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Achieving Safe System Speeds on Urban Arterial Roads: Compendium of Good Practice

Achieving Safe System Speeds on Urban Arterial Roads: Compendium of Good Practice

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Abstract

This compendium presents information on speed as a contributor to urban arterial road crashes. It provides information on treatments that can be used to address speed at intersections and midblock locations.

The intention in using these treatments is to move closer to Safe System objectives by helping to avoid death and serious injury when crashes do occur. The main focus is on road engineering based treatments but information is also provided on other approaches that may be used (e.g. enforcement and in vehicle devices).

Keywords

Speed, urban arterial, treatments, countermeasures, Safe System, intersections, midblock.

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- Department of State Growth Tasmania
- Department of Transport Northern Territory
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- Australian Government Department of Infrastructure and Regional
- Australian Local Government Association
- New Zealand Transport Agency.

Summary

A significant proportion of road crashes occur on urban arterial roads including those that lead to fatalities and serious injuries. Vulnerable road users are particularly at risk on these roads, while intersection crashes are typically high risk locations. Urban arterial roads cover a variety of environments including high speed roads (80 km/h), strip shopping centres and school zones with lower speed limits (e.g. 40 km/h) and have a mix of road users and functions. The key aim of this project was to identify effective measures for speed and crash management on urban arterial roads while taking into account the different road environments, functions and the presence of vulnerable road users.

This *Compendium of Good Practice* provides information on speed and crash effectiveness, indicative costs, applicability, and current uses for 27 engineering-based treatments on urban arterial roads at intersections and midblocks. An inclusive definition has been used for urban arterial roads in this study, with information on treatments provided for 'higher traffic volume' roads. While the focus is on engineering (infrastructure) measures, some information on non-engineering-based treatments (e.g. enforcement, in-vehicle systems, road user education, and publicity) is also provided for completeness. Similarly, some information on speed management measures in work and school zones is provided.

The *Compendium* embraces the Safe System approach to road safety, seeking to ensure, wherever practicable, that the measures (either as a stand-alone treatment or in combination) will lower the operating speed at intersections and midblock sections to Safe System speeds. Both the incidence and severity of crashes on urban arterial roads are likely to be reduced as a result.

The underlying principles of the treatments types are set out in Section 5. Each treatment is then discussed in more detail in Appendix A, where every effort has been made to provide robust performance data, including on likely speed and crash reduction. However, the list of measures should not be seen as exhaustive and gaps were found in the information on implementation of such measures and their evaluation. Most of the measures are adaptations of successful local area traffic management (LATM) measures put forward for application on busier and faster-flowing roads. Applying any treatment requires professional judgement and local knowledge. Further, where combinations of treatments are considered, recognising that trade-offs and compromises might be required is also important.

Commonly applied treatments include roundabouts, horizontal deflection on approach and lower speed limits at intersections; and pedestrian refuges, medians and variable speed limit signs at midblocks.

Several emerging treatments were identified as having considerable potential for effective long-term usage, namely signalised roundabouts, turbo roundabouts, and road diets, raised intersections, wombat crossings, and raised platforms at midblocks and dwell-on-red signals.

The effectiveness measures for some of the treatments, based on existing literature, were less reliable and so the information provided in the *Compendium* is supported by evaluations of a number of these treatments (road diets, raised intersections, wombat crossings, raised platforms at midblocks and dwell-on-red signals).

This project strengthens the need for on-going robust evaluation of any measures implemented, and particularly for innovative measures.

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1. Introduction

1.1 Background

Core to the Safe System approach is management of vehicle speeds to ensure that crashes are survivable without serious injury. Currently, there are known treatments for local roads (e.g. local area traffic management (LATM) devices). Speed zoning guidelines also provide adequate guidance on speed limit setting. However, there has been limited information to date on how to manage speeds on urban arterial roads, particularly in situations where there is a mix of road user types (particularly pedestrians and cyclists).

This project sought to identify solutions for managing speeds in such environments. These solutions have been assessed in light of the Safe System approach, and particularly with a view to harm minimisation utilising speed management principles. A significant proportion of road crashes occur on urban arterial roads, including those that lead to fatalities and serious injuries. Vulnerable road users are particularly at risk, while intersection crashes are typically high risk locations.

While reducing the incidence of all severities of crashes is obviously important, this project focused on Safe System countermeasures for managing urban arterial speeds. This relates to those treatments that achieve Safe System speeds (e.g. 30 km/h for pedestrians; 50 km/h at intersections) or make progress in that direction (i.e. incremental improvements in safety). The treatments that produce Safe System speeds are most desirable but the other treatments are also worthwhile, as in some situations the treatments that bring speeds to Safe System levels may not be practical, and an incremental improvement is usually better than none at all.

There are differing definitions of an urban arterial road and as a result, the definition used for this research was set broadly. The working definition generally includes higher volume roads, some of which may be designated as collector roads. The current speed limits for arterial roads are typically 60 km/h and above. In New Zealand, arterial roads are typically 50 km/h. Urban freeways were excluded unless a treatment was found that could be transferred from the urban freeway context to an urban arterial road. Further definition and description of urban arterials is provided in Section 2.

Urban arterial roads are not a homogenous road type, but rather cover a variety of different road environments. They include high speed roads (80 km/h) with limited access through to strip shopping centres with speed limits as low as 30 km/h as illustrated in Figure 1.1. This issue was reinforced during the literature review, international consultation, data analysis and site inspections. Therefore, the types of measures available to address any speed problem on these roads are likely to vary by road type.

1.2 Method

The research program included:

- a literature review and international review of expert opinion
- the development of a strategy for future research to address gaps in knowledge
- data analysis of crashes on urban arterial roads
- site inspections
- consultation with industry through Australian and New Zealand practitioner workshops
- trials of new treatments and development of guidance.

Figure 1.1: Illustrating the range of urban arterial environments

Source: ARRB Group.

The literature review was conducted using the resources of ARRB Group's MG Lay Library, the leading land transport library in Australia. The Australian Transport Index (ATRI) was used in identifying literature, as was TRID, which is a newly integrated database that combines the records from the TRB's TRIS database and the OECD's ITRD database. This information was supplemented with searches using Google Scholar.

The focus of the project has been on engineering-based treatments to achieve reductions in operating speeds on urban arterial roads. Detailed reviews for non-engineering-based treatments were outside the scope of the project. However, for completeness on the topic of speed management, some non-engineering treatments have been briefly covered.

1.3 Purpose of the Project

The project was based on local and international practice and experience, with the inclusion of research, trials and analysis to provide robust information. The results are presented as a compendium of good practice to inform practitioners of the extent of the speed issue on urban arterials and to provide guidance on effective actions that can be taken to reduce the incidence and severity of crashes through speed reduction, particularly road engineering treatments.

1.4 Structure of the Compendium

The *Compendium* is comprised of seven sections, as follows:

- Section 1 (this section) presents the background to the Austroads project and outlines the scope and intent of the report.
- Section 2 presents a definition of urban arterials.
- Section 3 outlines the crash and speed problem on urban arterial roads.
- Section 4 outlines the issue of speed and speed selection on urban arterial roads.
- Section 5 identifies the engineering-based treatments for reducing urban arterial speeds.
- Section 6 discusses basic elements relating to the monitoring and evaluation of treatments.
- Section 7 provides the concluding comments, including the key findings and limitations of the research, as well as identification of areas for future study.

Appendix A provides detailed information on 27 engineering-based treatments covering the following areas:

- Appendix A.1 – Urban arterial intersection
- Appendix A.2 – Urban arterial midblocks.

Each treatment contains a list of key references and sources separate from those in the main body of the text.

Appendix B identifies some non-engineering treatments. Although technically outside the scope of this project, these treatments are briefly covered for completeness and interest. The areas covered are:

- Appendix B.1 – Enforcement and penalties
- Appendix B.2 – In-vehicle treatments
- Appendix B.3 – Education, training and publicity
- Appendix B.4 – Penalties.

2. Defining Urban Arterials

Speed choice depends on a variety of factors, including road use and function. Consequently, to effectively analyse and manage traffic, it is crucial to have a fundamental understanding of road hierarchy and functional road classification (Brindle 1996). It is helpful to classify roads into a functional classification in order to better manage planning, design and operation. When considering the classification of a road, it is essential to take into account not just motor vehicles but all road users, including pedestrians and cyclists.

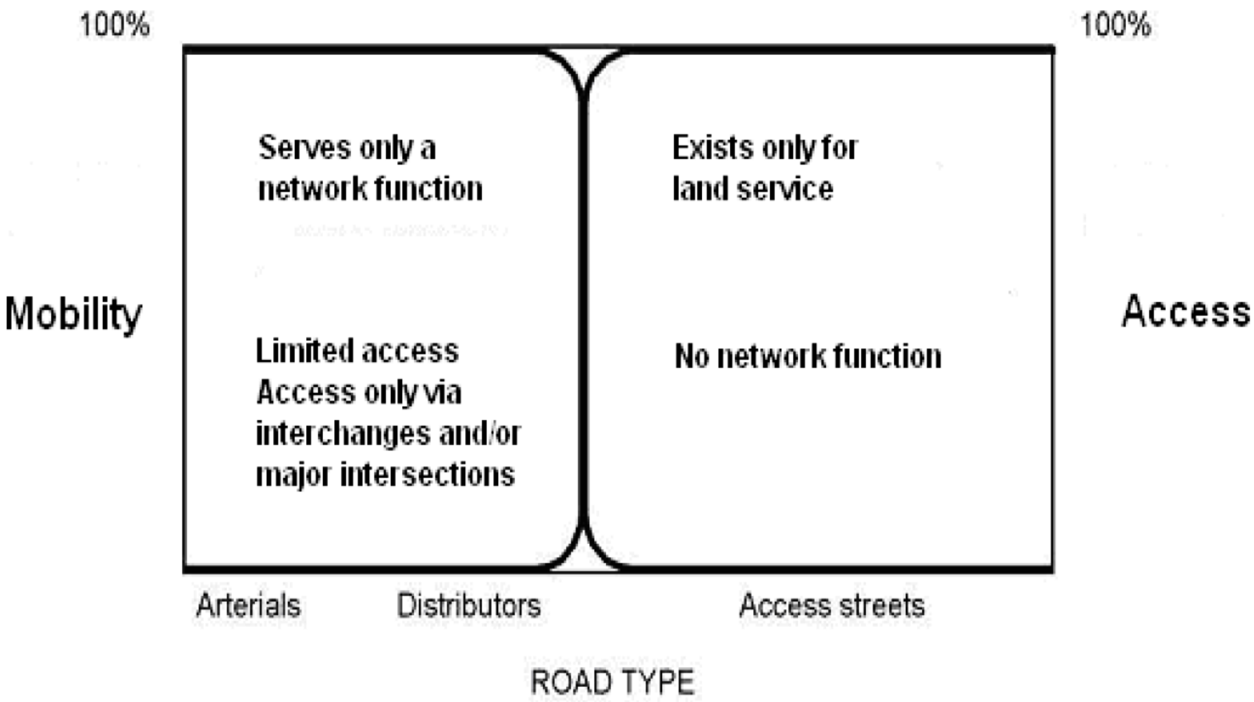
Research into forming a functional road classification or hierarchy has been ongoing and although road agencies have generally adopted classifications that serve a similar purpose, the definitions used across jurisdictions vary significantly.

Two fundamental classification systems have been adopted by road agencies and planners. The 'two-class' or 'separate functions' model, illustrated in Figure 2.1, reflects the two fundamental needs which must be met by the road network:

- mobility that is concerned with the movement of through traffic and focused on the efficient movement of people and freight
- access that relates to the ease with which traffic from land abutting roads can enter or leave the road and the ease with which pedestrians and other active modes access other land use activities along the route.

This model puts an emphasis on separating these two needs wherever possible, and stressing that any distributor road must serve minimal access functions (Brindle 1996).

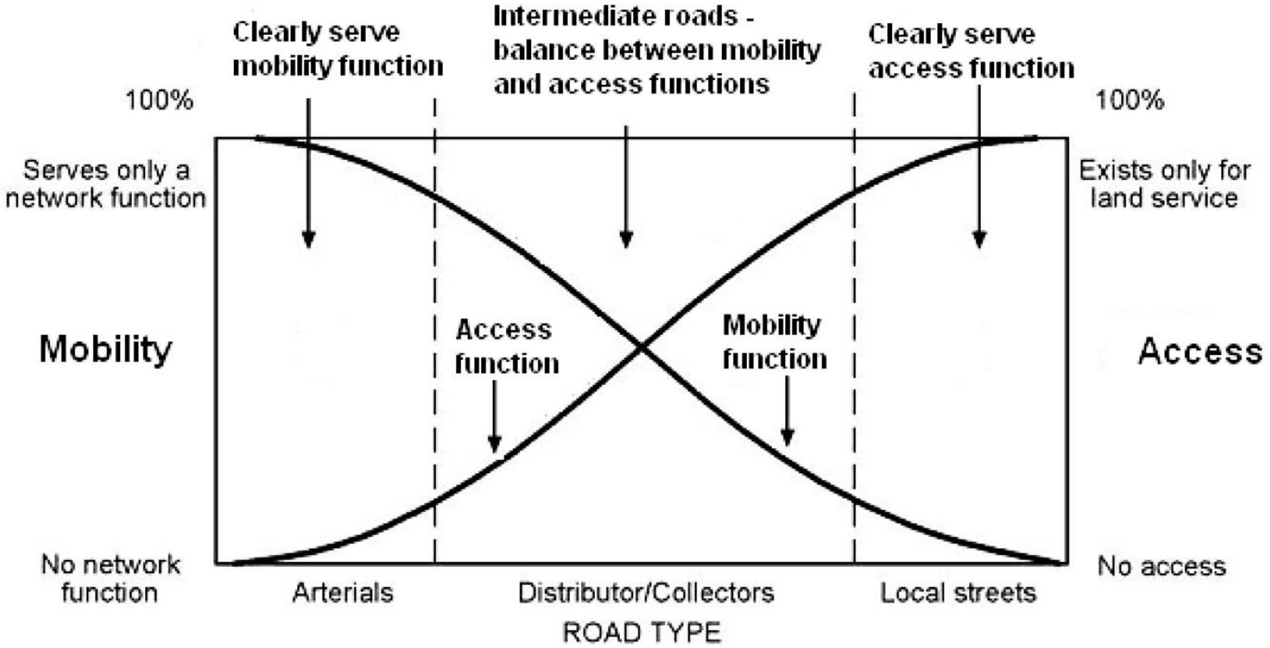
Figure 2.1: Road type and function: two-class model



Source: Brindle (1987) in Austroads (2009).

The reality of the road network dictates that very few roads within the distributor category do not also have a demand for access functions. This gives rise to the balanced functions model in Figure 2.2, where there is no distinct line separating roads with a mobility or access function, but a fluid continuum ranging from high mobility highways and freeways through to high access local streets. In between there is a broad category of intermediate roads, serving a mix of access and mobility functions.

Figure 2.2: Road type and function: the reality



Source: Brindle (1987) in Austroads (2009).

The *Austroads Glossary of Terms* (Austroads 2015a) defines an urban arterial as 'road that provides the main basis for public and private movements of persons and goods in urban areas'. As outlined in Section 1, the scope of this project includes addressing speed on some designated collector roads. In Austroads (2015a), a collector road is defined as 'a non-arterial road that collects and distributes traffic in an area as well as serving abutting property'.

The urban road network can be divided into four functional road types, as defined by Austroads (2009) and detailed in Table 2.1.

Urban arterial roads, in the context of this project and as defined by the project steering committee, include the class of arterial roads and are consistent with elements of the distributor/collector road function, with shading used in the table to identify arterial roads and distributor/collector roads, the main and secondary foci of this project.

Austroads (2009) also outlines the key traffic management principles for each road class, as detailed in Table 2.2. In regard to arterial and distributor/collector roads, there are different guidelines when considering existing and new roads. For new arterial roads, there is a stronger emphasis on minimising access to abutting land, and on incorporating planning and local development into traffic management. The length of new collector roads is to be minimised as far as possible, and where required they should be designed with appropriate treatments to limit speed and other adverse impacts.

Most other countries have similar classifications and definitions for urban road networks.

Table 2.1: Roles of urban roads

Road class	Role
Freeways/motorways	Freeways/motorways are a particular form of arterial road in a hierarchical sense, but are considered separately in Part 4 of the Guide because of their distinctive operating characteristics. Provide for major regional and inter-regional traffic movement in a safe and operationally efficient manner. The prime traffic movement function dominates entirely and full access control ensures there are no competing access issues.
Arterial roads	Provide for major regional and inter-regional traffic movement in a safe and operationally efficient manner. Commercial or industrial access requirements, or local public transport priorities may need to be given significant weight in developing suitable traffic management strategies.
Distributor/collector roads	Streets which do not easily fall into either the arterial or the local road category. Distribute traffic and bus services within the main residential, commercial and industrial built-up areas and link traffic on local roads to the arterial road network. May be streets which have been designed as local streets, but which have additional traffic functions, usually serving major traffic generators or providing for some non-local traffic movements. Problems often arise with intermediate streets, as their design usually promotes the traffic movement function, while the residents and sometimes the local council, consider the street to be a local street with emphasis on the need for low traffic speed and restricted width. Alternatively, in newer growth areas they may sometimes be under-designed in response to a desired emphasis on local road functions, resulting in operational and safety problems for the higher traffic volume that must use them.
Local roads and streets	May serve several functions to a greater or lesser degree. Some of the functions are at least partially incompatible. Typical functions include: • providing vehicular access to abutting property • providing vehicular access to other properties within a local area • providing access for emergency and service vehicles • providing a network for the movement of pedestrians and cyclists • providing a means to enable social interaction within a neighbourhood, e.g. serving as a play area or community open space • contributing visually to the 'living' environment. The extent of each of these functions will vary within a local street network. For example, a street which provides access to several other streets, will have a more prominent vehicle movement role than a small cul-de-sac.

Note: Table shading indicates the relevant roads under consideration in this project.

Source: Austroads (2009).

