

# Contributed articles

## Recent research on safe roads and infrastructure

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### Introduction

Safe roads and infrastructure are key factors in the likelihood and severity outcome of road crashes. Although the vast majority of crashes are as a result of some form of human error, or of human error in combination with the road and/or the vehicle, we also know that the greatest determinant of crash severity will be the infrastructure that is provided. As an example, Stigson et al. [1] reviewed fatal crashes based on in-depth crash investigation, with crashes categorised based on factors that contributed to the crash outcome (as opposed to crash causation). Their study found that there were strong interactions between the different pillars of the ‘system’ (road user, road and vehicle), but also that the road and roadside were the most strongly linked to fatal crash outcomes. Further evidence for the importance of infrastructure comes from evaluations of safety treatment effectiveness. Individual infrastructure treatments, or treatments used in combination can significantly reduce death and serious injury. The most recent BITRE evaluation of the federal blackspot funding program showed that benefits from targeted infrastructure treatments outweighed the costs by a factor of 8 to 1 [2]. As an example, well-designed roundabouts are able to virtually eliminate deaths at intersections (by up to 80% [2]). When joined with benefits from other Safe System pillars (including vehicle improvements, speed management and improvement in road user behaviour) the combined benefits will be greatest.

Based on Austroads figures [3], roads are the largest asset owned by the community in Australia and New Zealand. They suggest the value of the road asset is around \$200 billion, and that every year, \$18 billion is spent on maintenance and construction. Some of this investment will have direct safety benefits. There are also significant investments made in infrastructure safety programs, including the federally-funded blackspot program. It is important to fine-tune this investment to ensure that societal benefits from infrastructure improvements are maximised.

Despite the annual investment in infrastructure, and the potential for safety improvements through this mechanism, the level of research conducted on this issue is extremely limited. ARRB Group (ARRB; formerly the Australian Road Research Board) has been working on the topic of safe roads and infrastructure for a number of decades.

The issue is of high interest to ARRB’s members who include Australian and New Zealand federal, state and local government bodies responsible for managing the nation’s road networks. This paper outlines recent research relating to safe roads and infrastructure; particularly work undertaken at the national level for Austroads, or for individual state road agencies. Much of this work is ‘applied’ in nature, aimed at providing direct guidance and tools to assist road agencies and practitioners in implementing findings to help improve the management of road infrastructure.

### Themes for research

ARRB research on road infrastructure has been varied, extending beyond safety. Core areas of research include issues relating to the design, construction, management, maintenance, operation and use of the road network. The following sections concentrate on research relating to safe roads and infrastructure. Research on this topic generally falls into a number of themes, or research programs. Several of these are described below, including those that relate to:

- Safe System infrastructure
- Crash risk assessment
- Effectiveness of road safety treatments (Crash Modification Factors)
- Speed research, and the speed/infrastructure relationship
- Addressing key crash types and user groups by improving infrastructure
- Data and benchmarking
- Development of road safety tools and dissemination.

### Safe System infrastructure

The Safe System approach was adopted a number of years ago in Australia. Although the concepts are now well-

understood, the direct actions required by road agencies • to implement improvements to infrastructure are less well developed. Intensive research on the implementation of Safe System infrastructure commenced in 2009, with a workshop involving key road agency stakeholders [4]. This event was an important forum for discussing the approaches being taken by road agencies, and emerging gaps in knowledge. One of the key outcomes from this event was that a distinction was drawn between different types of road infrastructure treatments. Some treatments provide substantial safety improvements, moving us close to the Safe System objective of eliminating death and serious injury. These were termed ‘primary’ treatments and include treatments such as grade separation, roundabouts, and raised platforms at intersections; roadside protection through the use of wire rope barrier systems; separation of vehicles to prevent head-on crashes; and separation of vulnerable road users (e.g. dedicated cycle lanes; adequate footpaths for pedestrians). Other treatments provide safety benefits, but when used in isolation will leave a substantial residual in terms of deaths and serious injury. These ‘supporting’ treatments include signs, line-marking, and also traffic signals.

