Austroads projects (e.g. Austroads 2010; Austroads 2012; Austroads 2015a), as well as several Safe System infrastructure national round-table workshops (the first documented in Turner et al. 2009; second as part of the 2013 Australasian Road Safety Research, Policing and Education conference, and the last as part of the Framework development project). The information presented is indicative only, and careful thought should be given to the selection of treatments. Certain specific types of infrastructure, and the way that they are applied might mean that the location within the hierarchy might vary. Also future research may revise effectiveness of some treatments.

Table 3. 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

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.

Once solutions are identified, the assessment process can be repeated to determine the likely benefits when compared to the original design. Different options can also be compared to help identify the most appropriate solution.

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 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 all cases, but it is important that a systematic approach be taken to the selection of treatments and that this process be documented. 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 at this time. Trials using objective assessment (e.g. outputs from ANRAM) should be undertaken and clear guidance produced to demonstrate this process.

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.

Safe System implementation requires a systematic approach to measuring every project's level of alignment with the vision's objectives. The Safe System Assessment Framework provides this facility for the practitioners in a form which is easy to apply and scalable with the project size. Application of the framework will be greatly assisted by training of road agency and consulting practitioners.

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