Table 2.2: Traffic management principles for different urban road classes

Road class	Existing/new	Traffic management guidelines
Freeways/motorways	Existing and new	Freeways and motorways do not have direct access to abutting land. There is thus effectively no access function and traffic management is directed entirely at the traffic movement function and associated aspects of capacity, congestion and speed.
Arterial roads	Existing	Aim to obtain a balance between providing for traffic and providing for activities which occur, or are desired to occur, beside and across the road. The balance will generally favour traffic movement rather than the abutting access function with a focus on capacity and congestion management. Obtaining this balance will involve negotiations with affected parties including councils.
	New	Planning and design of new arterial roads (other than freeways and motorways) need not necessarily seek to entirely eliminate access to abutting land. However, it is desirable to have substantial control of access for these roads. Opportunity to plan for the desired balance between traffic and other activities beside and across the road. The planning of that 'balance' should consider: • type of land use allowed to locate beside the road • interactions between land uses on either side of the road • degree of access control for the arterial road, recognising that design and traffic management objectives on arterial roads should be biased towards the needs of through traffic. Coordinate the planning and design of new arterial roads with the land use development and amending of town planning schemes. Encourage roadside developments and access arrangements that are compatible with arterial road traffic conditions.
Distributor/collector roads	Existing	Traffic management principles are less well-defined than for arterial roads and local streets. As a consequence actions which result in the traffic function, or roadside factors dominating the road environment will not normally be able to be implemented. Traffic management will normally be aimed at managing relatively high levels of conflict between: • traffic movement and activities generated by abutting land use • the desire of residents for local street functions to dominate, with severe restrictions on traffic speed and the width allocated to traffic movement. The extent of these conflicting demands may vary considerably throughout the day and a balance needs to be made to achieve traffic operations acceptable to the needs of both motorists and abutting residents.
	New	In new street and road networks, the length of intermediate road classed as distributor/collector should be minimised as far as possible. Where these streets are included, they should have complementary abutting land uses which generate a low degree of non-motorised traffic demands or incorporate a degree of access control, or include appropriate treatments to reduce traffic speed and other adverse impacts.
Local roads and streets	Existing and new	Convey to motorists the impression that they are operating in a space or area which has not been designed solely for motor traffic. In many instances with residential streets, this desirably requires the road reservation to be constructed in such a way as to eliminate clear, visual impressions of separate vehicle and pedestrian space. Detailed guidance can be found in Part 8: Local Area Traffic Management.

Note: Table shading indicates the relevant roads under consideration.

Source: Austroads (2009).

2.1 Network Operating Plans and Level of Service

A complimentary approach involves determining the level of service (LOS) framework for a network operation plan (NOP). An NOP aims to direct the operation and developments of the road network to prioritise different competing transport modes and the surrounding land use. The NOP contains short-term works aimed at facilitating daily network operations (Austroads 2015b).

NOPs outline the objectives and relative priorities for different transport modes, network performance, and strategies for guiding the implementation of priorities and performance gap reductions. A NOP will also include operation management plans for day-by-day operations and processes for reviewing and updating the plan.

Road use priorities identified and determined for the different transport modes in the NOP can be displayed as road use priority maps or road use hierarchy maps. These are used to differentiate or define the route function, enabling the network to operate efficiently and provide adequate levels of service for a specific mode at different times of the day and days of the week.

The principles of NOPs represent a major shift in road design from roads aimed at reducing travel time and facilitating motorised vehicle mobility to planning and designing roads focusing on the safety, access and mobility for all road users appropriate to the surrounding land use. According to LaPlante (2007), NOPs transform urban arterial road design from motor vehicle centric to considering all road users, particularly vulnerable road users.

The LOS framework within an NOP is assessed from the perspective of different road users. It can be applied for motorists, freight operations, transit users, cyclists and pedestrians across different transport needs, i.e. mobility, safety, access, information and amenity (Austroads 2015b). The NOP compliments a functional classification, and it is more fine-grained and responsive in real time to reflect the different priorities for all modes. This is also a relatively new and still evolving concept in Australia and New Zealand, with different forms practiced across the jurisdictions. Guidance on NOPs is provided in Austroads (2015b).

3. Scale of Problem

3.1 Australian and New Zealand Research

Research on the scale of the urban arterial speed problem is surprisingly scarce, although data typically exists within individual road agencies. As a result of this lack of information, the discussion below concentrates on the issue of urban arterial crashes as an indicator of the size of the problem that may in turn be addressed in part by speed management initiatives. However, there is also very little research available on urban arterial crashes. While there is data on crash rates on urban roads, there is nothing specific on urban arterial roads. A number of studies have identified the design elements which may contribute to urban arterial crashes, but these have not generally been reviewed in this study.

McLean (1997) reviewed crashes on urban arterials to determine the influence of cross-section elements on crash frequency. Although no figures were provided on the scale of the urban arterial safety problem, the study included an analysis of crash rates for different road types. Table 3.1 and Table 3.2 provide crash rates for different descriptors/definitions of urban arterial roads. McLean suggested that the figures for Australian jurisdictions should not be compared due to differences in data collection and reporting rates. What is clear from this analysis is that the multilane undivided roads have the highest crash rate of all urban arterials – between 3 and 6.6 times the level of risk per vehicle compared with freeways.

Table 3.1: Crash rates for urban arterial road stereotypes (WA and NSW)

Road type	Crashes per 10^6 vehicles per km	
	WA	NSW
Freeway	0.86	0.39
Multilane divided	1.00	1.52
Multilane undivided	3.50	2.57
2 lane undivided	2.20	1.32

Source: McLean (1997).

Table 3.2: Casualty crash rates for arterial roads in Melbourne

Road type	Crashes per 10^6 vehicles per km
Freeway	0.11
Divided primary arterial	0.26
Undivided primary arterial	0.32

Source: McLean (1997).

Austroads (2015d) analysed fatal and serious injury crashes from 2001 to 2010 across Australia and New Zealand. The analysis showed that in Australia, the largest number of fatal and serious injuries appear to occur on roads zoned at 60 km/h or 70 km/h, roads that generally comprise the urban arterial road network.

Anderson (2008) identified that in Adelaide, almost all pedestrian fatalities occurred on urban arterials, specifically arterial roads with a 60 km/h or greater speed limit. The study also identified that most casualty crashes outside of the CBD occur on roads with a 60 km/h speed limit (now typically the arterial network).

Similarly, Jurewicz et al. (2015) in a study on operating speeds and speed limit compliance in Queensland found that 60 km/h divided multilane urban arterial roads had very high speeds, with 48% of vehicles exceeding the posted speed limit. Additionally, operating speeds exceeded the speed limit by more than 6 km/h.

Stephan and Newstead (2012) examined the issue of safety on strip shopping centres on urban arterial roads in Melbourne. The study analysed crashes at 141 road segments, ranging in length between 200 m and 4 km. The median casualty crash rate for these segments was 20.7 per km over a five-year period. Only three of the segments had experienced no crashes during the analysis period. No information was provided on the severity of these crashes, or how the crash performance compared with other arterial or non-arterial road types.

The study also assessed the relative risk associated with different features including road design, traffic volume and mix, speed limit and demographics. It is important to note that although care is taken in such studies to minimise the effect of differing road types, it is often difficult to explain the effect on safety of different variables. As an example, a safety feature may be installed at a high risk location. When compared to locations where such a feature is not present, it may appear that the risk is increased by the presence of that feature. Rather, the overall risk may have been reduced, but not to a level where the residual risk is at or below the overall risk at the location without that feature. A further discussion of this issue is provided in Kim and Washington (2006).

Stephan and Newstead (2012) identified a number of features that appear to contribute to risk on urban arterial strip shopping centres. These factors included:

- speed limit (with 60 km/h zones having higher crash rates than 40 or 50 km/h)
- primary arterials (higher rates than secondary)
- number of lanes and lane width (higher risk for more lanes, and for narrower lanes).

There were also some counterintuitive results (some of which are contradicted by before and after studies) including increased risk when medians were present when there was parking on both sides and when there was a service road. These issues need to be explored in further detail and issues such as endogeneity and covariance assessed to see if they account for the results.

Austroads (2014a) also identified run-off-road and head-on crashes as key crash patterns on urban arterial roads in Australia and New Zealand. In order to achieve a Safe System, it is therefore important that factors that reduce the incidence or severity of these crash types be identified. The analysis identified road and environmental factors, vehicle factors and driver characteristics.

3.2 International Research

The Insurance Institute for Highway Safety (2000) reported that 8000 fatal and almost a million injury crashes occurred on urban arterial roads every year in the USA. Comparing this figure for fatal crashes with that for all fatal crashes in the USA in the same time period (42 000 in 2000 according to NHTSA 2000), it appeared that around 20% of all fatal crashes in the USA occurred on urban arterial roads. No information was provided on the contribution of speed.

Chapman (1978) conducted an analysis of the urban arterial safety problem. Based on a sample of roads in four urban centres in the UK it was identified that 30% of injury crashes occurred on urban arterials. A quarter of these involved pedestrians, almost the same proportion involved motorcyclists (23%), and 15% involved cyclists. A clear majority of crashes occurred at intersections (60%).

Chapman's analysis also assessed crash performance (crashes per 100 million vehicle kilometres travelled) for different types of land use. Of most significance was the number of crashes occurring on arterial roads with shops. The crash rate at these locations was double that of the average and comprised around 30% of all casualty crashes. Over 40% of the pedestrian crashes occurred on these roads.

The study concluded that due to high concentrations of crashes on urban arterial roads, it should be relatively easy to achieve crash reductions with targeted safety treatments.

In the UK, *The road safety good practice guide* (Department for Transport, Local Government and the Regions 2001) highlighted the scale of the problem on high volume urban roads. Urban 'A roads' accounted for around 30% of all casualty crashes in 1999, and 25% of all severe crashes (killed or seriously injured).

The guide identified that on major roads, 22% of all casualty crashes occurred at urban major road intersections. It was recommended that features that help to slow vehicle speeds through intersections as well as those that increase awareness should be used. Examples of suggested treatments included signing, refuge islands, vehicle activated signs, visual cues, speed and red light cameras and coordinated signals.

Based on the same dataset, it was calculated that 8% of all reported UK crashes in 1999 occurred on major road links (i.e. midblock locations). Pedestrians and cyclists were highlighted as being of particular concern on these roads. Again, forms of speed management were suggested as a method of improving safety. Indeed, the guide suggested that urban speed management is the single most important factor in improving urban safety.

4. Speed as a Contributor to Urban Arterial Crashes

4.1 Safe System

The Safe System approach represents a significant change in the way that road safety is managed and delivered in Australia and New Zealand. The approach recognises that humans, as road users, are fallible and will continue to make mistakes. In addition, humans are physically vulnerable and are only able to withstand limited kinetic energy exchange (e.g. during the rapid deceleration associated with a crash) before serious injury or death occurs. Infrastructure is required that takes account of (or 'forgives') these errors and vulnerabilities so that road users are able to avoid serious injury or death in the event of a crash.
Safe System principles aim to manage vehicles, road and roadside infrastructure and speeds to eliminate death and serious injury as a consequence of a road crash. The Safe System approach reflects a holistic view of the combined factors involved in road safety.

The Safe System approach is based primarily on the Swedish 'Vision Zero', and the Dutch 'Sustainable Safety' approaches. Vision Zero suggests that it is not acceptable for fatal or serious injuries to occur on the road system and that account must be taken of human tolerances when designing road infrastructure (e.g. Tingvall 1998). The Sustainable Safety approach (Wegman & Aarts 2006) is based on the following concepts, the first four of which relate most directly to road infrastructure improvements and road use management:

- Functionality: roads should be differentiated by their function, with through roads which are designed for travel over long distances (typically at high speed, ideally on a motorway); distributor roads which serve districts, regions and suburbs; and local roads, which allow access to properties.
- Homogeneity: differences in vehicle speeds, direction of travel and mass on specific roads should be minimised.
- Predictability: the function and rules of a road should be clear to all road users. This approach has led to the development of the 'self-explaining road' concept (e.g. Schermers 1999; Theeuwes & Godthelp 1992).
- Forgivingness: roads and roadsides should be forgiving to road users in the event of an error.
- State awareness: road users should be able to assess their capability of handling the driving task.

4.2 Speed within the Safe System Context

Management of speed is a core feature of the Safe System approach. Human tolerances need to be considered in the setting of speed limits so that in the event of a crash, the chances of road users being killed or seriously injured are minimised. Fildes et al. (2005) summarised the biomechanical tolerances of humans for different crash types. Table 4.1 shows the impact speed ranges for various crash types at which the probability of death was estimated to be around 10%. Human tolerances need to be considered in the management of speed to ensure that in the event of a crash, death and serious injury are minimised.

Table 4.1: Biomechanical tolerances to impact[1]

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)	50 km/h
Car/car (head-on)	70 km/h

Source: Fildes et al. (2005).

Table 4.1 suggests that speeds of less than 30 km/h are required to minimise vulnerable or unprotected road user deaths, particularly those involving pedestrians. These speeds are common on many local roads in Europe, but less so in Australia and New Zealand. Speeds at this level would also be required at key points where vulnerable road users are present on arterial roads. Where speeds higher than these are desired, appropriate infrastructure, for instance, the use of adequate separation, is required to minimise death and serious injury.

Speeds of below 50 km/h are appropriate at intersections as this is the speed above which the chance of death rapidly increases in the event of a crash involving two vehicles. Speed can be managed at intersections through good design. For example, roundabouts provide geometric constraints that act to manage speeds.

Speeds of around 70 km/h or less are considered appropriate, given current vehicle design, to minimise death from head-on crashes. Rural speed limits of 70 and 80 km/h on low-quality undivided roads are being investigated in various countries around the world. Where higher speeds are required, roads need to be divided to minimise death and serious injury from head-on crashes. Similarly, in urban areas where speeds are greater than 70 km/h on arterial roads, roads would need to be divided to help eliminate death and serious injury.

These speed thresholds have been central to the Safe System infrastructure discussion to date. They are often considered the maximum or 'survivable' impact speeds which can be tolerated in relation to intersection design, pedestrian activity areas, or provision of medians.

Although this concept has been widely applied in early Safe System research, a recent study highlighted the difficulty of applying it to a Safe System road infrastructure discussion. The difficulty arises from the fact that the likely outcome is based on a crash characteristic and lacks a direct relationship to road design inputs (Austroads 2015c). The research developed and demonstrated the generalised relationships between impact speeds, impact angles and severe injury probability, enabling road agencies to modify this probability through improved design of infrastructure elements. The main finding was a different set of critical impact speeds for major crash types based on fatal and serious injury risk of 10%. In general, Austroads (2015c) suggests speeds of 20 km/h or less for vulnerable road users, approximately 30 km/h in two-vehicle crashes and 55 km/h for rear-end collisions. These values were considered preliminary and subject to further refinement.

Although the approaches adopted by Sweden and the Netherlands recognise the tolerances that can be withstood by humans in the event of a crash, current speed limit setting in these countries also reflects that the speed limit should be credible, particularly the expectations of motorists based on the road layout (e.g. SWOV 2012). Austroads (2005) suggests that most jurisdictions will accept the underlying principles of the harm minimisation approach but that the practical implementation of such a system will prove more challenging, especially given the difference between current limits and those proposed in the model they present. However, the point is also made that high speeds cannot remain unchanged simply because lower speeds would be unpopular with some motorists.

[1] The chance of a fatal outcome increases sharply above these impact speeds.

Typical speed limits currently used on higher volume urban roads in Australia and New Zealand are provided in Table 4.2 and Table 4.3. These limits are above the Safe System speeds. Note that New Zealand has produced a new speed management framework (NZ Transport Agency 2015), although at the time of publication this was still in draft form.

Table 4.2: Summary of typical urban speed limits in Australia

Speed limits (km/h)	Road function	Typical application	Key features
40	Traffic	Strip shopping centres	Physical treatments (e.g. LATM) may be necessary to constrain vehicle speeds. The speed limit may be applied on roads within a strip shopping centre during times of high crash risk to pedestrians.
	Traffic (part-time)	Urban roads outside of schools	On roads otherwise speed limited to 50, 60, 70 and 80 km/h, the school zones may require 40 km/h school zone ahead signs with school times, or transition/buffer speed limit signs with school times.
50	Local	Residential streets and collector roads	Default urban speed limit. Undivided arterial roads within a commercial or industrial roadside environment.
60	Traffic	Urban arterial roads	Generally undivided roads within a residential road environment. Divided arterial roads within a commercial or industrial environment.
	Traffic (part-time)	Rural roads outside of schools	On roads otherwise speed zoned 80 km/h or more. The school speed zones may require 60 km/h school zone ahead signs with school times, or transition/buffer speed limit signs with school times.
70	Traffic	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	Traffic	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.

Note: table shading indicates the relevant roads under consideration in this project.

Source: Adapted from Austroads (2009).

Table 4.3: Summary of typical urban speed limits in New Zealand

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

Note: table shading indicates the relevant roads under consideration in this project.

Source: Adapted from Austroads (2014c).

Further information on the speed limits used in different road environments and for different vehicle types can be found in Austroads (2008; 2014c). Recent research undertaken by Austroads has explored ways that differences between current speed limit setting and the speeds required under the Safe System approach can be reconciled (Austroads 2014b). As an example, Austroads (2010) developed a process to help achieve implementation of these Safe System speed limits, with particular emphasis on the link between speed and infrastructure. The process identified involves the following four steps:

1. Identify what speed limit is expected for a given road class and function.
2. Identify what harm minimisation speed limit is applicable.
3. Carry out a Safe System analysis to match the speed limit with road infrastructure.
4. Manage driver perception of the road environment and traffic speeds if necessary.

The first of these steps is to determine the likely speed limits given the expected road class and function of the road. These are based on speeds typically used in Australia and New Zealand as indicated in Table 4.2 and Table 4.3. These speeds have evolved over many years and typically do not reflect the more recent understanding of survivability for different crash types. The speeds from this assessment represent the high end of a possible speed limit.

The second step requires determination of the speeds that would be applicable under the Safe System, taking account of road use and function. As indicated above, these are likely to be less than 30 km/h where vulnerable road users are present, 40 km/h where there are unprotected roadside hazards, 50 km/h at intersections and 70 km/h where there is no separation between opposing traffic streams. The speed from such an assessment will likely form the lower end of a possible speed limit.

A significant gap may be evident from these first two steps (i.e. the Safe System assessment may suggest that a much lower speed is required than the assessment based on road class and function).

The third step involves an analysis to assess what road infrastructure could be used to minimise the risk of key crash types. This may involve the provision of new infrastructure or a lower speed in order to meet Safe System objectives. Where it is not possible to eliminate all crashes, supporting road safety treatments should be used that will provide incremental improvements in safety.

The final stage of the assessment involves addressing the issue of driver perceptions. If driver speed is currently a lot higher than the desired speed, measures will need to be taken to help support the new speed limit. This might require additional features (e.g. narrower traffic lanes, gateway treatments) to lower the speeds, or alternatively a higher rate of enforcement.

This approach is now being further developed with the aim of producing model guidelines. (Elements of the process have already been included in practice in some jurisdictions (see e.g. New Zealand's speed management framework; NZ Transport Agency 2015).

4.2.1 The Link Between Speed and Safety

The relationship between speed and safety has been extensively covered in previous literature (e.g. Elvik et al. 2004, Global Road Safety Partnership 2008, Kloeden et al. 1997, OECD 2006; Wegman & Aarts 2006). It is suggested that speed, whether exceeding the posted speed limit or driving too fast for prevailing conditions, contributes to around one-third of all fatal crashes in high income countries (OECD 2006, World Health Organisation 2004).

Presently, the relationship between speed and safety is best described by a Power Model for speed. The model shows that even small reductions in mean speed can result in substantial decreases in fatal and serious injury crashes. Detailed information on the Power Model for speed is outlined in Nilsson (2004), Elvik (2009) and Elvik et al. (2004).

Elvik (2004) concluded that there is a causal relationship between speed and road safety based on a number of arguments, including 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).

Recent research proposes that an exponential model (rather than a Power Model), is the preferred form for estimating the safety impact of changes in speed (Elvik 2013). The research extends the notion that the impact of speed on safety is dependent on the initial mean speed (addressed previously only in terms of 'high' and 'low speed' roads).