Other key findings included that:

- there is a greater need to share good practice in Safe System implementation
- there is a need to provide ‘redundancy’ or ‘backup’ systems when installing safety treatments in case there are failures in one or more components
- development of a clear functional road hierarchy for speed management purposes is crucial for the implementation of Safe System infrastructure
- risk assessment is still an important tool in the implementation of Safe System infrastructure and;
- the timeframe for implementation of Safe System infrastructure is an important consideration.

The findings from this workshop led to a program of research conducted on Safe System infrastructure, funded mostly by Austroads. This included research and guidance on:

- Local government and the Safe System [5]
- Speed limit setting within the Safe System context [6, 7, 8]
- Infrastructure/speed limit relationship in relation to road safety outcomes [9]
- Safe System and design for roadsides [10]
- Assessments to improve safety performance of key types of infrastructure (including signalised intersections, roundabouts and barrier systems [11]
- Asset management and the Safe System approach [12]

Safe System as it applies to infrastructure planning [13]

- Implementing Safe System infrastructure in low and middle income countries [14]
- Feasibility and cost of moving towards a truly Safe System infrastructure [15, 16]

This research continues, with current projects assessing the level of Safe System alignment of intersection options as well as potential improvements; development of a Safe System infrastructure assessment framework; and further work on safety barriers. The work on Safe System infrastructure is assessing the fatal and serious crashes that remain, even when more effective infrastructure improvements are provided. Using the example of roundabouts, although a substantial proportion of fatal and serious injury crashes are eliminated, a number may still remain. Analysis of data on the remaining high severity crashes indicate that many of those who may continue to be killed or injured are either bicyclists or motorcyclists, and so current research is assessing improvements that can be made to address this residual severe injury problem. Similar research is being undertaken on other key types of road infrastructure.

The Safe System assessment framework is intended to assess infrastructure projects from the perspective of each Safe System pillar to determine likely safety outcomes. It also provides practitioner-level advice on appropriate improvements to minimise death and serious injury. A tool is being developed to allow simple assessments by practitioners; whether working with state or local government.

ARRB is working with CASR in South Australia to develop a ‘Safe System Book’ that provides direct and clear guidance to those designing and operating the road network. Austroads is revising national guidelines, including guidance on road safety, traffic management, road design, road tunnels and asset management to embed Safe System principles and practice.

Most recently, a symposium was attended by 35 leading road agency and academic experts to provide inputs into the Safe System Assessment Framework and practitioner guidance on Safe System infrastructure. The workshop explored current progress in implementing the Safe System approach as it relates to road infrastructure, gaps in knowledge and planned future activity. Further workshops are being held throughout 2015 to progress knowledge. The outputs from these events will be published in the near future, but key findings include better advice on treatment selection and design that will minimise death and serious injury for different road environments and users, as well as advice on a phased, cost-effective approach for the implementation of Safe System infrastructure.

## Crash risk assessment

A major area of research has also been development of new processes to identify, assess and treat high risk locations on the road network. The traditional approach in road safety has been to identify such locations based on crash history. Addressing such ‘blackspots’ has proven to be of high benefit, and continues to produce high returns on investments (as identified above, the most recent federal evaluation showed benefits of 8:1 when compared to costs; BITRE, [2]). However, it is known that many of the sites easiest to treat have already been treated. The majority of severe crashes are now estimated to occur outside what would traditionally be classified as ‘blackspots’. Conversely, a large proportion of more serious crashes occur at locations where there is no existing crash history [17]. As an example, in New Zealand 56% of fatal and serious crashes occur at locations on roads with no other injury crashes recorded in the previous five years [18]. In response to this issue, new tools have been developed to identify and treat risk locations, based on road design and traffic elements. Research has been conducted to determine the impact different design elements have on safety outcomes. For example, a straight road is safer than a road with a severe curve. International and local research has been reviewed to determine relationships between design elements and safety outcomes [19]. This information has been used to develop risk models that are able to predict the chances of high severity crashes occurring without the need for information on crash history. The data and approach identified through this research is now used nationally through the successful AusRAP program (<http://www.aaa.asn.au/aaa-agenda/road-safety/>) and has also formed the basis of the international approach to risk assessment (iRAP, see [www.irap.org](http://www.irap.org)).