Although there appear to be no national figures for Australia on the incidence of urban speed-related crashes, the figures for New Zealand show that over 30% of fatal and almost 17% of severe crashes (fatal and serious injury crashes combined) in urban areas occur where 'travelling too fast for the conditions' was a factor (NZ Crash Analysis System database, average for the period 2007 to 2011).

Kloeden et al. (1997) assessed the influence of speed on risk on Australian urban roads. They used a case-control study to compare safety of casualty-crash-involved drivers with vehicles at the same location and at similar times who were not involved in a crash. The study indicated that the risk increased exponentially as vehicle speeds increased above 60 km/h, doubling with each additional 5 km/h increase in travelling speed.

Several studies have distinguished between low-end and high-end speeding (i.e. those who are speeding by only a small margin versus those who are exceeding the speed limit by a greater margin).
Kloeden et al. (2001, 2002) analysed data from a sample in Adelaide and concluded that the risks were greater for low-end speeding (defined in this study as 61 to 75 km/h in a 60 km/h speed environment). This is because a large number of people exceed the speed limit by only a small amount and although the risk for any individual driver is not as great as for high-end speeding, in aggregate, this group contributes a greater proportion of risk (estimated to be 60%).

Arem et al. (2010) using data from New South Wales lends weight to the results from Kloeden et al. (2001, 2002). This study found that the greatest risks (in aggregate) were those for low-end speeding (defined in this study as exceeding the speed limit by up to 10 km/h), with this group contributing to 43% of fatal crash risk and 38% of casualty crash risk. The next highest contribution came from those who were exceeding the speed limit by between 11 and 20 km/h, with 31% of fatal risk and 35% of casualty risk.

The results from Adelaide have been updated and refined in a study by Doecke et al. (2011). This identified the likely casualty reduction from a 1 km/h reduction in speed for different road types. For urban roads posted with either 60 km/h or 80 km/h speed limits (likely to be urban arterials), more than half of the total reduction in casualty crashes would be expected to come from motorists who were between 1 and 5 km/h above the speed limit. The study concluded that reductions in speeds on any roads would be expected to improve safety but that reductions in low-level speeding (motorists travelling between 1 and 5 km/h above the speed limit) on lower speed roads would be expected to provide the greatest safety benefits.

4.2.2 How Drivers Select their Speed

A comprehensive review of this topic is provided in Austroads (2012a), and so is not repeated here in detail. That review concluded that a number of studies report that drivers select their current speed based on what they feel is ‘safe’ for the current conditions. More specific research describes a variety of factors that have been found to influence motorists’ selection of driving speed. Factors include behavioural issues such as self-image, influence of passengers, perception of enforcement, trip purpose attitudes to safety including crash history, and comparison with other drivers (Charlton et al. 2010). Factors relating to traffic were also found to be important, including volumes of other vehicles as well as pedestrians, speed of other vehicles, visual characteristics of the road environment and the presence of parked vehicles (this may be related to road width).

Of more interest to this project were those factors that related to the urban arterial road environment. Research on this topic is fairly consistent and includes the road layout (including lane and shoulder width), roadside development, hazards and activity, presence of a median, number of access points, horizontal alignment, sight distance and road smoothness. It also appears that these factors have greater influence in combination than as individual features.

It may be possible to manage a number of these factors in order to produce a reduction in speed. However, in some cases this would be prohibitively expensive, or lead to an increased overall level of risk (e.g. through the introduction of roadside hazards). Careful consideration of each issue is required to determine which factors might be cost-effective and safe options to effect a change in speed. Section 5 summarises engineering-based treatments that can be used to manage the speed of vehicles. Many of these treatments involve changes to one or more of these road environment factors.

5. Engineering-Based Treatments

As outlined in Section 1, the aim of this project was to identify solutions for reducing and managing speeds on urban arterial roads, while taking into account the presence of vulnerable road users and the different road functions and services, with the objective of moving towards Safe System speeds.

While a large number of road safety engineering measures are available that serve to reduce operating speeds on urban arterial roads, research on their effectiveness is not widely available. Consequently, this guide, along with practice, has leaned heavily on local area traffic management (LATM) treatments. Such treatments have been implemented over several decades and have been successful in reducing speeds and crashes on local street networks. Many of these treatments have been proven to work on local streets and high volume collector roads with similar speeds as arterial roads and, in some cases, traffic volumes. These treatments vary by cost and effectiveness in terms of speed and crash reductions and other road user impacts e.g. travel time and congestion. The crash effects are expressed in terms of crash modification factors (CMFs).

CMFs are defined as a ‘representation of the relative change in crash frequency that occurs due to a specific change in the road or its immediate environments’ (Austroads 2015a). The relationship of CMFs to crash reduction factors (CRFs) is defined as an ‘indication of the expected percentage reduction in road crashes following the introduction of a countermeasure’ (Austroads 2015a).

Section 5.1 to Section 5.2 provide a summary of the engineering treatments identified as part of this research, while further detail on treatments that can be used at urban arterial intersections and midblocks is provided in Appendix A.1 and Appendix A.2. The information provided in Table 5.1 and Table 5.2 is used in conjunction with that in Appendix A. A summary of engineering treatments at school and work zones is provided in Section 5.3. Information is also provided on non-engineering treatments for completeness (Appendix A). Unless specified, the effectiveness measures outlined in these sections refer to urban applications only. In some cases, effectiveness was only known from applications of measures on rural roads. This information is provided as a guide where no urban information is available, and is highlighted accordingly as being based on rural conditions. Judgement will be required in estimating the likely benefits of such measures in the urban context.

Appendix A provides information on:

- Treatment type and brief description.
- Known and expected treatment effectiveness – crash and speed reductions associated with the different treatments. The crash reductions (presented as CMFs) refer to casualty crash reductions, unless otherwise specified. Similarly, speed reductions (presented as percentage reductions) reflect changes in both mean and 85th percentile speed unless specified. Both crash and speed reductions are a suggested maximum, although in some cases there are instances where higher reductions may have been identified. The reliability of these values is currently not high in some cases. However, this project has improved their reliability via input from trials and reviews, and presents much of the current extent of knowledge on this subject.
- Usage – a summary of how frequently treatments are used in Australia and New Zealand on urban arterial roads is also provided for each treatment type in Table 5.1 and Table 5.2. The nominal categories of usage are: ‘well established’ (the treatment has been used in Australia and/or New Zealand for some time); ‘emerging treatment’ (has been used, but not widely); ‘shows promise’ (used on a trial basis only, or yet to be applied).

- Cost information for each treatment – the cost information is classified as low, medium or high. In instances where different combinations or approaches can be applied, a cost range is provided. Cost is an important factor in treatment selection, therefore providing this information assists in ensuring the implementation of cost-effective treatments and optimising road safety benefits from available budgets.
- Road user effects – information on the treatment's impact on pollution, traffic flow, delay, congestion, travel time and route selection is also provided. The aim is to illustrate any spill-over or trade-off effects, i.e. some factors that are beneficial to safety may have an impact (positive or negative) on mobility, accessibility and vulnerable road users.
- Implementation considerations – information on installation, maintenance and general considerations is also provided.
- Applicability – the tables outline typical applications for the different treatments. This information is available for only some of the treatments. Where possible, typical speed and traffic volumes are also provided.

Local guidelines and standards are likely to apply to the selection and design of these treatments, and in some cases special permission for the use of a treatment may be required. In most cases, local knowledge, skills, experience and regulations must be applied. It is suggested that practitioners consult with the relevant road agency when selecting treatments, particularly those that are not included as 'well established' in terms of usage. In addition, the legal implications of installing treatments need to be considered. Further advice on this topic can be found in the *Guide to Road Safety Part 6: Road Safety Audit* (Austroads 2009; Chapter 3 on Legal Issues).

The compendium, while encompassing most of the possible treatments found, cannot be exhaustive as innovation means that some of the treatments will evolve, improving their effectiveness and range of application. This means that there is a need for the compendium to be dynamic (supplemented or regularly updated).

It is important to note that some of the most successful approaches to managing speeds involve combinations of treatments, and this should be considered by practitioners when selecting appropriate treatments (DaCoTa 2012). Guidance on assessing the effectiveness of combined treatments and monitoring is provided in Section 4.6 and Section 6 of the *Guide to Road Safety Part 8* (Austroads 2015e).

Non-engineering treatments (outlined in Appendix A) should also be considered. For each of the different treatments, there is need for enforcement, monitoring and evaluation as outlined in the *Guide to Road Safety Part 8* (Austroads 2015e).

5.1 Intersections

As indicated in Section 4, current speeds at urban arterial intersections tend towards and often exceed the Safe System speed of 50 km/h or less that is required to minimise fatal crash outcomes. Furthermore, research on intersection safety highlights excessive and inappropriate approach and through-intersection speeds as key problems at these locations. Achieving the Safe System ideal therefore requires revising speeds to levels that reduce fatalities and serious injuries. This can be achieved through speed management, conflict-point reduction, managing vehicle movements, addressing impact angles and vulnerable user accessibility. The following treatments have been assessed to determine likely safety outcomes (speed and crash reductions) at urban intersections (Table 5.1).

Table 5.1: Engineering-based intersection countermeasures

Urban arterial intersections								Appendix reference
Treatment type	**Brief description**	**Crash modification factor (CMF)(1)**	**Speed reduction(1)**	**Usage**	**Cost**	**Treatment life**	**Image**	
Vehicle activated signs (VAS)	Used to warn drivers of changes in road conditions/emerging hazards. They are mainly installed in locations with an existing crash history or where the use of standard static warning signs has not been effective in altering driver behaviour.	Unknown (0.40 for rural)	Unknown (5 km/h 85^{th} percentile speed and 2 km/h mean speed for rural)	Shows promise	Medium	10 years+		Appendix A.1.1
Roundabouts	Intersection control measure implemented in order to reduce speeds and reduce road user conflict points.	0.25	10 km/h 85^{th} percentile speed	Well established	High	20 years+		Appendix A.1.2
Signalised roundabout(2)	Entry into the roundabout is gated by signals or movements are controlled by signal phasing. Signal operation can be full time or part time, e.g. in peak times only.	0.72	Unknown	Emerging	High	20 years+		Appendix A.1.3
Turbo roundabout	Multilane roundabouts where vehicles are required to enter the roundabout in specific lanes depending on which exit they wish to take.	0.30	Unknown	Shows promise	High	20 years+		Appendix A.1.4
Raised intersections(3)	Either the entire intersection is raised, acting as a type of speed platform, or raised sections can be placed in advance of the intersection (sometimes referred to as raised stop bars).	0.60	8 km/h 85^{th} percentile speed 3 km/h mean speed	Shows promise	Medium–high	20 years+		Appendix A.1.5
Horizontal deflection on approaches	Installation of kerb extensions, medians and/or pedestrian refuge islands to alter the physical layout of the intersection approach. The treatments are designed to slow vehicles to a safe intersection speed.	Up to 0.65	5 km/h 85^{th} percentile speed	Emerging	Medium	10 years+		Appendix A.1.6

Urban arterial intersections								Appendix reference
Treatment type	**Brief description**	**Crash modification factor (CMF)[1]**	**Speed reduction[1]**	**Usage**	**Cost**	**Treatment life**	**Image**	
Perceptual countermeasures	Manipulations of the road environment to influence drivers' speed behaviour on intersection approach.	Unknown (0.40 for rural)	Unknown (8 km/h 85th percentile speed for rural)	Shows promise	Low	1–5 years		Appendix A.1.7
Transverse rumble strips	Lines or sections of profiled road markings placed across the carriageway so as to cause noise and vibration in the vehicle to alert the driver to the presence of an intersection.	Unknown (0.80 for rural)	Unknown (5 km/h 85th percentile speed for rural)	Shows promise	Low	1–5 years		Appendix A.1.8
Reduce excessive sight distance	Involves reducing 'excess' sight visibility at the intersection (particularly roundabouts) so that drivers do not anticipate gaps in traffic too far in advance.	0.60 (roundabouts)	(18 km/h 85th percentile speed (roundabouts))	Shows promise	Low	5–10 years		Appendix A.1.9
Lower speed limits	Involves lowering the mandatory (posted) speed limit on the approaches to the intersection.	Unknown	Unknown	Emerging	Low	10 years+		Appendix A.1.10
Variable speed limits (VSL)	Dynamic speed limit signs that activate based on changing traffic speed, traffic volume, weather, and road surface conditions. Some activate a lower speed limit for through traffic when vehicles approach the intersection from a side road.	Unknown (0.92 for rural)	Unknown (17 km/h 85th percentile speed for rural)	Emerging	Low–medium	10 years+		Appendix A.1.11
Lane narrowing	Narrowing lane width on approach or at intersections through perceptual and physical measures, e.g. kerb extensions, wide medians or shoulders.	0.70	7 km/h 85th percentile speed	Emerging	Low–medium	15 years		Appendix A.1.12

Urban arterial intersections								Appendix reference
Treatment type	**Brief description**	**Crash modification factor (CMF)(1)**	**Speed reduction(1)**	**Usage**	**Cost**	**Treatment life**	**Image**	
Signals: green wave	Local coordination of adjacent traffic signals or linking several signals at intersections along a particular route segment on major urban arterial roads such that a vehicle travelling at a recommended speed will be rewarded with consecutive green lights.	Unknown	Unknown	Well established	Low	1–5 years		Appendix A.1.13
Signals: dwell on red[3]	Red signals to vehicles and pedestrian in all directions forcing approaching vehicles to slow down. A red signal is displayed until the system is activated by a vehicle or pedestrian.	0.55	11 km/h 85th percentile speed	Emerging	Low	1–5 years		Appendix A.1.14

1 Suggested maximum value. This will differ based on factors such as the road environment and design of the treatment.
2 Effectiveness over and above roundabout effect.
3 Evaluated in this project.

5.2 Midblocks

While intersections pose a greater safety concern on urban arterial roads, the approach and through speeds are also determined by midblock speeds. Additionally, midblock locations include mixed traffic and generally have higher speeds than intersections. Moving midblock speeds closer to Safe System compliant speeds requires speed reductions while maintaining mobility, accessibility and overall safety of all road users.

Table 5.2: Engineering-based midblocks countermeasures

Urban arterial midblocks								
Treatment type	**Brief description**	**Crash modification factor (CMF)[1]**	**Speed reduction[1]**	**Usage**	**Cost**	**Treatment life**	**Image**	**Appendix reference**
Humps/platforms[2]	Vertical deflection treatments used to control speed, with various forms of speed humps available for different road types.	0.60	Up to 25 km/h 85^{th} percentile speed 25 km/h mean speed	Shows promise	Medium–high	10 years+		Appendix A.2.1
Vehicle activated signs (VAS)	Dynamic signs displaying speed or hazard warnings when an approaching vehicle exceeds the threshold speed.	Unknown (0.65 for rural)	Unknown (10 km/h 85^{th} percentile speed for rural)	Emerging	Medium	5–10 years		Appendix A.2.2
Raised pedestrian crossings/wombat crossings[2]	Similar profile and speed reduction effect as flat-top speed humps but differ by giving priority to pedestrians rather than motorists.	0.60	9 km/h 85^{th} percentile speed 8 km/h mean speed	Emerging	Medium–high	10 years+		Appendix A.2.3
Road diet[2]	Road narrowing measure typically involving the conversion of a four-lane road (two each way) into a road with only one lane in each direction, and a central two-way right-turn lane.	0.65	4 km/h 85^{th} percentile speed 5 km/h mean speed	Emerging	Low–medium	1–5 years		Appendix A.2.4
Pedestrian refuge	Raised median island in the middle of the road with at-grade space provided for pedestrians to wait until a gap in traffic allows them to cross the road.	0.75	Unknown	Well established	Low–medium	20 years+		Appendix A.2.5

Urban arterial midblocks								
Treatment type	**Brief description**	**Crash modification factor (CMF)[1]**	**Speed reduction[1]**	**Usage**	**Cost**	**Treatment life**	**Image**	**Appendix reference**
Medians	Involves separation between opposing traffic streams, and typically the narrowing of existing lanes.	0.85 for flush median 0.54 for raised median	Mixed results	Well established	Medium–high	Up to 10 years+		Appendix A.2.6
Gateway treatments	Use of signs with other techniques to create a threshold or gateway between high and low speed environments.	Unknown (up to 0.60 for rural)	Unknown 25 km/h 85^{th} percentile speed; 15 km/h mean speed for rural	Shows promise (well established for rural)	Low–medium	5–20 years		Appendix A.2.7
Transverse rumble strips	Audio-tactile treatments applied transversely or across the driving lane to warn of approaching hazards.	Unknown (up to 0.64 for rural)	Unknown	Emerging	Low	1–5 years		Appendix A.2.8
Shared spaces/naked roads	Urban design concept where the priority for users is shifted from vehicles towards pedestrians and cyclists, complemented by a speed limit reduction.	Mixed results	13 km/h mean speed	Emerging	Medium–high	10 years+		Appendix A.2.9
Lower speed limits	Involves managing posted speed limits, revising them towards Safe System levels.	0.75	6 km/h 85^{th} percentile speed	Well established	Low	10 years+		Appendix A.2.10
Variable speed limits (VSL)	Dynamic signs displaying variable statutory speed limits depending on prevailing traffic, weather and road conditions.	0.92	Unknown	Well established	Low	10 years+		Appendix A.2.11
Variable message sign (VMS)	Traffic control device used for warning drivers of changing conditions and for traffic management and routing.	0.90	Up to 2 km/h mean speed	Well established	Low–medium	10 years+		Appendix A.2.12
Repeater signs	Speed restriction sign used to reinforce the posted speed limit that applies to the speed zone or speed limit in a specific area. The signs are smaller than the speed limit sign.	Unknown	Up to 4 km/h mean speed	Well established	Low	5–10 years		Appendix A.2.13

1 Suggested maximum value. This will differ based on factors such as the road environment and design of the treatment.
2 Evaluated in this project.

5.3 Roadworks and School Zones

The identification of engineering treatments at work sites (roadworks) and school zones on urban arterial roads did not form a core part of this project. However, during the project important information was obtained on various treatments that can be applied at these sites and has been collated and recorded here.

5.3.1 Roadworks

In order to improve safety outcomes (reducing speeds, crashes and crash risks) at work zones, different speed control techniques are typically implemented. These include static speed signs, variable speed limit signs, rumble strips, traverse strips, lane narrowing and closure, police enforcement, radar activated trailers etc. (Table 5.3). Much of the research on this topic is based on evaluations at rural roadwork sites, although some of this may be transferable to the urban arterial context. When considering appropriate measures at work sites, the relevant standards (particularly AS 1742.3-2009, Standards Australia 2009) as well as local guidance should be consulted.

Table 5.3: Engineering-based roadworks countermeasures

Roadworks					
Treatment type	**Brief description**	**Speed reduction**	**Road user effect**	**Usage**	**Key references and sources**
Vehicle activated signs (VAS)	Dynamic signs displaying speed limit in the work zone when an approaching vehicle exceeds the threshold speed.	Up to 19 km/h mean speed	• Increased compliance • Increases driver awareness	Well established	Mattox, J, Sarasua, W, Ogle, J, Eckenrode, R & Dunning, A 2007, 'Development and evaluation of a speed activated sign to reduce speeds in work zones', *Transportation Research Record*, no. 2015, pp. 3-11.
Variable message signs (VMS)	Traffic control device used to warn drivers of changed or real-time work zone conditions.	Up to 18 km/h 85th percentile speed Up to 6.4 km/h mean speed	• Increased compliance • Increased vehicle speeds towards the end of the work zone • Increased traffic flow in work zones, with reduced delays • More effective when used with speed recording device	Well established	Brewer, M, Pesti, G & Schneider, W 2006, 'Improving compliance with work zone speed limits: Effectiveness of selected devices'. *Transportation Research Record*, no. 1948, 67-76. Bai, Y, Finger, K & Li, Y 2010, 'Analysing motorists' responses to temporary signage in highway work zones'. *Safety Science*, vol. 48, no. 2, pp. 215-21. Fontaine, M, Carlson, P & Hawkins, H 2000, *Evaluation of traffic control devices for rural high-speed maintenance work zones: second year activities and final recommendations,* College Station, TX: Texas Transportation Institute. Garber, N & Patel, S 1994, *Effectiveness of changeable message signs in controlling vehicle speeds in work zones*, VTRC/VA-95-R4, Virginia Research Council, Charlottesville, VA, USA.

Roadworks					
Treatment type	**Brief description**	**Speed reduction**	**Road user effect**	**Usage**	**Key references and sources**
					Garber, N & Srinivasan, S 1998, *Final report: effectiveness of changeable message signs in controlling vehicle speeds in work zones phase II*, VTRC 98-R10, Virginia Transportation Research Council, Charlottesville, VA, USA.
Variable speed limit signs (VSL)	Dynamic road signs displaying variable work zone speed limits.	12 km/h mean speed	• Reductions in travel time through the work zone • Reduced speed variability near the activity area of the work zone	Well established	Lyles, R, William, C, Taylor, W, Lavansiri, D & Grossklaus, J 2004, *A field test and evaluation of variable speed limits in work zones*, Michigan State University, USA, viewed 5 August 2015, <http://ssom.transportation.org/Documents/ TRB2004-001180.pdf>. McMurtry, T, Saito, M, Riffkin, M & Heath, S 2009, 'Variable speed limits signs: effects on speed and speed variation in work zones', *Transportation Research Board , annual meeting, 88th, Washington, DC*, TRB, Washington, DC, 9 pp.
Speed limit sign	Static sign displaying work zone speed limits.	Unknown	• Increased compliance levels where the speed limit sign was associated with a speed limit reduction	Well established	Bham, G & Mohammadi, M 2011, *Evaluation of work zone speed limits: an objective and subjective analysis of work zones in Missouri,* MATC report 25-1121-0001-119, Mid-America Transportation Centre & Missouri Science & Technology, Lincoln, Nebraska, USA. Debnath, A, Blackman, R & Haworth, N 2012, 'A review of the effectiveness of speed control measures in roadwork zones', *Occupational safety in transport conference, 1st, 2012, Crowne Plaza, Gold Coast, Queensland, Centre for Accident Research and Road Safety*, Brisbane, Qld.
Lane narrowing	Reduction of lane width through a work zone.	Up to 16 km/h mean speed	• Unknown	Well established	Chitturi, MV & Benekohal, RF 2005, 'Effect of lane width on speeds of cars and heavy vehicles in work zones', *Transportation Research Record,* no. 1920, pp. 41-8.
Portable rumble strips	Portable audio-tactile strips applied across the driving lane to warn of work zone.	3 km/h mean speed	• Drivers may manoeuvre around the rumble strips	Emerging	Debnath, A, Blackman, R & Haworth, N 2012, 'A review of the effectiveness of speed control measures in roadwork zones', *Occupational safety in transport conference, 1st, 2012, Crowne Plaza, Gold Coast, Queensland, Centre for Accident Research and Road Safety*, Brisbane, Qld. Maze, T, Kamyab, A & Schrock, S 2000, *Evaluation of work zone speed reduction measures*. Ames, IA: Centre for Transportation Research and Education, Iowa State University.

5.3.2 School Zones

The use of school speed zones has been widespread throughout Australia and New Zealand for some time. They are designed to improve safety for students and parents as they enter or exit the school and typically involve the lowering of speed limits close to the schools, focusing on major entry/exit points and crossings. For example, speed zones on gazetted school days were introduced in NSW in 1993. Speed limits in 60 km/h areas were reduced to 40 km/h during arrival and departure times (at that time, between 8.00 and 9.15 am, and from 3.15 to 4.00 pm). Presently, the standard school zone speed limits in NSW and most of Australia are set at 40 km/h between 8.00 and 9.30 am and 2.30 to 4.00 pm in most cases (there are some schools with a full 8.00 to 4.30 pm school zone speed limit). In New Zealand, the school speed zone operating times fall between 30 minutes before start of school and 5 minutes before end of school to 15 minutes after end of school.

Speed management measures in school zones include the use of static, variable speed limit and/or vehicle activated signs. A summary of key engineering treatments at these sites is outlined in Table 5.4. Where Safe System speeds cannot be achieved, more extensive engineering features such as pedestrian overbridges are often considered.

Table 5.4: Engineering-based school zone countermeasures

School zones					
Treatment type	**Brief description**	**Speed reduction**	**Road user effect**	**Usage**	**Key references and sources**
Flashing lights	Flashing beacon/lights added to a school zone sign to indicate operation of the zone and to increase sign conspicuity.	10 km/h mean speed	Increases awareness of school zone	Well established	Turner, B 2005, 'Literature review of speed reducing measures in school zones', contract report, ARRB Group, Vermont South, Vic. Fitzpatrick, K, Brewer, M, Obeng-Boampong, K, Park, E & Trout, N 2008, *Speeds in school zones*. Texas Transport Institute Report 0-5470-1. Roper, P, Thoresen, T, Tziotis, M & Imberger, K 2006, 'Evaluation of flashing lights in 40 km/h school speed zones with comparison of different sign types', contract report VC3930, ARRB Group, Vermont South, Vic.
Static speed limit signs	Static signs displaying reduced school zone speed limits and when these are applicable.	6 km/h 85th percentile speed	Slight increases in compliance, however, the magnitude of this effect is not available	Well established	Fitzpatrick, K, Brewer, M, Obeng-Boampong, K, Park, E & Trout, N 2008, *Speeds in school zones*. Texas Transport Institute Report 0-5470-1.
Variable speed limit signs (VSL)	Dynamic road signs displaying variable school zone speed limits.	10 km/h 85th percentile speed 9 km/h mean speed	Increases driver awareness Increased compliance	Well established	Singh, R 2011, Queensland multi-lane school zone trial, *Australasian road safety research, policing and education conference, 2011, Perth, Western Australia, Australia, Insurance Commission of Western Australia*, Perth, WA, 11 pp.

School zones					
Treatment type	**Brief description**	**Speed reduction**	**Road user effect**	**Usage**	**Key references and sources**
Vehicle activated signs (VAS)	Dynamic signs displaying speed when an approaching vehicle exceeds the threshold speed.	16 km/h 85^{th} percentile speed 12 km/h mean speed	Increased compliance	Well established	Fitzpatrick, K, Brewer, M, Obeng-Boampong, K, Park, E & Trout, N 2008, *Speeds in school zones*. Texas Transport Institute Report 0-5470-1. Singh, R 2011, Queensland multi-lane school zone trial, *Australasian road safety research, policing and education conference, 2011, Perth, Western Australia, Australia, Insurance Commission of Western Australia*, Perth, WA, 11 pp.
Wombat crossing	Similar profile and speed reduction effect as flat-top speed humps but they differ in that they give priority to pedestrians rather than motorists.	4 km/h 85^{th} percentile speed	Increases pedestrian visibility	Well established	Fitzpatrick, K, Brewer, M, Obeng-Boampong, K, Park, E & Trout, N 2008, *Speeds in school zones*. Texas Transport Institute Report 0-5470-1.
Advance warning sign	Static warning sign on approach to a school zone.	8 km/h 85^{th} percentile speed	Increases awareness of school zone	Well established	Turner, B 2005, ‘Literature review of speed reducing measures in school zones’, contract report, ARRB Group, Vermont South, Vic. Fitzpatrick, K, Brewer, M, Obeng-Boampong, K, Park, E & Trout, N 2008, *Speeds in school zones*. Texas Transport Institute Report 0-5470-1.

6. Monitoring and Evaluation

According to Austroads (2015e), it is important to monitor and evaluate the safety performance of treatments. This is achieved through development of program evaluation frameworks, and systematic data collection on speed, crashes, traffic mix and volumes at different points in time. It is noted that:

> Post-implementation monitoring is essential to ascertain the positive and negative effects of a treatment and thus improve the accuracy and confidence of predictions of that treatment's effectiveness in subsequent applications. There is a duty to ensure that the public does not experience additional hazards as a result of treatments and this duty carries with it an implied need to monitor what happens when a scheme is introduced (p 66).

The purpose of monitoring is to assess changes in speed, crash occurrence and severity and determining whether the treatments are achieving the intended safety objectives. The four main steps in monitoring and evaluation are:

- carefully monitoring of the treated site before and immediately after treatment installation
- long-term data collection to determine the treatment's effectiveness involving statistical analyses of crash, speed and traffic volume data
- analysis of key crash patterns and types, especially fatal and serious injury crashes (FSI)
- dissemination of evaluation effectiveness findings into programs and policy.

Performance monitoring and evaluation should also include monitoring the number of crashes and crash type, crash severity, crash distribution across the network, traffic flow and travel time and vehicle movements at the intersection. Further details on monitoring and evaluation methods and approaches are provided in Austroads (2012b) and Austroads (2015e).

7. Discussion and Conclusions

The aim of this project was to identify approaches to speed management on urban arterial roads while taking into account the different environments, functions and the presence of vulnerable road users. It involved identifying the nature and extent of the speed issue on urban arterials and providing information on effective measures to reduce the incidence and severity of crashes, particularly through road engineering treatments.

Engineering/infrastructure measures that have the potential either in isolation or in combination to reduce current operating speeds between 60–80 km/h towards or under Safe System speeds have therefore been the focus.

The majority of the measures identified have evolved or have been adapted from past usage around the world on lower volume local roads, often under the banner of LATM. However, every effort has been also made to identify and collate measures that have promise in this field.

The compendium contains an array of practical measures but it should not be seen as exhaustive. Devising and formally piloting innovative measures will be extremely important over time. It should also be remembered that on a site-by-site basis, applying any treatment requires professional judgement and local knowledge. Further, where combinations of treatments may need to be considered, recognising that trade-offs and compromises might be required is also important.

Key findings from the project include:

- There is limited information on the size of the speed and crash problem on urban arterial roads.
- Commonly applied treatments on urban arterial roads include:
  - roundabouts, horizontal deflection on approach and lower speed limits at intersections
  - pedestrian refuges, medians, lower speed limits and variable speed limit signs at midblocks.
- New and promising treatments include:
  - road diets, raised platforms and wombat crossings at midblocks
  - raised intersections, signalised roundabouts, turbo roundabouts and dwell-on-red signals at intersections.

There is a lack of robust treatment performance data relating to speed and crash reduction. On-going evaluation of measures is crucial, regardless of whether the treatment has been successful in the past or whether it is innovative. The Compendium should be a dynamic document, regularly updated so that emerging measures are identified and the range and status of existing treatments is expanded, thereby enhancing practitioner knowledge.

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Appendix A Engineering Treatments

A.1 Urban Arterial Intersections

A.1.1 Vehicle Activated Signs (VAS)

Source: Burbridge et al. (2010).

Description

Vehicle activated signs are electronic roadside warning signs, often solar powered, which are triggered by road users when they exceed a pre-determined speed trigger. At all other times the sign is blank. Once triggered, the sign displays the pertinent hazard ahead, and may include a message to slow down or a travel speed. This alerts drivers to the presence of the intersection with the aim being that they increase their alertness and reduce their speed to negotiate the intersection safely.

The findings are based on rural applications due to limited information on urban applications.

Effectiveness

Speed reduction*:

- 5 km/h reduction in 85th percentile speed and 2 km/h reduction in mean speed.
- Overall reductions in mean speeds and the proportion of vehicles exceeding the speed limit.
- Sustained reductions in the percentage of vehicles exceeding the speed limit compared with static signs.

Crash reduction*:

- 70% reduction in crashes (CMF 0.40).

Road user effect/s (delays, congestion, consistency of travel time):

- Unknown.

*Note that robust data from urban use is unavailable, so results from rural applications are presented as a guide.

Implementation issues

- Determining the safe speed (trigger speed) at which the sign will be activated.
- Vandalism has been noted as an issue, however, this is mainly on rural roads.
- Overuse of the treatment may increase familiarity, and therefore reduce effectiveness.
- Sign placement to ensure that the line of sight from the sign to the vehicle is clear so that the radar works effectively, and the sign is clearly visible.
- The placement of VAS should allow adequate time and distance for drivers to adjust their speed appropriately.
- Signs can present a hazard to errant vehicles, and therefore should be sited appropriately and in some cases consideration may need to be given to the use of a frangible base (pole).
- Sign design and configuration should be consistent so as reduce driver confusion.

Cost

Medium

Treatment life

5–10 years

Applicability

- Signs should only be applied where there is a crash problem related to inappropriate speed not adequately addressed by static signs.
- Also applied in work zones, school zones and at curves.

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A.1.2 Roundabouts

Source: ARRB Group.

Source: ARRB Group.

Description

Roundabouts are circular central islands, around which (in Australia and NZ) traffic circulates in a clockwise direction, which are used where T or X intersections may not be appropriate. Entry to the roundabout is controlled by way of signs and markings, with all entering traffic required to give way to the right and to traffic on the circulating roadway. However, in certain circumstances roundabouts are signalised, either partly or wholly and either at peak times only or all the time. Other roundabout types include turbo and mini roundabouts. Mini roundabouts are not typically applied on high volume roads therefore are not addressed in this report.

Effectiveness

Speed reduction:

- 10 km/h reduction in 85th percentile speed.

Crash reduction:

- 75% reduction (CMF 0.25).

Road user effect/s (delays, congestion, consistency of travel time):

- General/overall reduction in delays and emissions.
- Minimises delay during off-peak periods (when considered against a conventional intersection).
- Fewer conflict points and improved angles of conflict in comparison with conventional intersections, contributing to a reduction in the incidence and severity of crashes.
- More time for drivers to react to potential dangers.
- Priority is simple and consistent on all approaches (give way to right and to circulating traffic).
- Since most road users travel at similar speeds through roundabouts, crash severity can be reduced compared to some traditionally controlled intersections.
- The visibility of the intersection is increased.

Implementation issues

- Good design (including deflection) is required to reduce vehicle speeds on the approach to the roundabout. Additional signs may also be used to provide advance warning.
- Loss of parking and limited road reserves are concerns on arterial roads.

- If traffic flows are unequal on approaches, additional features may be needed.
- Can increase the risk for vulnerable road users, e.g. increased crash risk for cyclists. Pedestrian crossing facilities needed in some circumstances.
- Need to be able to accommodate the turning circle of emergency services vehicles and large goods vehicles.
- Must consider angle of deflection and distribution of lanes (exclusive left or right-turn lanes) in design.
- Concerns with roundabout installations in close proximity to signals.
- Increased crash rates and difficulty determining vehicle turning movements at 3-lane roundabouts.

Cost

High

Treatment life

20 years+

Applicability

- Requires a larger area of land than traditional intersection.
- A large number of circulating and approach lanes, traffic volumes and the presence of pedestrians and cyclists affect the safety and operation of roundabouts.
- Appropriate when the peak circulating flow plus entry flow is moderate (i.e. up to approximately 2000 to 3000 veh/h for two-lane roundabout), but this is dependent on design and traffic conditions (see Austroads 2013).
- Consider using advisory speeds on vehicles approaching in order to reduce speeds and speed variability.

Key references and sources

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A.1.3 Signalised Roundabouts

Source: Google Maps 2015, ‘Carlton, Victoria’ map data, Google, California, USA.

Description

Signalising roundabouts involves the use of partial or full signalisation at roundabouts. They are mainly implemented at roundabouts with significant growth in traffic flow, unbalanced flows and high circulating speed. Partially signalised roundabouts have part-time metering that only operates during peak periods, and normal roundabout priority is used at all other times. Fully signalised roundabouts have signals at all approaches which operate at all times.

Note treatment refers to both signalising an existing roundabout and new installation of signalised roundabout.

Effectiveness

Speed reduction:

- Unknown.

Crash reduction:

- 28% reduction in all crashes compared to non-signalised roundabouts (CMF 0.72).

Road user effect/s (delays, congestion, consistency of travel time):

- Reductions in traffic delay during peak periods for fully signalised and partially signalised roundabouts.
- Provides pedestrian crossing facilities.
- Improves cyclist safety.
- Increases in traffic delay at fully signalised roundabouts in the off-peak periods.
- Prioritises different legs, creating more balanced flows and regulating traffic patterns.

Implementation issues

- Requires clear line/lane marking for circulating vehicles.
- The placement of signals should be clear to avoid confusion with neighbouring signals and also provide adequate sight distance and angling for vehicle controllers.
- Need to optimise cycle time length in order to reduce queuing.
- The choice of full or partial signalisation depends on site-specific conditions. Where partial signalisation is adopted, additional signage on operating times is required in order to reduce confusion about the difference between metered and signalised roundabouts.
- Need to consider whether to partially or fully signalise intersection, or use advanced signal greens for cyclists.

Cost

High

Treatment life

20 years+

Applicability

- Generally applied at high capacity and high speed intersections on high order arterial roads.
- Can also be applied at existing congested roundabouts with unbalanced flows.

Key references and sources

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A.1.4 Turbo Roundabouts

Source: SWOV (2012).

Description

Multilane roundabouts where vehicles are required to enter in specific lanes depending on which exit they wish to take. Raised line markings can be used to further discourage lane changing and lower speeds. This style of roundabout requires some vehicles to give way to two lanes when entering the roundabout.

Effectiveness

Speed reduction:

- Slower mean and 85th percentile speeds.

Crash reduction:

- Up to 70% reduction in crashes (CMF 0.30).

Road user effect/s (delays, congestion, consistency of travel time):

- 25–35% higher capacity than conventional two-lane roundabouts
- Reduction in the number of conflicts due to elimination of weaving.

Implementation issues

- Requires clear line/lane marking for circulating vehicles.
- May be difficulty in managing longer vehicles around the roundabout.
- Possible drainage issues at separator islands.
- Requires additional signage on roundabout approaches.

Cost

High

Treatment life

20 years+

Applicability

- Generally applied at high capacity and high speed intersections on high order arterial roads, with traffic volumes of up to 35 000 vehicles per day.
- Should not be used on high cyclist volume roads. If applied on these roads, cyclist lanes should be considered to eliminate the crash risk.

Key references and sources

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A.1.5 Raised Intersections

Source: ARRB Group.

Source: VicRoads.

Description

Raised intersections (also known as platform intersections, raised junctions or plateaus) are a speed management device, typically with the aim of reducing the speed of vehicles to 50 km/h or less. The entire intersection can be raised, with the pavement surface sometimes flush with the adjoining footpath. Alternatively, raised sections can be placed in advance of the intersection (sometimes referred to as raised stop bars) in order to achieve a similar effect. Raised intersections can be painted or paved in a manner such that they serve to further increase driver awareness of the intersection.