In areas where crashes are more dispersed (such as lower volume rural roads), a greater weighting is applied to the design elements as a predictor of serious injury

Most recently, the information on crash risk through assessment of road design has been combined with information on crash locations. This combined approach provides a powerful tool in the assessment of risk locations, and in the identification of effective treatments. To this end, the Australian National Risk Assessment Model (ANRAM)

was developed and is now being used by most Australian jurisdictions, and is included in the National Road Safety Strategy and associated Action Plan as a key mechanism for prioritising investments in infrastructure. The model places a greater emphasis on crash history where information is more reliable (e.g. in higher traffic volume areas where crash trends are a more reliable indicator of future crash occurrence), while in areas where crashes are more dispersed (such as lower volume rural roads), a greater weighting is applied to the design elements as a predictor of serious injury. The approach provides greater reliability in predicting future high severity crash locations, as well as information on the solutions to address these crashes. Further information can be found in Jurewicz and Steinmetz [20], or on the ANRAM knowledge hub (<http://www.arrb.com.au/Safe-Systems/Assessing-and-managing-road-crash-risk/ANRAM-Hub.aspx>). An example of the successful application of this tool by a state road agency can be found in a study by Eveleigh et al. [21].

## Effectiveness of road safety treatments (Crash Modification Factors)

Accurate knowledge on the effectiveness of road safety treatments is required to make informed decisions on road safety funding. It is only with sound information that the most appropriate safety treatment can be selected. Poor information can lead to treatments that will have little or no effect, thereby wasting valuable limited resources. One key element of this decision making process is the Crash Modification Factor (or CMF; sometimes termed a crash reduction factor, or CRF) for different remedial treatments. Research has involved the assessment of different evaluation studies to help identify appropriate CMFs for Australian conditions.



Tactile strips on line markings can provide audio warning to motorists

The most recent summary of this information can be found in Turner et al. [22]. This report includes information on the likely safety benefit of different commonly used treatments, as well as the level of confidence in this figure. An extract of this information can be seen in Figure 1.

Treatment	Environment type	Crash reduction factor	Crash modification factor	Confidence	Year most recently assessed	Reference location
<b>Intersection treatments</b>						
Signal visibility	Replace a pedestal mount with mast arm mount signal	35%	0.85	Low	2011/12	Appendix C.7
	Increase lens size to twelve inches	5%	0.95	Low	2011/12	Appendix C.7
	Provide additional signal head	20%	0.8	Medium	2011/12	Appendix C.7
Roundabouts	Install roundabout – rural	70%	0.3	High	2008/09	Austrroads 2010a
	Install roundabout – urban	55%	0.45	Medium		Austrroads 2010a
	Install roundabout – all environments	70% (all) 60% (pedestrians)	0.3 (all) 0.4 (pedestrians)	High Low		Austrroads 2010a
					2010/11	Appendix C.18.7

Source: [22]

Figure 1. Effectiveness of treatments - extract

The values in this report have been widely adopted by Australian road agencies as well as international bodies (including iRAP). Given one of ARRB's objectives is to provide relevant road safety tools to practitioners on infrastructure safety, the information on CMFs has also been included in a freely accessible website, the Road Safety Engineering Toolkit ([engtoolkit.com.au](http://engtoolkit.com.au); also see Jurewicz [23]). This provides advice on suitable measures to address road safety problems, including information on their benefits. An international version of this tool, intended for use by those in Low and Middle Income Countries has also been developed (the iRAP Road Safety Toolkit, available at <http://toolkit.irap.org/>; also see [24]).

This research has helped identify a number of key treatments which are only used to a limited extent in Australia. Greater use of such treatments has the potential to improve safety significantly. This program of work has also helped identify the gaps in understanding that currently exist on this issue. Individual studies have been undertaken to help fill some of these gaps. This has included recent evaluations on gateway treatments [25]; vehicle activated signs [26, 27]; speed limit change [28]; and centre-of-road wire rope barrier [29].

Recognising the significant gaps in knowledge regarding some of the most widely used treatments, as well as those showing promise, ARRB in association with the US Federal Highway Administration (FHWA) initiated an international collaboration through OECD/ITF to facilitate the sharing of information on this topic. This work identified a methodology for effective sharing of information [30] (also see Cairney, Turner and Steinmetz [31] for an Australian-centred examination of this issue). There are still significant areas of work required, particularly around the benefits in terms of fatal and serious injury reduction from road engineering treatments. This issue is discussed in further detail as follows.