Effectiveness

Speed reduction*:

- 3 km/h reduction in mean speed.
- 8 km/h reduction in 85^{th} percentile speed.

Crash reduction*:

- 40% reduction in casualty crashes (CMF 0.60).

Road user effect/s (delays, congestion, consistency of travel time):

- ‘Downgrading’ of functionality of road – e.g. urban arterial potentially becomes a lesser road.
- Inconvenience and delay to buses and emergency vehicles.
- Increased noise levels.
- Pedestrians confusing ramp markings for crossing facilities.

*These results include outcomes from an evaluation conducted through this Austroads project. This work will be published separately in the near future.

Implementation issues

- Increased height and a steeper ramp gradient lead to a greater level of speed reduction. Austroads classifies a 1:30 gradient as bus friendly, but this flatter ramp may result in less speed reduction for other vehicles.
- Need to consider the impact on drainage.
- Require appropriate delineation.

- Traffic volume, composition and geometry should be taken into considerations when determining the suitability of this treatment.
- Confusion of priorities may occur, therefore proper pedestrian crossing should be designed with raised intersections.

Cost

Medium to high

Treatment life

20 years+

Applicability

- Recommendation that raised intersections and raised stop bars are not utilised on roads with posted speed limits of above 60 km/h.
- Should not be used where there is limited or restricted sight distance.

Key references and sources

Fortuijn, L, Carton, P & Feddes, B 2005, ‘Safety impact of raised stop bars on distributor roads: draft’, CROW, Ede, the Netherlands.

Gordon, G 2008, *Mixed priority routes road safety demonstration project: summary scheme report,* Department for Transport & WSP Development and Transportation, Birmingham, UK.

Gordon, G 2008, ‘Cowley Road, mixed priority route road safety demonstration project’, WSP Development and Transportation, Birmingham, UK.

Gordon, G 2008, ‘Walworth Road, Borough of Southwark, mixed priority route demonstration project’, WSP Development and Transportation, Birmingham, UK.

Gordon, G 2008, ‘St Peter’s Street, mixed priority route demonstration project’, WSP Development and Transportation, Birmingham, UK.

Gordon, G 2008, ‘Newland Avenue, Kingston-upon-Hull City Council, mixed priority route demonstration project’, WSP Development and Transportation, Birmingham, UK.

Gordon, G 2011, ‘Mixed priority routes: results update and cost review’, Department for Transport, London, UK.

Pratt, K, McGarrigle, S & Turner, B 2015, ‘The hurdles of introducing innovative road safety infrastructure solutions: a case study on raised safety platforms’, *Australasian road safety conference,* Gold Coast, Qld, 13 pp.

Van der Dussen, P 2002, ‘Verhoogde plateaus effectief en goedkoop bij terugdringen aantal ongevallen’, [in Dutch Raised plateaus effective and cheap in reducing number of crashes], *Wegen*, vol. 76, no. 8, pp. 18-20.

A.1.6 Horizontal Deflection

Source: Austroads (2011).

Description

Horizontal deflection treatments often involve the installation of kerb extensions, medians and/or pedestrian refuge islands at intersection approaches. This combination of treatments can be used to slow vehicles to a Safe System compliant intersection speed, as well as to facilitate shorter and safer pedestrian crossings.

Additionally, a similar approach involves installing splitter islands at intersections, generally on the approach to give-way or stop-controlled intersections. The splitter island slows and directs traffic, and also separates opposing traffic streams. Splitter islands can also serve as pedestrian refuge islands if required. This treatment is often applied at roundabouts, but it is also used on minor intersection approaches.

Effectiveness

Speed reduction:

- Up to 5 km/h.

Crash reduction:

- 30% reduction in pedestrian crashes (CMF 0.70).
- 35% reduction in crashes for splitter islands (CMF 0.65).
- 15% reduction in crashes for a mountable median (CMF 0.85).
- 25% reduction in crashes for a non-mountable median (CMF 0.75).

Road user effect/s (delays, congestion, consistency of travel time):

- Evidence from literature indicates volume reductions
- Improves access, crossing and pedestrian visibility
- Reduces vehicle-to-vehicle and vehicle-to-pedestrian conflict points
- Little/minimal effect on emergency vehicle access.

Implementation issues

- There is little known literature on the use of horizontal deflection to slow vehicles at non-roundabouts. This is an area where further study is required to determine accurate crash and speed reductions.
- Can cause lane keeping issues through intersections due to lack of delineation.
- Deflection is generally achieved through narrowing and can cause lane reductions for cyclists and lane keeping issues for heavy vehicles (especially in turning movements).
- Some concern about deflecting vehicles into oncoming traffic, pedestrians or cyclists.
- Concerns on whether deflection is a forgiving treatment, especially to those exceeding the speed limit.
- Deflection is generally used in combination with other treatment types.

Cost

Medium

Treatment life

10 years+

Applicability

- Often applied at roundabouts, but it is also used on minor intersection approaches.
- Not suitable for bus routes and high commercial vehicle volumes.

Key references and sources

Austroads & ARRB Group 2010, *Treatment type: design issues: kerb extensions,* Austroads road safety engineering toolkit, Austroads & ARRB Group, Vermont South, Vic, viewed 29 November 2015, <http://www.engtoolkit.com.au>.

Austroads 2011, *Safe intersection approach treatments and safe speeds through intersections: phase 2,* AP–R385-11, Austroads, Sydney, NSW.

A.1.7 Perceptual Countermeasures

Source: Macaulay et al. (2004).

Description

The treatments are used to alter a driver's perception of the environment. Can be used to make drivers think they are going faster than they are, or that the road narrows. Both of these cause the driver to slow on approach to the intersection. In addition, the treatments are likely to raise awareness of the presence of the intersection. This type of treatment is quite common in the UK, particularly on the approach to roundabouts.

There was limited research and application of perceptual countermeasures on urban arterial roads and consequently the findings on rural roads are provided as an indicative measure of effectiveness.

Effectiveness

Speed reduction*:

- 13 km/h reduction in 85th percentile speed from perceptual narrowing
- 11 km/h reduction in 85th percentile speed from lane narrowing through buildings, parked cars etc.
- Up to 8 km/h reduction in 85th percentile speed from markings that give the appearance of travelling faster on the approach to an intersection.

Crash reduction*:

- 60% on roundabout approach (CMF 0.40).

Road user effect/s (delays, congestion, consistency of travel time):

- Increased awareness of intersection.

*Note that robust data from urban use is unavailable, so results from rural applications are presented as a guide.

Implementation issues

- Overuse of the treatments can lead to them losing their effect and drivers not responding to the same extent.
- Careful consideration on placement of the treatment needs to be undertaken to ensure that drivers have enough time to brake safely before the intersection after encountering the treatment.
- Additional line marking may have a negative effect on skid resistance, particularly for motorcyclists.
- Tends to draw the eyes down towards the line marking and away from focus on the road.
- Additional noise that the markings create can be an issue for urban or residential environments.
- There could be confusion about priorities between pedestrians and vehicles at crossing points.
- Need for on-going maintenance where trafficked.

Cost

Low

Treatment life

1–5 years

Applicability

- Should not be placed too far in advance of intersection.
- Line spacing and width should be consistent.

Key references and sources

Charlton, SG 2011, ‘Improving driver awareness of road risk and driver behaviour using KiwiRAP ratings’, TERNZ research report, Transport Engineering Research, Auckland, New Zealand.

Macaulay, J, Gunatillake, T, Tziotis, M, Fildes, B, Corben, B & Newstead, S 2004, *On-road evaluation of perceptual countermeasures,* report CR 219, Australian Transport Safety Bureau, Canberra, ACT.

A.1.8 Transverse Rumble Strips

Source: ARRB Group.

Description

Transverse rumble strips are small raised lines across the width of the lane that are designed to produce an audio-tactile effect that alerts drivers to an upcoming intersection. They are often used where there are stopping sight distance restrictions, high approach speeds, or a history of stop violations.

As with perceptual countermeasures, the findings are based on rural road environments due to limited information on the effectiveness and application on urban arterial roads.

Effectiveness

Speed reduction*:

- Up to 5 km/h reduction in speed.

Crash reduction*:

- 30% reduction in FSI crashes (CMF 0.70).
- 20% reduction in casualty crashes (CMF 0.80).

Road user effect/s (delays, congestion, consistency of travel time):

- Increased awareness of the intersection.
- More time to react to other vehicles on the intersection.

*Note that robust data from urban use is unavailable, so results from rural applications are presented as a guide.

Implementation issues

- Need to be placed so that the driver has enough time to slow down before the intersection and stop if necessary.
- Signs are also required to indicate the reason(s) to slow down.
- Significant maintenance costs due to cracking at the interface with the pavement.
- The profile for the rumble strips needs to be suitable so as not to present a hazard to motorcyclists.
- Noise issues in urban and residential areas.

Cost

Low

Treatment life

1–5 years

Applicability

- Rumble strips are noisy and should not be used near residential areas, with peri-urban and industrial areas more ideal. However, if driven over at higher speeds the noise and vibratory effects are less severe.

Key references and sources

Hore-Lacy, W 2008, ‘Rumble strip effectiveness at rural intersections and railway level crossings’, contract report VC73896-1, ARRB Group, Vermont South, Vic.

Srinivasan, R, Baek, J & Council, F 2010, ‘Safety evaluation of transverse rumble strips on approaches to stop-controlled intersections in rural areas’, *Journal of Transportation Safety and Security,* vol. 2, no. 3, pp. 261-78.

Thompson, TD, Burris, MW & Carlson, PJ 2006, ‘Speed changes due to transverse rumble strips on approaches to high-speed stop-controlled intersections’, *Transportation Research Record,* no. 1973, pp. 1-9.

A.1.9 Reduce Excessive Sight Distance

Source: Leicestershire County Council (2010) (UK example).

Description

Adequate sight distance is essential to provide drivers with enough reaction and manoeuvring time to adapt to the road features and to other road users. This involves improving the triangle sight distance at intersections, enhancing visibility for all road users at the intersection and, in some cases, reducing excess sight distance.

Although at first seemingly counter-intuitive, reducing excess sight distance at certain locations can also be effective at improving safety, particularly at roundabouts. Examples tend to involve the use of screens or hedges to reduce the view available of traffic approaching the intersection from other directions as in the above image. This prevents drivers from taking risks (including increasing their speed) by anticipating gaps that might not still be present when the traffic approaches the intersection. It also forces them to slow down in case they need to stop at the intersection. **Note that the minimum sight distance is still required at these locations.** This treatment is relatively untested in Australia or New Zealand and so detailed assessment should be undertaken at any potential sites before this treatment is used. Following installation, close monitoring should also be undertaken.

Effectiveness

Speed reduction:

- Up to 20 km/h reduction in 85th percentile speed at roundabouts.

Crash reduction:

- Up to 40% (CMF 0.60) for reductions in excess sight distances at roundabouts.

Road user effect/s (delays, congestion, consistency of travel time):

- Unknown.

Implementation issues

- Should allow sufficient sight distance for the driver or vehicle controller to make a sound judgement.
- Potential safety risks as a result of reduced visibility and the legal implications if any crashes were to happen as a result.
- Concerns about what effect this would have on vulnerable road users.
- Necessary to maintain the minimum sight distance required, but ‘excess’ sight distance could be removed.

Cost

Low

Treatment life

5–10 years

Applicability

- Best locations are lower speed/local environments, however, treatment use is site specific.

Key references and sources

Austroads & ARRB Group 2010, *Treatment type: sight distance improvements: intersection,* Austroads road safety engineering toolkit, Austroads & ARRB Group, Vermont South, Vic, viewed 29 November 2015, <http://www.engtoolkit.com.au>.

Charlton, S 2003, ‘Restricting intersection visibility to reduce approach speeds’, *Accident Analysis & Prevention,* vol. 35, no. 5, pp. 817-23.

Charman, S, Grayson, G, Helman, S, Kennedy, J, de Smidt, O, Lawton, B, Nossek, G, Wiesauer, L, Fürdös, A, Pelikan, V, Skládaný, P, Pokorný, P, Matejka, M & Tucka, P 2010, *Speed adaptation control by self-explaining roads: deliverable no 1: self-explaining roads literature review and treatment information,* Road ERA net, European Commission, Brussels, Belgium.

Elvik, R & Vaa, T 2009, *The handbook of road safety measures,* 2nd edn, Elsevier, Oxford, UK.

Leicestershire County Council 2010, *Road safety in Leicestershire 2010,* Leicestershire County Council, Leicester, UK, viewed 30 November 2015, <http://www.leics.gov.uk/road_safety_report_web.pdf>.

Rodegerdts, L, Nevers, B & Robinson, B 2004, *Signalized intersections: informational guide,* FHWA-HRT-04-091, Federal Highway Administration, Turner-Fairbank Highway Research Center, McLean, Virginia, USA.

Turner, SA, Roozenburg, AP & Smith, AW 2009, *Roundabout crash prediction models,* report 386, NZ Transport Agency, Wellington, New Zealand.

York, I, Bradbury, A, Reid, S, Ewings, T & Paradise, R 2007, *The manual for streets: evidence and research,* report no. 661, Transport Research Laboratory, Crowthorne, UK.

A.1.10 Lower Speed Limits

Source: ARRB Group.

Description

Involves lowering the mandatory (posted) speed limit on the approach to an intersection. This is typically used in combination with other treatments (for example, enhanced signage) and is rarely used as a sole method of speed reduction. No evidence was identified indicating a reduction in speed or crashes from reductions in speed limits using static signs alone; however, when used in combination with other treatments it appears that this treatment has promise. The effect also depends on the magnitude of the speed limit change.

Effectiveness

Speed reduction:

- Unknown.

Crash reduction:

- Unknown.

Road user effect/s (delays, congestion, consistency of travel time):

- Minimal increases in travel time likely.
- Mainly effective where there is a transition from high to low speed environment.

Implementation issues

- Risk of merging or conflicting with other road signs at intersections.

Cost

Low

Treatment life

10 years+

Applicability

- Typically needs to be combined with other treatments to help ensure compliance.

Key references and sources

Archer, J, Fotheringham, N, Symmons, M & Corben, B 2008, *Impact of lowered speed limits in urban and metropolitan areas,* report 276, Monash University Accident Research Centre, Clayton, Vic.

Austroads 2008, *Austroads guide to road safety part 3: speed limits and speed management,* AGRS03-08, Austroads, Sydney, NSW.

Austroads 2010, *Infrastructure/speed limit relationship in relation to road safety outcomes,* AP-T141-10, Austroads, Sydney, NSW.

Austroads 2010, *Impact of lower speed limits for road safety on network operations,* AP-T143-10, Austroads, Sydney, NSW.

Austroads 2011, *Safe intersection approach treatments and safe speeds through intersections: phase 2,* AP–R385-11, Austroads, Sydney, NSW.

Austroads 2014, *Model national guidelines for setting speed limits at high-risk locations,* AP-R455-14, Austroads, Sydney, NSW.

Austroads 2014, *Guide to traffic management part 5: road management,* 2nd edn, AGTM05-14, Austroads, Sydney, NSW.

Jaarsma, R, Louwerse, R, Dijkstra, A, de Vries, J & Spaas, J 2011, 'Making minor rural road networks safer: the effects of 60 km/h-zones', *Accident Analysis & Prevention,* vol. 43, no. 4, pp. 1508-15.

Jurewicz, C & Turner, B 2011, 'Risk-based approach to speed limits: a step towards safe system', *Australasian College of Road Safety conference, 2011, Melbourne, Victoria,* Australasian College of Road Safety (ACRS), Pearce, ACT, 17 pp.

Sharma, A, Wu, Z, Wang, S & Rilett, L 2012, *Speed limit recommendation in vicinity of signalized, high-speed intersection,* report SPR-P1 (11) M307, Mid-America Transportation Center, Lincoln, Nebraska, USA.

A.1.11 Variable Speed Limits (VSL)

Note: the yellow line indicates that the VSL is triggered by the presence of a vehicle on the side road.

Source: Mackie et al. (2014).

Description

Variable speed limit (VSL) signs are dynamic or adjustable road signs displaying variable statutory speed limits depending on prevailing traffic, weather and road conditions. They are a form of intelligent transport system (ITS) technology with the simplest informing drivers of designated speed limits along roadways. The VSL system utilises information about prevailing road environment conditions such as traffic speed, traffic volume and weather, road surface conditions and/or approaching traffic to determine appropriate speed limits.

The findings are based on rural roads as there was limited research on urban arterial applications of VSL.

Effectiveness

Speed reduction*:

- Up to 17 km/h reduction in 85th percentile speed.

Crash reduction*:

- 8% reduction (CMF 0.92).

Road user effect/s (delays, congestion, consistency of travel time):

- Improved traffic flow.

*Note that robust data from urban use is unavailable, so results from rural applications are presented as a guide.

Implementation issues

- The post presents a hazard to errant vehicles and frangible posts should be used where possible.
- A power supply is needed, which is particularly an issue in remote rural areas, although solar powered signs are now available.
- The speed limit should not change too frequently as this might cause confusion.
- Enforcement is needed to encourage/promote compliance.

Cost

Low to medium

Treatment life

5–10 years

Applicability

- Also applied where there are variable traffic conditions and traffic mix, e.g. in high pedestrian activity areas where there is potential for conflict between pedestrians and vehicles.

Key references and sources

Austroads 2009, *Best practice for variable speed limits: literature review,* AP-R342-09, Austroads, Sydney, NSW.

Austroads 2009, *Best practice for variable speed limits: report on user perception and comprehensive study,* AP-R343-09, Austroads, Sydney, NSW.

Austroads 2014, *Guide to traffic management part 5: road management,* 2nd edn, AGTM05-14, Austroads, Sydney, NSW.

Bham, GH, Long, S, Baik, H, Ryan, T, Gentry, L, Lall, K, Arezoumandi, M, Liu, D, Li, T & Schaeffer, B 2010, *Evaluation of variable speed limits on I-270/I-255 in St. Louis,* report RI08-025, Missouri University of Science and Technology, Rolla, MO, USA.

Lennie, S & Han, C 2010, ‘Best practice for VSL signs in Australia’, *ARRB conference, 24th, Melbourne, Victoria, Australia,* ARRB Group, Vermont South, Vic, 12 pp.

Mackie, H, Holst, K, Brodie, C & Tate, F 2014, ‘New Zealand’s rural intersection active warning system’, *Australasian road safety research policing education conference, 2014, Melbourne, Victoria, Australia,* Australasian College of Road Safety, Mawson, ACT, 11 pp.

Swedish Road Administration 2006, ‘Variable speed limits: evaluation at intersections’, Vagverket, Borlange, Sweden.

A.1.12 Lane Narrowing

Source: ARRB Group (example from UK).

Austroads, (2011).

Description

Lane narrowing at intersections is usually achieved with kerb extensions, solid or painted medians and wider shoulders. This encourages motorists to slow down to navigate through the narrower section at a more appropriate speed. Additionally, perceptual countermeasures may also act to produce a perceived narrowing of lanes on approach to intersections.