Centre-of-road wire rope barrier

## Speed/infrastructure relationship

Much of the research on road infrastructure includes consideration of other pillars of the Safe System approach. Infrastructure changes have the potential to impact on driver behaviour and indeed reduction in the likelihood of road user error through this mechanism is often the intention. Similarly, there is a strong link between speed management and road infrastructure. Ideally, all roads would form part of a clearly defined hierarchy that relate to the appropriate speed limit for the function of the road. The place within the hierarchy would be supported, and clearly communicated to road users through the design and features of that road.

Effective speed management, which includes speed limits and supporting infrastructure, has great potential for improving road safety outcomes. Speed is an element in all crashes; influencing both the likelihood and severity. In

support of more effective speed management methods a number of projects have been undertaken. This has included the development of a process to integrate speed limit setting with infrastructure provision to help achieve Safe System outcomes [9]. The outcome of this work includes a process that recommends the assessment of the current road function and speed environment, a review of current road features and completion of a gap analysis. Model national guidance has been developed on implementing reduced speed limits on roads with high risk of severe crashes which cannot be reasonably treated with cost-effective engineering treatments [32]. Information has also been provided on some of the trade-offs between speed and other transport policy outcomes [33].

Along with existing guides on speed management for local roads from Austroads [34, 35], recent research and advice has centred on the approaches that may be taken to addressing speed at key points on rural roads [36]. A compendium has been produced, highlighting the speed issue on rural roads. Around 30 treatments have been provided that address ‘unsafe speed’ at locations such as curves, intersections, approaches to townships and along routes. Some highly effective treatments were identified and in some cases these are used rarely in Australia. Key treatments included:

- Consistent speed warning and design for curves (also see [37])
- Gateway treatments on the approach to townships (also see [25])
- Roundabouts at intersections
- Vehicle activated signs for curves and intersections (also see [26]) and;
- Speed limits combined with narrow centreline treatments for routes.

Current research is examining effective speed moderating treatments that can be applied to the urban arterial network [38]. This road type has now been identified as the leading location of death and serious injury in Australia [39]. Specific treatments include:

- greater use of roundabouts (including signalised roundabouts) at intersections
- raised road surface treatments at intersections (platforms; raised stop lines)
- raised midblock treatments
- raised treatments for pedestrians (i.e. Wombat crossings) and;
- ‘road diets’ on high volume routes (i.e. converting four lane roads to two lane, with a central turning lane).



**Current research is examining effective speed moderating treatments that can be applied to the urban arterial network**

Evaluations are currently being undertaken on several of these promising treatments to help improve knowledge on effectiveness.

### Addressing key crash types and user groups

Another area of research has been the production of direct advice on the extent of key crash types, as well as the solutions that may be applied to address these crash types. This research has generally been based on key crash types that contribute most to fatal and serious crash outcomes. Although much of the guidance is on infrastructure solutions, other non-infrastructure options are also typically addressed to some extent. Examples include:

- Run-off-road crashes and roadside safety [40]
- Head-on crashes [41, 42]
- Intersection crashes [43]
- Rear end crashes [44]
- Fatigue-related crashes [45]
- Motorcycle crashes (in progress) and;
- Cyclist crashes at roundabouts (in progress).

## Crash data and benchmarking

Integral to this research is the need for good quality data. In Australia, each jurisdiction collects its own crash data and historically only the fatal data has been recorded at Commonwealth level. This has presented a barrier to the comprehensive assessment of crash data. To the best of our knowledge, the first published study on all fatal and serious crashes from Australia was only released this year [39]. This study indicated that when analysing just these high severity crash outcomes, the key crash types for Australia involved vehicles ‘off-path’ (35% of fatal and serious casualties, involving road users running off the road); head-on (17%); adjacent approaches (i.e. intersection; 14%) and same direction (i.e. rear-end; 14%). The results also indicated that urban arterial roads were a key location for fatal and serious crashes, a markedly different result than when an analysis on just fatal crashes is conducted (note that the national strategy calls for reduction in fatal and serious casualties).

One advantage of obtaining this data from each Australian jurisdiction is the ability to benchmark performance between areas, regions or jurisdictions. The advantage of the approach is that it allows identification of areas and issues that might produce quick gains in safety improvements. For instance, if one area has high pedestrian risk when compared to another similar area, this might help identify a need for further investigation, and also ideas on effective solutions. This approach has been widely applied in Europe for a number of years. For example, the European Transport Safety Council regularly publishes a road safety Performance Index (or ‘PIN’, see <http://etsc.eu/projects/pin/>). However, the approach has not been widely applied in Australia. A current project with Austroads takes this approach, but also provides the basis for a comparison with key leading overseas jurisdictions. Measures of risk based on amount of travel undertaken gives a direct comparison for infrastructure safety performance. This involves a complex process of joining crash, traffic volume and asset data together (see Jurewicz and Bennett [46] for a description of an approach previously used). It should be feasible to compare how different road types in Australia compare to the leading countries (e.g. rural freeways in Australia compared with the Netherlands); or how the design of individual infrastructure elements might compare (e.g. rural roundabout in Australia compared with roundabouts in Sweden). Again, this approach is expected to identify areas where quick gains might be made, particularly through improvements in design of road infrastructure.

The data assembled through this work has had many additional uses, including as a platform for research for many of the studies identified above. This work has also highlighted the difficulties in collecting detailed crash data at national level, as well as differences in the way that data is collected in each jurisdiction. Unfortunately, funding for the collection of this detailed data is not certain, and so in-depth national analysis may not be possible in to the future.

Non-crash data is also of high importance for the effective management of road safety [47]. The link between intermediate measures and final outcomes (typically the crash data) is critical to help determine the effect of safety investments. From an infrastructure perspective, the non-crash data includes information on road and roadside design and management. This information has typically been collected in the past by asset managers, but in recent years this has been put to good use for the effective management of safe infrastructure. This approach has been used by AusRAP, iRAP and ANRAM to identify risk locations, and to develop business plans for future investments in road infrastructure. The data is also increasingly recognised for its ability to help monitor performance against key targets. The use of probe data (gathered from in-vehicle GPS, including mobile phones) is also proving useful as an intermediate measure, particularly in measuring speeds at points on the road, or across the road network.

## Development of tools and dissemination

A key objective for ARRB and its member road agencies is to ‘package’ new and existing research and processes to help achieve better safety outcomes. Without dissemination of research findings and outcomes, the cost and effort of research is largely wasted. This has led to the development of tools for use by practitioners that package up research findings and good practice. These tools include:

- ANRAM (highlighted above) and similar crash risk assessment tools;
- Road Safety Engineering Toolkit (and iRAP Road Safety Toolkit; both highlighted above) that provide direct advice on safety problems and appropriate treatments;
- The Road Safety Audit Toolkit (<http://www.rsatoolkit.com.au/>) – designed to help step practitioners through the road safety audit process, and documentation of this;
- XLIMITS – a set of tools designed to assist in the appropriate assessment of roads for the purpose of speed limit setting (used in Australia, New Zealand and the United States) and;
- Guides, such as those produced by Austroads.

Much of the work undertaken is aimed at updating national guidelines, including improvement of processes and delivery. This includes recent research on crash costing (e.g. advice on willingness to pay [48, 49]; and treatment life [50]); and a study on ‘failed’ blackspots, or treated locations that do not meet their potential (in progress).

Guidance production and training are key dissemination mechanisms that are used to translate research outcomes into practice. Guidance documents primarily include the Austroads guides, including those on road safety (currently nine parts), traffic management, road design and road tunnels. All of these are available from the Austroads website ([www.austroads.com.au](http://www.austroads.com.au)). However, this guidance

development also includes significant input to global guides, including those on speed management, drinking and driving, data systems, pedestrian safety, and motorcycle safety (see <http://www.who.int/roadsafety/publications/en/>).

Most recently, ARRB has been leading a team of international experts in the development of the World Road Association's (PIARC) Road Safety Manual. This document collects good practice from many countries around the world on effective management and delivery of Safe System infrastructure. It is expected to be the new global guide on safe roads and infrastructure, and will provide advice that will be directly relevant to those working on this issue in Australia, as well as elsewhere in the world.