Kerb extensions limit the use of kerbside turning lanes, so lane narrowing is generally not recommended for high-capacity roads, or where there is a significant volume of buses, heavy vehicles or cyclists.

Effectiveness

Speed reduction:

- 7 km/h reduction in 85th percentile speed.

Crash reduction:

- Up to 30% reduction (CMF 0.70).

Road user effect/s (delays, congestion, consistency of travel time):

- Improved pedestrian safety due to reduced crossing distances.

Implementation issues

- Ensure consistency in application to avoid driver confusion.
- Adequate lane width is needed for emergency and heavy vehicles to navigate.
- Introduces issues for cyclist movements.
- Can potentially reduce road capacity, therefore application should be carefully considered.

Cost

Low

Treatment life

15 years

Applicability

Narrowing the road at intersections is a treatment generally reserved for residential streets, as a narrow road design can negatively impact on heavy vehicles, transit vehicles and bicycles, although a narrower road can create space for wider footpaths, kerbside parking or central medians.

Key references and sources

Austroads & ARRB Group 2010, *Treatment type: intersections: splitter islands,* Austroads road safety engineering toolkit, Austroads & ARRB Group, Vermont South, Vic, viewed 29 November 2015, <http://www.engtoolkit.com.au>.

Austroads 2011, *Safe intersection approach treatments and safe speeds through intersections: phase 2,* AP–R385-11, Austroads, Sydney, NSW.

NCHRP 2008, *Guidelines for selection of speed reduction treatments at high-speed intersections,* NCHRP report 613, Transportation Research Board, Washington, DC, USA.

A.1.13 Signals: Green Wave

Source: ARRB Group.

Description

Localised green wave or linked signals refer to coordinating adjacent traffic signals or linking several signals at intersections along a particular route segment on major urban arterial road such that a vehicle travelling at a recommended speed will be rewarded with consecutive green lights. This is likely to reduce travel time, speed variability and emissions. The approach is used to manage traffic, but is sometimes assumed to be an effective method for reducing speeds. No evidence was identified relating to speed reduction or safety benefits from this treatment.

Effectiveness

Speed reduction:

- Unknown.

Crash reduction:

- Unknown.

Road user effect/s (delays, congestion, consistency of travel time):

- Reduced braking and stopping, in turn reducing the likelihood of rear-end crashes.
- Reduction pollution and emissions (10–40% reduction).
- Reduced wear and tear on vehicles due to smoother traffic flow.
- 10–20% reduction in travel time.
- Increases in noise levels in-between intersections.

Implementation issues

- Coordination usually results in increased delay for vehicles entering the coordinated system. It can also be costly if major signal controller or communications hardware upgrades are necessary. The time taken to design the coordination scheme and program the signal controllers can vary.
- Concerns if it is implemented to speeds more than 50 km/h as vehicles might speed to get into the green wave.
- Speed guidance may be required as road users may not know what speed to travel at in order to get the green wave.
- Operation of traffic signals should be reviewed every two to three years.

Cost

Low

Treatment life

1–5 years

Applicability

- Works best in unsaturated traffic conditions.

Key references and sources

De Coensel, B, Can, A, Degraeuwe, B, De Vlieger, I & Botteldooren, D 2012, ‘Effects of signal coordination on noise and air pollutant emissions’, *Environmental Modelling & Software,* vol. 35, pp. 74-83.

Stevanovic, AZ, Stevanovic, J & Kergaye, C 2012, ‘Impact of signal phasing information accuracy on green light optimized speed advisory systems’, *Transportation Research Board 92nd annual meeting,* TRB, Washington, DC, USA, 13 pp.

A.1.14 Signals: Dwell-on-red

Source: ARRB Group.

Description

The dwell-on-red (or rest-on-red) treatment involves programming an additional phase into signalised intersections and pedestrian crossings so that an all red phase is displayed when there is no traffic or pedestrian demand. The signals only switch to green when a vehicle or pedestrian activates the change, either through vehicle detection, or through manual activation by pedestrians at a crossing point. The treatment is applied in high night-time pedestrian activity centres, including those where pedestrians are likely to be alcohol affected. The overall aim of rest-on-red signals is to reduce vehicle speeds and bring down the proportion of vehicles travelling at a speed that threatens severe pedestrian injury.

Effectiveness

Speed reduction*:

- Up to 11 km/h.

Crash reduction*:

- Up to 45% reduction (CMF 0.55).

Road user effect/s (delays, congestion, consistency of travel time):

- Possible vehicle delay, however, this is in off-peak conditions.

*These results include outcomes from an evaluation conducted through this Austroads project. This work will be published separately in the near future.

Implementation issues

- Treatment effectiveness depends on traffic flow, implementation should therefore take traffic flow during operating times into consideration.
- Local knowledge of high alcohol times should be applied.

Cost

Low

Treatment life

1–5 years

Applicability

- This treatment has typically been applied on arterial roads where there are likely to be high volumes of alcohol-affected pedestrians, and is only activated late at night and into the early morning.

Key references and sources

Archer, J, Candappa, N & Corben, B 2008, Effectiveness of the dwell-on-red signal treatment to improve pedestrian safety during high alcohol hours, *Australasian road safety research policing education conference, 2008, Adelaide, South Australia*, Department for Transport, Energy and Infrastructure, Walkerville, South Australia, 14 pp.

Lenne, MG, Corben, BF & Stephan, K 2007, 'Traffic signal phasing at intersections to improve safety for alcohol-affected pedestrians', *Accident Analysis & Prevention*, vol. 39, no. 4, pp. 751–6.

A.2 Urban Arterial Midblocks

A.2.1 Humps/Platforms

Source: ARRB Group.

Description

Humps/platforms refer to vertical deflection treatments used to control speed, with various forms of speed humps available for different road types. Speed humps are around 100 mm high and 3–4 m wide and are generally recommended for use on local roads. Speed tables and platforms consist of an approach transition of approximately 1.8 m, rising to a height of 70–100 mm above the road surface, with a flat section of around 3–6 m in between. The exact length and grade of entrance and exit ramps and the length of the table will differ depending on the function of the road.

Effectiveness

Speed reduction*:

- Up to 25 km/h reduction in 85th percentile speed.
- 25 km/h reduction in mean speed.
- 5–15% reduction in 85th percentile speeds at Seminole humps and 11–18% at Watts humps.

Crash reduction*:

- 40% reduction in serious injury and minor injury crashes (CMF 0.60).

Road user effect/s (delays, congestion, consistency of travel time):

- increase in vehicle delay and travel time
- increase in emissions.

*These results include outcomes from an evaluation conducted through this Austroads project. This work will be published separately in the near future.

Implementation issues

- At higher speeds, aggressive humps/platforms can cause significant driver discomfort and damage to some vehicles. Milder ramp profiles of 1:12 used on roads ≤ 60 km/h and 1:30 or 1:35 on 70 km/h roads.
- There also needs to be consideration for heavy and emergency response vehicles.
- Through traffic and overall traffic volumes, and traffic mix should be considered before application.
- Adequate provision of drainage should be considered.
- Should be applied with associated advance warning signs.
- Priority issue – pedestrians interpreting raised platform as pedestrian crossing.
- Inconsistency in design (colour/texture etc.) across the road network may affect user perception.
- Potential noise concerns.

Cost

Medium

Treatment life

10 years+

Applicability

- Suitable for lower tier arterial roads with limited emergency and heavy vehicle volumes.
- Typically applied in environments of up to 60 km/h.

Key references and sources

Austroads 2015, *Improving the performance of safe system infrastructure: final report,* AP-R498-15, Austroads, Sydney, NSW.

Elvik, R & Vaa, T 2009, *The handbook of road safety measures,* 2nd edn, Elsevier, Oxford, UK.

Gordon, G 2011, 'Mixed priority routes: results update and cost review', Department for Transport, London, UK.

Marek, J & Walgren, S 2000, *Mid-block speed control: chicanes and speed humps,* City of Seattle, Washington, USA.

Moreno, AT, Garcia, A & Romero, MA 2011, 'Speed table evaluation and speed modeling for low-volume crosstown roads', *Transportation Research Record,* no. 2203, pp. 85-93.

Pratt, K, Roper, P & Wright, B 2015, 'Innovative safety platform trials', contract report 009261-1 ARRB Group, Vermont South, Vic.

A.2.2 Vehicle Activated Signs (VAS)

Source: Burbridge et al. (2010).

Description

The main types of vehicle activated signs (VAS) implemented at midblock segments are hazard warning (e.g. curve warning) and speed advisory signs. They are mainly installed in locations with known/identified speeding problems or speed-related crash history or in instances where the use of standard static speed and warning signs has not been effective in lowering travelling speeds or altering driver behaviour.

The findings are based on rural applications.

Effectiveness

Speed reduction*:

- 10 km/h reduction in 85^{th} percentile speed.

Crash reduction*:

- 35% reduction in casualty crashes (CMF 0.65).

Road user effect/s (delays, congestion, consistency of travel time):

- Increases driver awareness of surrounding environment.

*Note that robust data from urban use is unavailable, so results from rural applications are presented as a guide.

Implementation issues

- Vandalism has been noted as an issue, especially in isolated rural locations.
- Overuse of the treatment may reduce its novelty value, and therefore effectiveness.
- The line of sight from the sign to the vehicle should be clear so that the radar detection works effectively, and the sign is clearly visible.
- There may be power supply issues in rural areas, although solar-powered devices are now available.
- As the sign presents a hazard to errant vehicles, it should be frangible.
- Consistency across the road network is required.

Cost

Medium

Treatment life

5–10 years

Applicability

- Generally applied at hazardous locations or when entering a mixed traffic zone, e.g. school zones, work zones or strip shopping centres.
- Can be applied at isolated hazard locations e.g. curves.

Key references and sources

Austroads & ARRB Group 2010, *Treatment type: miscellaneous: vehicle activated signs,* Austroads road safety engineering toolkit, Austroads & ARRB Group, Vermont South, Vic, viewed 29 November 2015, <http://www.engtoolkit.com.au>.

Austroads 2014, *Methods for reducing speeds on rural roads: compendium of good practice*, AP-R449-14, Austroads, Sydney, NSW.

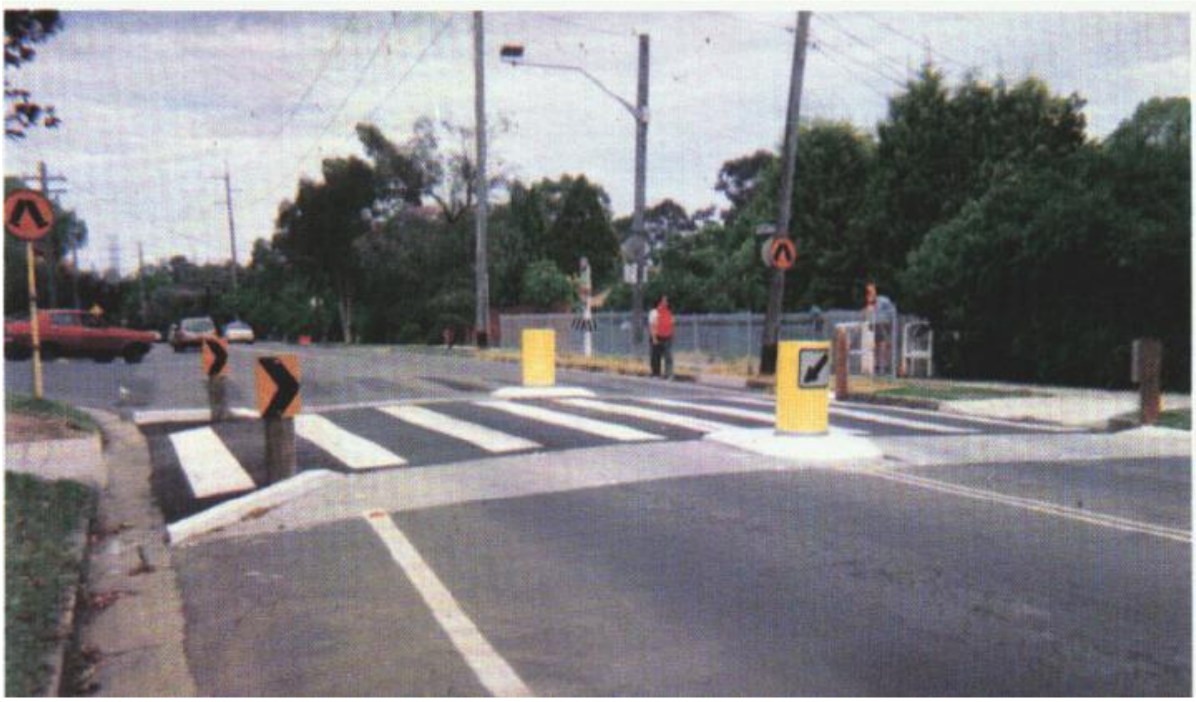
Burbridge, A, Eveleigh, M & Van Eysden, P 2010, 'Queensland experiences with vehicle activated signs', *Australasian road safety research policing education conference, 2010, Canberra, ACT,* Conference Logistics, Kingston, ACT, 12 pp.

Gardener, R & Kortegast, P 2010, *Trial of vehicle activated electronic signs for improved driver awareness at known crash sites in Tasman and Marlborough districts*, technical note, NZ Transport Agency, Wellington, New Zealand.

Makwasha, T & Turner, B 2014, 'Evaluating vehicle activated signs on rural roads', *ARRB conference, 26th, 2014, Sydney, New South Wales,* ARRB Group, Vermont South, Vic, 15 pp.

Winnett, MA & Wheeler, AH 2002, *Vehicle-activated signs: a large scale evaluation*, report 548, TRL Limited, Crowthorne, UK.

A.2.3 Wombat Crossing (Raised Pedestrian Crossing)



Source: Hawley et al. (1993).

Description

Raised pedestrian crossings, typically termed wombat crossings in Australia, have a similar profile and speed reduction effect as flat top speed humps but they differ in that they give priority to pedestrians rather than motorists. Wombat crossings consist of a raised platform with a marked pedestrian crossing on top, with a central refuge and kerb blisters if space permits. The raised crossing serves the purpose of slowing vehicles, as for a speed hump or platform, but also increases the visibility of pedestrians due to the increased height.

Effectiveness

Speed reduction*:

- Up to 9 km/h reduction in 85th percentile speed.
- Up to 8 km/h reduction in mean speed.

Crash reduction*:

- 40% reduction in casualty crashes (CMF 0.60).
- 30% reduction in serious and minor injury crashes (CMF 0.70).
- 45% reduction in vehicle-pedestrian crashes (CMF 0.55).

Road user effect/s (delays, congestion, consistency of travel time):

- Increased response time for emergency vehicles, increases in noise levels, drainage problems.

*These results include outcomes from an evaluation conducted through this Austroads project. This work will be published separately in the near future.

Implementation issues

- Wombat crossings have similar dimensions to road platforms, with more gradual ramps and longer flat sections recommended on bus and bicycle routes.
- Ongoing maintenance required for the trafficked area.
- Drainage needs to be considered during platform installation.
- Need to be highly visible to drivers–this can be achieved by using lighting treatments or contrasting pavement designs.
- Less priority concerns/confusion than humps/platforms, provided adequate crossing signs are consistently installed.

Cost

Medium to high

Treatment life

10 years+

Applicability

- Suitable for high pedestrian volume locations e.g. strip shopping centres, school zones and in low speed sections of arterial roads.
- Usage has historically been on local/lower category roads, however, the treatment shows promise on arterial roads.
- Generally not applied on multilane roads as the higher crossing distance might present a crash risk for pedestrians and also cause vehicle delay.

Key references and sources

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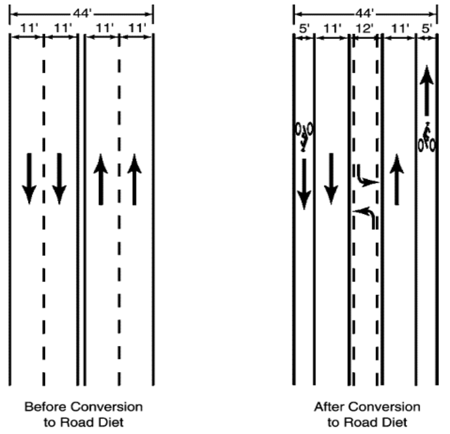
Zegeer, CV, Stewart, JR, Huang, HH, Lagerwey, P, Feaganes, J & Campbell, BJ 2005, *Safety effects of marked versus unmarked crosswalks at uncontrolled locations: final report and recommended guidelines*, HRT-04-100, Federal Highway Administration, McLean, Virginia, USA.

A.2.4 Road Diet (Median Turning Lanes)



Source: Saak (2007).

Source: ARRB Group.

Description

Road diets have been extensively used in the USA and involve converting a four-lane road (two each way) into a road with only one lane in each direction, and a two-way right-turn lane in the centre. A road diet can also provide enough space to install a bicycle lane or on-street parking.

Effectiveness

Speed reduction*:

- 4 km/h reduction in 85th percentile speed
- 5 km/h reduction in mean speed.

Crash reduction*:

- 35% reduction in casualty crashes (CMF 0.65).

Road user effect/s (delays, congestion, consistency of travel time):

- minimal increases in travel time
- reduces turning movement conflicts
- reduces crossing distance for pedestrians
- possible reallocation of road space to transit, cyclists and or emergency vehicles
- reduces speed differentials.

*These results include outcomes from an evaluation conducted through this Austroads project. This work will be published separately in the near future.

Implementation issues

- Installation of median turning lanes should not impede traffic flow or create operation problems.
- A clear understanding of the turning volumes and movements at the treatment site is required.
- Relatively cheap but can greatly impact and reduce road capacity and vehicle volumes.

Cost

Low to medium

Treatment life

1–5 years

Applicability

- Typically applied to high traffic volume four-lane undivided arterials with a high volume of vehicles sharing the inside lane for higher speed through movements and right turns.
- Suitable for roads with traffic volumes of up to 20 000 vehicles per day.

Key references and sources

Harkey, D, Srinivasan, R, Baek, J, Persaud, B, Lyon, C, Council, F, Eccles, K, Lefler, N, Gross, F, Hauer, E & Bonneson, J 2008, *Crash reduction factors for traffic engineering and ITS improvements*, NCHRP report 617, Transportation Research Board, Washington, DC, USA.

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Noyce, D, Talada, V & Gates, T 2006, *Safety and operational characteristics of two-way left-turn lanes*, report MN/RC 2006-25, Minnesota Department of Transportation, St Paul, MN, USA.

Pawlovich, MD, Li, W, Carriquiry, A & Welch, T 2006, 'Iowa's experience with road diet measures: use of Bayesian approach to assess impacts on crash frequencies and crash rates', *Transportation Research Record*, no. 1953, pp. 163-71.

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Saak, J 2007, 'Using roadway conversions to integrate land use and transportation: the East Boulevard experience', slide presentation, *SDITE annual meeting, 2007, Knoxville, TN, USA*, Southern District of ITE (SDITE), USA.

A.2.5 Pedestrian Refuge Island

Source: ARRB Group.

Source: ARRB Group.

Description

A pedestrian refuge island is a raised median island in the middle of the road with at-grade space provided for pedestrians to wait until a gap in traffic allows them to complete crossing the road. It also acts as a median island that can narrow the travel path and have a speed reduction effect. Refuges effectively allow pedestrians to cross two narrow one-way streets rather than attempt to cross one wide two-way street. Refuges are particularly beneficial to elderly pedestrians and those with impaired mobility who may otherwise find it difficult to cross a street in one movement.

Effectiveness

Speed reduction:

- Potential for speed reduction due to lane narrowing, however, no statistics available.

Crash reduction:

- 25% reduction in casualty crashes (CMF 0.75)
- 45% reduction in pedestrian crashes (CMF 0.55).

Road user effect/s (delays, congestion, consistency of travel time):

- Provides pedestrian crossing facility, encouraging walking.
- Reduces pedestrian exposure to traffic by splitting crossing distances and pedestrian crossing points.
- Reduces pedestrian waiting time.

Implementation issues

- Clear delineation and lighting required to ensure the refuge is clearly visible to approaching traffic.
- Placement of the refuge should also allow for or take into consideration other road space needs at the location, e.g. the presence of cyclists might mean provision of additional space.
- Turning movements from driveways and intersections need to be carefully evaluated when considering the location of a refuge.
- Islands should be designed to cater for pedestrians with visual and mobility impairment.
- Refer to local standards and guides for treatment implementation, e.g. AS 1742.10-2009.

Cost

Low to medium

Treatment life

20 years+

Applicability

- Used where there is a high concentration of pedestrians and where it is difficult to cross the full roadway in one stage.
- Speed reductions are dependent on how much the traffic lane is narrowed.
- Also used in locations where pedestrian movements are distributed over a length of road, rather than centralised, e.g. strip shopping centres.
- Suitable for low volume arterial roads and strip shopping centres.
- Applied where there is sufficient room for vehicles to pass.

Key references and sources

Austroads 2012, *Effectiveness of road safety engineering treatments*, AP-R422-12, Austroads, Sydney, NSW.

Department for Transport 1995, *The design of pedestrian crossings*, Local Transport Note 2/95, DfT, London, UK.

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Retting, R, Ferguson, S & McCartt, A 2003, 'A review of evidence-based traffic engineering measures designed to reduce pedestrian-motor vehicle crashes', *American Journal of Public Health*, vol. 93, no. 9, pp. 1456-63.

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Zegeer, C, Stewart, J, Huang, H & Lagerwey, P 2001, 'Safety effects of marked versus unmarked crosswalks at uncontrolled locations', *Transportation Research Record,* no. 1773, pp. 56–68.

A.2.6 Medians

Source: ARRB Group.

Description

A median reduces speeds through the installation of a raised or painted (flush) median treatment. This involves the physical separation between opposing traffic streams, increasing the distance and the recovery area in case of a driver error. In some cases safety barrier systems can also be employed to prevent vehicle encroachment into opposing traffic lanes. Provision of a physical median is usually associated with a major road upgrade or a duplication of carriageways while flush medians are a low cost alternative.

Effectiveness

Speed reduction:

- Mixed results.

Crash reduction:

- 15% reduction in casualty crashes (CMF 0.85) for flush/painted median.
- 46% reduction in casualty crashes (CMF 0.54) for raised median.

Road user effect/s (delays, congestion, consistency of travel time):

- Likely to restrict right turns in or out of side roads and properties.
- May require design of median breaks and turning lanes.
- Potential to increase efficiency through improved traffic flow.

Implementation issues

- The use of medians varies depending on available space and surrounding land use. This determines the extent and type of median solution applied. Community acceptance of the medians that restrict turning movements may be an issue. Regular gaps may need to be provided, along with sheltered turning lanes.
- Regular and on-going maintenance is required. The maintenance costs vary by median type.
- Drainage should be taken into consideration before median installation.
- Concern that vehicles may try to overtake using flush medians.
- Questionable whether speeds are reduced.

Cost

Medium to high

Treatment life

1–5 years for flush median

10 years+ for raised median

Applicability

- Very narrow medians often cannot accommodate signs, traffic signal hardware, or provide staging for pedestrians.
- Speed reductions are dependent on how much traffic lane is narrowed.
- Providing adequate roadside lighting for a narrow median may be an issue if the carriageways are wide.

Key references and sources[2]

Ahmed, M, Abdel-Aty, M & Park, J 2015, 'Evaluation of the safety effectiveness of the conversion of two-lane roadways to four-lane divided roadways: Bayesian vs. empirical Bayes', *94th Annual meeting of the Transportation Research Board*, TRB, Washington, DC, USA, paper no. 15-0830.

Austroads & ARRB Group 2010, *Treatment type: midblock: median retrofit,* Austroads road safety engineering toolkit, Austroads & ARRB Group, Vermont South, Vic, viewed 25 November 2015, <http://www.engtoolkit.com.au>.

Charlton, S & Baas, P 2006, *Speed change management for New Zealand roads*, research report 300, Land Transport New Zealand, Wellington, NZ.

Zegeer, C, Stewart, J, Huang, H & Lagerwey, P 2001, 'Safety effects of marked versus unmarked crosswalks at uncontrolled locations', *Transportation Research Record,* no. 1773, pp. 56–68.

[2] Austroads forthcoming, Guidance on median and centreline treatments to reduce head-on casualties, Austroads, Sydney, NSW.

A.2.7 Gateway Treatments

Source: Land Transport Safety Authority (2002).

Source: Transport and Main Roads.

Description

Gateway treatments (also referred to as entry treatments or thresholds) are used to delineate transitions from higher speed to lower speed environments, or mark a change from a major to a residential road. This is achieved through the use of raised pavements, speed signs, coloured pavements and different pavement types.

There was no available literature on the effectiveness of gateway treatments on urban roads. Consequently, the findings on rural roads are provided as an indicative measure.

Effectiveness

Speed reduction*:

- Up to 25 km/h in 85th percentile speed.
- Up to 15 km/h in mean speed.

Crash reduction*:

- 25% reduction in casualty crashes (CMF 0.75).
- 35% reduction if pinch point used (CMF 0.65).
- 40% reduction in FSI crashes if pinch point is used (CMF 0.60).

Road user effect/s (delays, congestion, consistency of travel time):

- Raised awareness of a change in road environment.

*Note that robust data from urban use is unavailable, so results from rural applications are presented as a guide.

Implementation issues

- Needs to be located at the point where development commences to be most effective.
- Should be backed up by changes in the environment (e.g. use of painted medians) after the threshold to maintain the speed reductions.
- Introduction of street furniture may introduce hazards for errant vehicles.
- Care should be taken so that the gateway does not have a negative effect on skid resistance, presenting an additional risk, particularly for motorcyclists.
- There may be maintenance issues associated with this treatment.

Cost

Low to medium

Treatment life

5–20 years depending on selected features

Applicability

- Suitable for transition zones or where there are clear changes in traffic conditions and speed environment (e.g. entry to a shopping strip).

Key references and sources

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Forbes, G 2011, *Speed reduction techniques for rural high-to-low speed transitions,* NCHRP SHP 412, Transportation Research Board, Washington, DC, USA.

Galante, F, Mauriello, F, Montella, A, Pernetti, M, Aria, M & D'Ambrosio, A 2010, 'Traffic calming along rural highways crossing small urban communities: driving simulator experiment', *Accident Analysis & Prevention*, vol. 42, no. 6, pp. 1585-94.

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Makwasha, T & Turner, B 2013, 'Evaluating the use of rural-urban gateway treatments in New Zealand', *Australasian road safety research policing education conference, 2013, Brisbane, Queensland, Australia,* Australasian College of Road Safety, Mawson, ACT, 9 pp.

Steinbrecher, J 1992, 'Restructuring of town entrances on roads classified as major', *Road safety in Europe conference, 1992, Berlin, Germany*, VTI rapport 380A, part 4, Swedish Road and Traffic Research Institute, Linköping, Sweden, pp. 17-31.

Wheeler, A, Taylor, M & Payne, A 1993, *The effectiveness of village 'gateways' in Devon and Gloucestershire*, project report no. 35, Transport Research Laboratory, Crowthorne, UK.

A.2.8 Transverse Rumble Strips

Source: ARRB Group.

Description

Transverse rumble strips are audio-tactile strips that extend across the travel lane to alert drivers to unusual or changing traffic conditions. They can be placed at midblock locations to warn drivers of an upcoming curve or hazard, especially where the advised speed at the curve is significantly different to the speed limit. The strips work due to the unpleasant feeling they produce through vibrations and wheel noise, and can be used at decreasing intervals to give drivers a sensation of speeding up.

The findings are for rural applications.

Effectiveness

Speed reduction:

- Unknown.

Crash reduction*:

- 34% reduction in all crashes (CMF 0.66).
- 36% reduction in serious and minor injury crashes (CMF 0.64).
- 25% reduction in FSI crashes (CMF 0.75).

Road user effect/s (delays, congestion, consistency of travel time):

- Motorcyclist and cyclist vehicle control concerns.

*Note that robust data from urban use is unavailable, so results from rural applications are presented as a guide.

Implementation issues

- Ongoing maintenance required as treatment loses effectiveness in trafficked areas.
- Noise can be an issue in built-up areas.

Cost

Low

Treatment life

1–5 years

Applicability

- Transverse rumble strips are noisy when driven over, so are more suited to low speed environments where the noise is less severe e.g. industrial sites, urban fringes or rural roads away from residential/built up areas.

Key references and sources

Charman, S, Grayson, G, Helman, S, Kennedy, J, de Smidt, O, Lawton, B, Nossek, G, Wiesauer, L, Fürdös, A, Pelikan, V, Skládaný, P, Pokorný, P, Matejka, M & Tucka, P 2010, *Speed adaptation control by self-explaining roads: deliverable no 1: self-explaining roads literature review and treatment information*, Road ERA net, European Commission, Brussels, Belgium.

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Hore-Lacy, W 2008, 'Rumble strip effectiveness at rural intersections and railway level crossings', contract report VC73896-1, ARRB Group, Vermont South, Vic.

Srinivasan, R, Baek, J & Council, F 2010, 'Safety evaluation of transverse rumble strips on approaches to stop-controlled intersections in rural areas', *Journal of Transportation Safety and Security*, vol. 2, no. 3, pp. 261-78.

Thompson, T, Burris, M & Carlson, P 2006, 'Speed changes due to transverse rumble strips on approaches to high-speed stop-controlled intersections', *Transportation Research Record*, no. 1973, pp. 1-9.

A.2.9 Shared Spaces/Naked Roads

Source: ARRB Group (UK example).

Description

Shared spaces, otherwise known as 'naked roads', are an urban design concept where the priority for users is shifted from vehicles towards pedestrians and cyclists. This shared use encourages better public spaces for the community. While shared spaces can be achieved in different ways, the general concept involves removing conventional road management systems such as traffic signals and signs, kerbs, barriers and line markings. Shared spaces are related but different to shared zones which typically do not involve the removal of this infrastructure.

Effectiveness

Speed reduction:

- There are mixed results for this treatment, although some studies show up to a 13 km/h reduction in mean and 85^{th} percentile speed.

Crash reduction:

- There are mixed results for this treatment with some studies showing safety improvements, while others report increases in risk, particularly for vulnerable roads users. Some studies show a 49% reduction in casualty crashes (CMF 0.51).

Road user effect/s (delays, congestion, consistency of travel time):

- 20% increase in pedestrian usage.
- Increased risk for vulnerable road users (pedestrians and cyclists); additionally, evidence of safety concerns for vision and hearing impaired pedestrians.
- The low speed environment results in less severe crash outcomes.

Implementation issues

- Shared space applications depend on the area specific traffic and spatial problems.
- They require substantial re-design of road and pedestrian space to create a distinct environment.
- There could be confusion with who has priority.
- This treatment can present some problems for the visually and hearing impaired.

Cost

Medium to high

Treatment life

10 years+

Applicability

- Shared space is typically applied in high pedestrian volume areas, including strip shopping centres.
- Not considered possible for roads with traffic volumes of more than 15 000 vehicles per day.

Key references and sources

Austroads 2014, *Guide to traffic management part 5: road management*, 2nd edn, AGTM05-14, Austroads, Sydney, NSW.

Department of Transport 2012, ‘Bendigo town centre: creating shared space to improve pedestrian safety’, Department of Transport Victoria, Melbourne, Vic.

Gordon, G 2008, ‘Newland Avenue, Kingston-upon-Hull City Council, mixed priority route demonstration project’, WSP Development and Transportation, Birmingham, UK.

Quimby, A & Castle, J 2006, *A review of simplified streetscape schemes*, Transport Research Laboratory, Crowthorne, UK.

A.2.10 Lower Speed Limits

Source: ARRB Group.

Description

Involves lowering the posted speed limits using static signs towards Safe System levels. This is a widely applied speed management measure aimed at producing lower vehicle speeds, and crash and injury severity reductions. Surrounding land use, traffic mix, volumes, overall road function and the road safety record should be considered before speed limit changes are applied.

Effectiveness

Speed reduction:

- 3–4 km/h reductions in mean speed (short term), in the long run, mean speed reverts to the speed limit reduction.
- 6 km/h reduction in 85th percentile speed.

Crash reduction:

- 25% reduction in casualty crashes (CMF 0.75).

Road user effect/s (delays, congestion, consistency of travel time):

- Reduced vehicle vibrations, noise and emissions.
- Increase in traffic flow reducing congestion and delays.
- Reduction in vehicle operating costs.

Implementation issues

- Speed limit reviews should be implemented as part of a wider speed management or zoning plan, taking into consideration the road function and recommended speed limit, surrounding land use, traffic mix, road alignment and crash history and record. Jurisdictional speed zoning/management guidelines and AS 1742.4-2008 provide detailed instructions on the process.
- Speed limit changes should be part of a combined strategy such as traffic calming or driver perception changes designed to reduce the speeds of vehicles.
- Consider intersecting local roads.
- Repeater signs, advance warning signs and enforcement should also be implemented in order to increase compliance.

Cost

Low

Treatment life

10 years+

Applicability

- Should be applied as an area or zone-wide measure.
- There may be a need to alter the speed environment to increase compliance as outlined in Section 4.2.2.

Key references and sources[3]

Archer, J, Fotheringham, N, Symmons, M & Corben, B 2008, *Impact of lowered speed limits in urban and metropolitan areas*, report 276, Monash University Accident Research Centre, Clayton, Vic.

Austroads & ARRB Group 2010, *Treatment type: speed limit change,* Austroads road safety engineering toolkit, Austroads & ARRB Group, Vermont South, Vic, viewed 25 November 2015, <http://www.engtoolkit.com.au>.

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De Pauw, E, Thierie, M, Daniels, S & Brijs, T 2012, 'Safety effects of restricting the speed limit from 90 to 70 km/h', *91st Annual meeting of the Transportation Research Board*, Washington, DC, USA, paper no. 12–1360.

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Haworth, N, Ungers, B, Vulcan, P & Corben, B 2001, *Evaluation of a 50 km/h default urban speed limit for Australia*, National Road Transport Commission, Melbourne, Vic.

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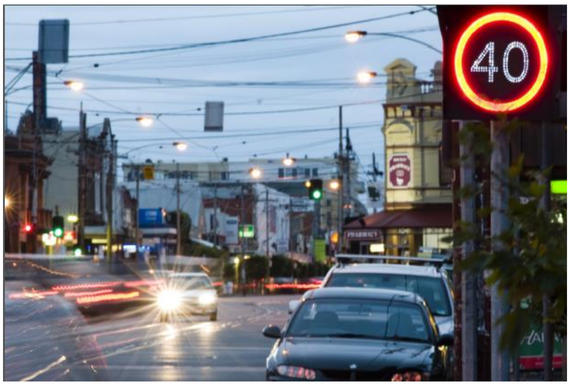
Roads and Traffic Authority 2000, *50 km/h urban speed limit evaluation: summary report*, RTA, Sydney, NSW.

Standards Australia 2008, *Manual of uniform traffic control devices: part 4: speed controls*, AS 1742.4-2008, Standards Australia, North Sydney, NSW.

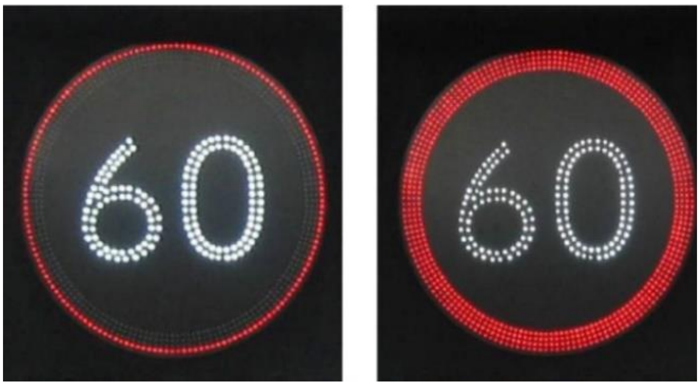
Walsh, D & Smith, M 1999, 'Effective speed management: the next step forward: saving lives by decreasing speeds in local streets', *Road safety research, policing, education conference, 2nd, 1999, Canberra, ACT*, Australian Transport Safety Bureau, Canberra, ACT, pp. 685–94.

Woolley, J 2005, 'Recent advantages of lower speed limits in Australia', *Journal of the Eastern Asia Society for Transportation Studies*, vol. 6, pp. 3562–73.

A.2.11 Variable Speed Limits (VSL)



Source: VicRoads.



Source: Roads and Maritime Services (2014).

Description

Variable speed limits (VSL) are dynamic road signs displaying variable enforceable speed limits depending on prevailing traffic, weather and road conditions. There are three main types of VSL: speed harmonisation, speed buffering and speed reduction. Speed harmonisation VSL reduce speed differentiation between vehicles and lanes; speed buffering VSL produce gradual reduced speed zones and are mainly applied in cases of downstream congestion; speed reduction VSL reduce or lower speeds to match prevailing conditions (weather, road and traffic, e.g. congestion).

Effectiveness

Speed reduction:

- unknown, but evidence of overall reductions in speed
- increase compliance with prevailing speed limits.

Crash reduction:

- 8% reduction in casualty crashes (CMF 0.92).

Road user effect/s (delays, congestion, consistency of travel time):

- increase driver awareness of changing traffic and road conditions
- used for congestion management, improving travel speeds in congested conditions
- can create smoother and more regular flows.

Implementation issues

- Sign placement and visibility are crucial in the effectiveness of VSL in speed management. The threshold speed and traffic volume should be carefully considered to take into account local/location-specific conditions.
- Enforcement and consistent signage are required for compliance.
- Treatment ideal for high pedestrian activity areas, shopping strips and school areas.

Cost

Low

Treatment life

10 years+

Applicability

- VSL are applied on any arterial road, regardless of traffic volumes. Their adaptability to prevailing conditions makes them applicable in school and work zones as well.

Key references and sources

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Austroads 2014, *Guide to traffic management part 5: road management,* 2nd edn, AGTM05-14, Austroads, Sydney, NSW.

Bham, GH, Long, S, Baik, H, Ryan, T, Gentry, L, Lall, K, Arezoumandi, M, Liu, D, Li, T & Schaeffer, B 2010, *Evaluation of variable speed limits on I-270/I-255 in St. Louis,* report RI08-025, Missouri University of Science and Technology, Rolla, MO, USA.