## Gaps in knowledge

Although an extensive amount of research has been undertaken over recent years, there is still a large amount to be done. Given the scale of the problem, and annual expenditure on roads, the price of poor knowledge on safety outcomes is significant. There are many gaps in knowledge that mean that cost-effective road safety decisions can be limited. The gaps relating to treatment effectiveness (CMFs) have already been mentioned. Without an improvement in this knowledge there will be poor decisions regarding the selection of effective road safety infrastructure countermeasures. This requires a concerted international effort to identify and fill gaps in knowledge. An international collaboration has commenced, but further steps are required to continue this work. A new phase of collaboration is planned (through the Forum of European National Highway Research Laboratories, which also includes ARRB and FHWA in the US). However, appropriate funding is required to ensure key objectives are met from this work, particularly those relating to specific Australian needs.

Although many effective infrastructure solutions are well known and used, there are some areas where knowledge is limited, or solutions do not yet exist to help meet Safe System objectives. One example includes the use of effective infrastructure treatments to help improve safety for vulnerable road users, including cyclists, motorcyclists and pedestrians. The CMF research includes very little information on specific benefits of existing treatments for these vulnerable road users. It is also likely that existing treatments will need to be adapted, or new treatments devised to better address these road users, who are significant contributors to road trauma. Research has commenced, but greater efforts involving the international research community are required.

As further examples, current signalised intersection design is inherently unsafe and there is a need for direct guidance on issues such as roadside design, and rural intersections. Ongoing innovation in design will be required to address future needs, but this raises a number of issues, including a reluctance to install solutions that are not already part of design guidelines. Incentives and encouragement are required to help innovation, and find solutions that might effectively eliminate severe crash outcomes.

Similarly, there is a lack of information on the safety implications of different road design elements. Currently our knowledge base on several of these elements is severely limited, meaning that road construction decisions are not taking full account of safety. In some instances this might lead to significant increases in construction costs due to incorrect assumptions. One example, highlighted by Marsh [51] indicated that considerable savings to construction costs were made in Western Australia based on more accurate safety information relating to the benefits of roadside barriers. This led to reduced earthworks, and therefore substantially reduced costs, but with additional safety benefits.

There still appears to be a large amount of 'silo thinking' in road safety, and this has perhaps increased rather than decreased under the Safe System approach. Although various attempts have been made to capture and combine safety benefits across pillars, there is much to be done on this issue. As one example, the interaction between roads and emerging vehicle technologies need to be assessed. Several new technologies rely on road infrastructure to work most effectively. This includes lane departure systems, which typically monitor the vehicle's position in relation to a painted centre or median line. Further work is required to ensure potential safety benefits are maximised (as well as costs reduced) from such opportunities.

Lastly, there is currently a shrinking pool of funding to address the issue of road safety infrastructure research. Given the expenditure on construction, maintenance and operation of roads, it is likely that any further reduction in this spending will have a significantly adverse effect on efficient delivery of safe roads and infrastructure. Conversely, increased spending will most likely produce significant benefits for road agencies and the broader community.

## Concluding comments

The last decade has seen some substantial changes in the way that safe road infrastructure is delivered. The Safe System approach has meant new ways of analysing and addressing safety problems. The approaches used to assess risk and select locations for treatment are evolving. New 'hybrid' methods that combine crash history with knowledge of design features and their likely safety outcomes are being used to better predict future high severity crash locations. The solutions are being applied in more systemic ways, aided by a new generation of tools such as ANRAM.

Although there is improved information on effective infrastructure treatments, the knowledge base is still deficient. There are gaps in knowledge on ways to address some key crash problems. Some new or existing treatments that show great promise should be used more extensively. There is also a need to refine existing treatments, and develop new infrastructure solutions that will eliminate death and serious injury for different road environments and users.

Greater synergies are being developed between safety and other key aspects of transport policy and management, including asset management, and travel demand/transport planning. It will be important to expand these linkages to better capture safety benefits within these areas, especially in light of limited budgets specifically for safety.

Given the substantial investment in roads, a small improvement in delivery to direct efforts towards more effective safety outcomes is likely to produce significant benefits. Better knowledge and more effective use of existing knowledge are required to meet this objective. Road agencies, particularly through Austroads, have provided funding for safe road and infrastructure research over recent years. However, with road agencies needing to work smarter with reduced budgets and some significant knowledge gaps in delivering safe infrastructure, there is a need to renew efforts to find better ways to deliver safer roads.

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