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Roads and Traffic Authority 2004, *Speed management action plan 2002-2004,* RTA, Sydney, NSW, viewed 18 March 2016, <http://roadsafety.transport.nsw.gov.au/downloads/speedmanagement.pdf>.

Scully, J, Newstead, S & Corben, B 2008, *Evaluation of the crash effects of strip shopping centre treatments in Victoria,* Monash University Accident Research Centre, report no. 279, Clayton, Vic.

A.2.12 Variable Message Signs (VMS)

Source: Department of Transport (2010), Ireland.

Description

Variable message signs (VMS) are traffic control devices used for traffic management and also to warn drivers of prevailing conditions and display dynamic safety messages e.g. congestion and delay messages, road closures or crashes. There are three main types of VMS, permanent and enhanced permanent, mobile and vehicle-mounted VMS. VMS can be automated or manually controlled and are mainly implemented on motorways, highways and major arterial roads.

Effectiveness

Speed reduction:

- 1–2 km/h reduction in mean speed.

Crash reduction:

- 10% reduction in injury crashes (CMF 0.90).

Road user effect/s (delays, congestion, consistency of travel time):

- increased driver awareness of prevailing conditions and hazards
- traffic condition VMS reduce emissions and travel time.

Implementation issues

- Need to consider sign placement and visibility e.g. adequate roadside space and clearance.
- Use of gantries may be required on wide carriageways.
- Vandalism may be an issue.
- Sign posts are a roadside hazard, therefore they may require shielding.
- Should be positioned an adequate distance from the hazard to allow road users sufficient response time and distance.

Cost

Low to medium

Treatment life

5–10 years

Applicability

- Applicable where static signage is deemed inadequate or corridor-specific information is needed. They are also applied in school and work zones.
- The message should also be legible without interfering with the driving task.
- The messages should be short and clearly legible.

Key references and sources

Austroads 2009, *Intelligent transport systems and variable message signs for road safety applications: current status and future prospects,* AP-T133-09, Austroads, Sydney, NSW.

Chatterjee, K & McDonald, M 2004, 'Effectiveness of using variable message signs to disseminate dynamic traffic information: evidence from field trials in European cities', *Transport Reviews,* vol. 24, no. 5, pp. 559-85, DOI:10.1080/0144164042000196080.

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Levinson, D & Huo, H 2003, 'Effectiveness of VMS using empirical loop detector data', *Transportation Research Board 2003 annual meeting*, Washington, DC, USA.

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A.2.13 Repeater Signs

Source: ARRB Group.

Description

Repeater signs, static in nature, can be placed several hundred metres apart to remind drivers of the speed limit, especially on roads where the posted speed limit is not immediately apparent by the appearance of the road.

Repeater signs aim to reduce the number of drivers inadvertently exceeding the speed limit.

Effectiveness

Speed reduction:

- Up to 3.6 km/h reduction in mean speed.

Crash reduction:

- Unknown.

Road user effect/s (delays, congestion, consistency of travel time):

- Better traffic flow can improve the efficiency of traffic signals, and create larger gaps in traffic for pedestrians to cross the street.
- Repeater signs can ensure compliance/driver awareness, as it is sometimes easy to miss a speed zone change sign.

Implementation issues

- May increase clutter and add to roadside hazards.
- Placement and spacing of repeater signs determined by AS 1742.2-2009.
- Signs need to be visible in order to be effective.

Cost

Low

Treatment life

5–10 years

Applicability

- The sign size and spacing depend on the speed environment and the associated speed limit changes.

Key references and sources

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Appendix B Non-engineering Treatments

Although this project primarily focused on engineering-based treatments to manage speeds on urban arterial roads, there are various non-engineering treatments that can be used to complement the engineering treatments. This appendix provides a brief summary and a reference list separate from the main body of the text.

B.1 Enforcement and Penalties

B.1.1 Fixed Speed Cameras

ARRB Group (2005) undertook a study on the effectiveness of fixed speed cameras in NSW (similar to those in Figure B 1). The study involved a before and after assessment of speed and casualty reductions at 28 sites in rural and urban NSW. Matched control sites were included. The data across these sites showed a reduction in mean speed of around 6 km/h after both 12 and 24 months, with the 85th percentile speed dropping by between 4 and 20% over the 2–year study. The study found large reductions in the percentage of drivers exceeding the speed limit by 10 km/h, 20 km/h and 30 km/h, however there were small increases in the proportion of speeding drivers along adjacent lengths of road. Along the study routes, casualty crashes reduced by 23% while fatal crashes reduced by nearly 90%.

Figure B 1: Fixed speed camera in Adelaide

Source: ARRB Group.

Diamantopoulou and Corben (2002) found average vehicle speeds dropped by 3.4% in the Domain Tunnel in Melbourne. It was concluded that the cameras significantly reduced the proportion of drivers exceeding the 80 km/h speed limit and the incidence of extreme speeding (> 30 km/h over the limit).

International studies, such Elvik and Vaa (2009), Gains et al. (2004) and Mountain et al. (2004) have also indicated reductions in speed and the incidence and severity of crashes. The crash reductions ranged between 22% and 28% for all urban crashes.

B.1.2 Mobile Speed Cameras

Mobile speed cameras utilise a range of different technologies which can be relocated to target roads under specific conditions. Thus, speed enforcement can be more broadly targeted and support the general deterrent approach to speed enforcement.

The findings of local evaluations are similarly encouraging, e.g.:

- Christie et al. (2003) found a significant reduction in crashes within a 100 m radius of the camera sites, with non-statistically significant results beyond a 500 m radius. The crash reduction was found to be particularly strong during daytime hours on 30 mph (48 km/h) roads and for crashes involving pedestrians and vehicle passengers.
- Newstead and Cameron (2003) found a 45% reduction in the number of fatal crashes within 2 km of speed camera sites and significant reductions in other crash types, across a state-wide program.
- Anderson and Edgar (2001) reported 85^{th} percentile speed reductions on urban arterial roads in ACT, and that the number of drivers more than 10 km/h above the speed limit was 59% lower at the speed camera sites. Fatal and serious injury crashes were also lower (36%) at camera sites.

International studies, e.g. Cunningham et al. (2005), Gains et al. 2004 and Elvik and Vaa (2009) also found some benefit but results show a lesser effect on speed and casualty reduction than for fixed cameras with reductions of between 15% and 21%.

B.1.3 Point-to-point Speed Cameras

Point-to-point cameras work by capturing images of vehicles as they pass two points a known distance apart (Figure B 2). The timestamps of the images can then be checked to calculate the average speed of the vehicle between the two points. Number plate recognition technology is used to identify vehicles. The two cameras can be located anywhere from a few hundred metres to many kilometres apart. There is also potential for the cameras to be used for other purposes such as driving infringements, travel time estimations and criminal investigations (Austroads 2012). e.g. RTA/RMS Safe-T-Cam, controlling truck movements.

Austroads (2012) gives a broad overview of the recent implementation of point-to-point cameras across Australia and New Zealand, but no formal evaluation studies had been completed at the time of publication. It is stated that urban applications of the technology tend to be more common in Europe and accordingly international evaluations are included in the document e.g. Stefan (2006) and Speed Check Services (2010). However, it is understood that in some cases European systems are introduced at locations where there are no existing speed cameras, and therefore the benefits would be expected to be greater than for situations where speed cameras already were present.

In general terms it is concluded that a reduction in all crashes is possible, as well as traffic flow tending to be more homogeneous. However, effectively covering frequent entry and exit points on an arterial route can be challenging and improvements in technology are being developed. It is suggested that such systems tend to work more effectively on freeways and motorways.

Figure B 2: Point-to-point cameras on the Hume Highway, Victoria

Source: Gardiner (2010).

B.1.4 Combined Speed and Red Light Cameras

Red light cameras are installed at intersections and are linked to the traffic signals so that if a vehicle crosses the control line after the lights have turned red, it will be photographed and potentially penalties can be imposed. Many red light cameras are installed in conjunction with speed cameras (Figure B 3). Red light cameras can also have an effect on surrounding roads, due to the driver being unsure whether any given intersection is fitted with cameras.

A number of studies have assessed the impact of red light cameras on their own (e.g. Austroads 2004; Radalj 2001; Thoresen et al. 2008). This section focuses on local studies involving combination speed/red light cameras, e.g.:

- Budd et al. (2011) found that in Victoria such systems reduced casualty crashes by 47% on camera approaches and 26% across the whole intersection concerned. However, no relative reduction in crash severity was found. No statistically significant increase in the number of rear-end crashes resulted.
- The NSW Centre for Road Safety (2010) found that combined speed and red light cameras brought about a 26% reduction in all crashes and a 34% reduction in injury crashes.
- Figure B 3: NSW red light speed camera warning signs (school zones and fixed limits)

Source: NSW RTA Website (http://www.rta.nsw.gov.au/roadsafety/speedandspeedcameras/nswspeedcamerastrategy/safetycameras/index.html).

B.1.5 Feedback Signs (Speed Advisory Checks)

While feedback signs (also known as speed trailers) are basically a mobile form of vehicle activated sign, they have been included in this section given they are most typically used to encourage greater levels of compliance, thereby reducing the need for enforcement.

Radar or similar technology is deployed to measure the speed of an approaching vehicle and its speed is displayed.

Mabbott and Cairney (2002) suggested that such signs were of value given that they: make drivers aware of their speeding and the extent by which they are speeding; encourage conformity as drivers become aware that they were being monitored; and instil a fear of prosecution. The study indicates that reductions in mean speed in the order of 3.5 to 8 km/h are possible, and that the technology has potential to be included in any speed enforcement programs.

Feedback signs are also being extensively used in roadworks, e.g. drivers get thumbs up, thank you or smiley face for obeying the work zone speed limit.

B.2 In-vehicle Treatments

B.2.1 Intelligent Speed Adaptation

Intelligent speed adaptation (ISA) refers to advanced technology which assists drivers in being aware of, and adhering to, the posted speed limits, i.e. the infrastructure provided is supplemented and ultimately becomes more effective. The most widely applied ISA system uses the global position system (GPS) or satellite navigation technology to compare the local speed limits to the vehicle's travelling speeds, alerting the driver (visual or audible alert) if they exceed the speed limit. ISA is now included in the European New Car Assessment Program (Euro NCAP) Safety Assist Assessment Protocol (Euro NCAP 2013).

ISA interface types include:

- advisory systems – audio or visual information about the prevailing speed limits
- supportive systems – provide information on prevailing speed limits and also warn the driver when the speed limit has been exceeded
- limiting systems – interact with the vehicle, e.g. there is resistance on the accelerator pedal when the driver attempts to exceed the speed limit.

Table B 1 summarises the types of ISA and feedback methods.

Table B 1: ISA types

Level of support	Type of feedback	Feedback
Advisory – informing	Mostly visual	The speed limit is displayed and the driver is reminded of changes in the speed limit.
Advisory and supportive – warning (voluntary)	Visual/auditory	The system warns the driver when they exceed the posted speed limit at a given location. The driver decides whether to use or ignore this information and to adjust the speed.
Supportive – intervening (voluntary)	Haptic throttle (moderate/low force feedback)	The driver gets a force feedback through the accelerator if they try to exceed the speed limit. If applying sufficient force, it is possible to drive faster than the limit.
Limiting system – automatic control i.e. speed limiter (mandatory)	Haptic throttle (strong force feedback) and dead throttle	The maximum speed of the vehicle is automatically limited to the speed limit in force. Driver's request for speeds beyond the speed limit is simply ignored.

Source: SWOV (2010).

ISA can be implemented as a voluntary or mandatory system. Voluntary ISA compares the travelling speed with the posted speed limit but allows the driver to override the system. Mandatory ISA, on the other hand, exerts full control on the vehicle's speed (Carsten et al. 2006).

Table B 2 provides a summary of the ISA effects on mean speed and standard deviation of speed in various studies. The general trend of these suggests that ISA leads to reductions in mean speed, speed variability and speed violations.

Table B 2: ISA evaluation studies

Study	Methodology	Country	Effect on mean speed	Effect on standard deviation of speed	Speed violations
Comte (2000)	Driving simulator	United Kingdom	↓	↓	?
Peltola and Kulmala (2000)	Driving simulator	Finland	↑	↓	?
Hogema and Rook (2004)	Driving simulator	Netherlands	↓	↓	↓
Van Nes et al. (2007)	Driving simulator	Netherlands	↓	↓	↓
Brookhuis and De Waard (1999)	Instrumented vehicle	Netherlands	↓	↓	↓
Päätalo et al. (2001)	Instrumented vehicle	Finland	↓	?	↓
AVV (2001a; 2001b)	Field trial	Netherlands	↓	↓	?
Lahrmann et al. (2001)	Field trial	Denmark	↓	?	?
Biding and Lind (2002)	Field trial	Sweden	↓	↓	↓
Regan et al. (2006)	Field trial	Australia	↓	↓	↓
Vlassenroot et al. (2007)	Field trial	Belgium	↓	↓	↓

Note: ↓decrease, ↑ increase, ? not investigated.

Source: SWOV (2010).

The first Australian trial of ISA was conducted as part of the TAC SafeCar Project (Mitsopoulos et al. 2004). Fifteen vehicles in Melbourne were equipped with an advisory ISA system (visual and auditory signals) which became a supportive ISA system (upward accelerator pressure), if warning signals were ignored for more than 2 seconds. The vehicles were equipped with a following distance warning (FDW) system (to prevent tailgating), a seatbelt reminder, a reverse collision warning system (to prevent collisions while driving backwards), and daytime running lights. A control group consisted of eight drivers, with control vehicles not equipped with ISA or FDW. All 23 drivers travelled at least 16 500 km. The ISA system reduced mean, maximum and 85th percentile speed, and speed variability, in all speed zones. ISA + FDW tended to have better results than ISA used in isolation. ISA + FDW and isolated ISA reduced the percentage of time driven above the speed limit, while not increasing travel times. FDW alone did not significantly affect speed.

ISA fitted to truck fleets in Australia operating on certain routes or in industrial sites was evaluated by Crackel and Toster (2007). A later study by Crackel (2009) was positive about the technology.

More contemporary, larger-scale studies of ISA have since been undertaken in NSW (NSW Centre for Road Safety 2010; Wall personal communication on 24 June 2008, Wall et al. 2010, 2011). It has been found that drivers break the speed limit less often when ISA is activated/installed, but that the effects are not totally permanent if returning to a vehicle not fitted with ISA. Some ISA systems can also be switched off during the driving task and in some cases drivers can increase speed on roads where speed limit data is not available. Notwithstanding, it has been estimated that the use of ISA would have resulted in an 8.4% reduction in fatalities and a 5.9% reduction in injuries in the test area. ISA systems require accurate, up-to-date maps and speed limit data.

A recent study by MUARC (Young et al. 2013) found that speed alerting ISA devices led to reductions in mean and 85th percentile speeds. There were further reductions in time spent exceeding the speed and returning to the speed limit.

Potential overconfidence (in relying completely on the speed limit indicated by the system without observing real-time traffic circumstances) has been suggested as an issue by Morsink et al. (2007). ISA in its current format does not typically alert motorists to other risks that may require a reduction in speed (for example, a severe curve in the road). As a result, it would be of benefit to examine a variant of ISA that included other risk-based information, including advisory speeds.

B.2.2 In-vehicle Warning Systems

Over recent years, a number of car manufacturers have been fitting their various crash avoidance and speed management technologies. New technologies are developed every year so only the most common and promising treatments are summarised. Robust information is not yet available on the safety benefits of these systems.

Forward collision avoidance systems provide alerts to the driver if sensors detect that the vehicle is getting too close to the vehicle in front. Advance systems also include autonomous braking and severity reducing features such as tightening seatbelts or adjusting head restraints.

Adaptive cruise control means that the car automatically slows and speeds up depending on the distance to the vehicle in front. Should the vehicle need to slow down considerably, the system will either disengage or continue to slow the vehicle to a complete stop.

A number of in-vehicle safety systems utilise GPS technology through devices in the vehicle or with smartphones. This includes curve speed warnings, which involves matching vehicle location and speed to digital maps. If the calculations determine that the speed is unsafe for an approaching curve then a warning is issued to the driver. The same GPS technology can be applied to warn drivers of upcoming black spots, school zones, traffic incidents, roadworks and the location of speed and red-light cameras. These features are also being integrated into some ISA systems, as outlined in Appendix B.2.1.

There are a number of other in-vehicle safety features that do not have a direct impact on vehicle speeds but may help to reduce the number or severity of crashes. These include lane departure warnings, adaptive headlights, side view assist, electronic stability control, emergency brake assist, anti-lock brakes and more (Insurance Institute for Highway Safety 2013).

As systems become more sophisticated and the reality of driverless vehicles becomes more apparent, the ability of vehicles to detect and 'communicate' with infrastructure (such as line markings, road studs and signs) and vice versa becomes vital. These concepts are known as V2I and I2V communication.

B.3 Education, Training and Publicity

Education, training and publicity are all recognised as important elements of speed management. Education and training programs for all road users help to communicate the inherent risks involved in speeding. They are necessary to maximise the effectiveness of road safety initiatives such as new infrastructure, legislation, enforcement and vehicle technology (OECD 2006). These measures require road users to understand the importance of speed management and road safety, and how the particular measure seeks to contribute to these goals. Despite the importance of education, training and publicity, research suggests that these measures have a limited effect when conducted in isolation (OECD 2006). Road safety education has also tended to be focussed on schoolchildren and young drivers (Department for Transport 2009). As in-vehicle technologies emerge, users need to be informed and educated about their objectives, potential benefits, limitations and any nuances to their operation.

Behaviour change programs are also used heavily for recidivist speeding drivers. They aim to modify behaviour and are therefore supported by behaviour change theories. Behaviour change programs typically include support group discussions, educational material, individual counselling and computer-based assessments. . Young et al. (2013) found that behaviour change programs had a positive impact on speed knowledge, attitudes towards driving and overall speeding behaviour. Austroads (2008 and 2009) provide analysis of such programs.

B.4 Penalties

In order to maximise the effectiveness of engineering features and enforcement policies, authorities impose penalties on drivers who are caught speeding. These penalties can include monetary fines, the loss of demerit points, impounding vehicles and cancelling licences.

In terms of speed reduction, penalties seek to discourage drivers from breaking the speed limit. This is intended to reduce the number of drivers exceeding the limit and consequently lowering the mean and 85th percentile speeds. A number of studies have attempted to quantify the speed reductions and the subsequent impact that the strategies have had on crash incidence and severity and driver attitudes. Both Department of Planning, Transport and Infrastructure (2012) and Austroads (2013) have reported that the threat of immediate licence suspension due to speeding was felt to be more of a deterrent than a fine or a receiving demerit points although all are considered important components of a comprehensive penalty system.

For penalties to be effective, they need to be a general deterrence from engaging in unsafe behaviours, deter repeat offending and need to be enforced, increasing the likelihood of being caught when engaging in unsafe behaviour. Additionally, the penalties need to be communicated effectively, increases community awareness and increase progressively for repeat offending (Watson et al. 2015 and Job 2013).

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