Austroads

Research Report
AP-R508-16

Speed Reduction Treatments for High-speed Environments

Speed Reduction Treatments for High-speed Environments

Prepared by

Michael Levasseur

Project Manager

James Hughes

Abstract

This report examines the performance of different types of speed-reducing treatments (or combinations of treatments) in high-speed environments. The project also considered how desired speed can be aligned with a safe, anticipated operating speed with the goal of making high-speed roads more self-explanatory.

Treatments reviewed included: treatments to support development of road hierarchies in line with the concept of self-explaining roads; perceptual countermeasures; transverse rumble strips; vehicle activated signs; gateway treatments; route-based curve treatments; wide median centrelines; and sight distance adjustments on intersection approaches.

Based on the outcomes of this review, these treatments may merit further consideration for future Austroads research and guidance.

Keywords

road design, speed management, high-speed environment, speed reduction treatments

ISBN 978-1-925294-99-6

Austroads Project No. TT1545

Austroads Publication No. AP-R508-16

Publication date February 2016

Pages 57

© Austroads 2016

This work is copyright. Apart from any use as permitted under the *Copyright Act 1968,* no part may be reproduced by any process without the prior written permission of Austroads.

Publisher

Austroads Ltd.
Level 9, 287 Elizabeth Street
Sydney NSW 2000 Australia
Phone: +61 2 8265 3300
austroads@austroads.com.au
www.austroads.com.au

About Austroads

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

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

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

Austroads is governed by a Board consisting of senior executive representatives from each of its eleven member organisations:

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

This report has been prepared for Austroads as part of its work to promote improved Australian and New Zealand transport outcomes by providing expert technical input on road and road transport issues.

Individual road agencies will determine their response to this report following consideration of their legislative or administrative arrangements, available funding, as well as local circumstances and priorities.

Austroads believes this publication to be correct at the time of printing and does not accept responsibility for any consequences arising from the use of information herein. Readers should rely on their own skill and judgement to apply information to particular issues.

Summary

Speed management is a key component of the Safe System approach. The efficacy, including safety performance, of the various treatments and measures used to reduce vehicle speeds in high-speed environments is not well understood. This project was established to better understand the performance achieved by various types of speed-reducing treatments (or combinations of treatments) for high-speed environments. The project also sought to consider how desired speed can be aligned with a safe, anticipated operating speed with the goal of making high-speed roads more self-explanatory. This is expected to enable treatments to be applied more appropriately and effectively, with consequential benefits in maximising the safety and effectiveness of available funding levels for road improvements in high-speed environments.

The project reviewed available literature and Austroads guidance and obtained input from the Austroads Road Design Task Force in order to identify speed reduction treatments and road features influencing speed in high-speed environments.

The project was conducted over a two-year period with the first year conducting a broad review of speed reduction treatments applicable to different types of road sections including intersections, transition areas, curves and mid-block sections. The second year of the project focused more specifically on mid-block road segments and considered treatments and road features that influenced speed in high-speed environments.

The review of speed reduction treatments in higher-speed environments compiled information on a number of treatments including perceptual countermeasures, transverse rumble strips, vehicle activated signs, gateway treatments, route-based curve treatments, wide median centrelines and sight distance adjustments on intersection approaches. Based on the outcomes of this review, these treatments may merit further consideration for future Austroads research and guidance.

On mid-block sections of high-speed roads where the speed environment remains consistent, drivers seek to maintain a desired speed in line with the posted speed limit or design speed applicable to a section of road. There are a number of road features from which drivers obtain cues that may influence their speed. The project has identified a number of these features and has compiled existing research into the effect of individual and combined road features on speed in high speed environments. The research and guidance provided in a number of Austroads Guides on this topic merit further consideration for identifying road features that may aid in making high speed roads more self explanatory.

Contents

Tables

Figures

1. Introduction

1.1 Background

Austroads seeks to provide practitioners with information regarding speed management as a key component of the Safe System approach. This includes various treatments and methods that may be applied to reduce vehicle speeds. However, in high-speed environments, the effectiveness of these treatments is not well understood.

In low-speed environments, speed reduction devices typically consist of localised angled constrictions in roadway width, tight roundabouts, flat-top speed humps and the like. These are generally well accepted, widespread and their effectiveness is generally well understood. The *Guide to Traffic Management – Part 8: Local Area Traffic Management* (Austroads 2008) and sections of the Austroads *Guide to Road Design* address this topic.

In high-speed environments, speed reduction treatments may present safety difficulties, and it may be necessary to consider a more benign approach, aimed at reducing speed gradually and maintaining lower speeds. Treatments may include reverse curves, rumble strips and warning signs (including variable message, intermittent, flashing and static signs).

The effectiveness of these treatments in reducing vehicle speeds and/or increasing safety is limited and in some cases relatively unknown or anecdotal. The associated treatments are often used in combination, which clouds the assessment of the effectiveness of individual treatments.

Austroads project TT1545 was established to develop a better understanding of the performance achieved by various types of speed reducing treatments (or combinations of treatments) in high-speed environments. The outcomes of the project were expected to enable treatments to be applied more appropriately and effectively, thereby maximising the safety and effectiveness of available funding levels for road improvements in high-speed environments. The project also sought to consider how desired speed can be aligned with a safe, anticipated operating speed with the goal of making high-speed roads more self-explanatory.

1.2 Methods and Outcomes

The project method consisted of a series of tasks which included reviewing available literature and Austroads guidance and facilitating a workshop to obtain input from the Austroads Road Design Task Force. These tasks were used to identify speed reduction treatments and road features influencing speed in high-speed environments.

The project was conducted over a two-year period, which consisted of:

- first year of the project: a broad review of speed reduction treatments applicable to different types of road sections including intersections, transition areas, curves and mid-block sections
- second year of the project: a more specific focus on mid-block road segments and treatments and road features that influenced speed in high-speed environments.

1.3 Report Structure

The remainder of the report is structured as follows:

- Section 2 discusses a number of speed management considerations within the context of high-speed environments.
- Section 3 reviews promising speed reduction treatments that may be applied in high-speed environments.
- Section 4 discusses road features that influence speed in high-speed environments.
- Section 5 discusses the outcomes of the project and provides further considerations for Austroads research and guidance.
- Appendices provide supporting information on speed reduction treatments and road features that influence speed.

2. Speed Management Considerations

2.1 High-speed Road Environments

Part 3 of the *Guide to Road Design* (Austroads 2010a) defines a speed environment as 'the operating speed that drivers will adopt on less constrained elements, i.e. straights and large radius horizontal curves of a more or less uniform section of road when not constrained by other vehicles'. It represents the uniform desired speed of the 85th percentile driver.

The term 'high-speed' has not been given a strict definition in the Austroads *Guide to Road Design*. For some situations the Guide categorises low-speed, intermediate-speed and high-speed environments. In other instances, the distinction is only made between high-speed and low-speed environments.

Using the three-tiered approach, Austroads (2010a) defines high-speed environments as those where speed exceeds 90 km/h and intermediate-speed environments as those from 70–90 km/h.

For the purposes of this report, the high-speed environment has been based on the three-tiered categorisation, with a high-speed road defined as an environment where speed exceeds 90 km/h. However, the intent of the project was to consider speed environments where a more benign approach to speed management was necessary, which may include high-speed or intermediate speed environments. The term 'higher-speed environments' is used in the report where high-speed and intermediate-speed environments are collectively discussed.

Examples of high-speed and intermediate-speed rural road environments are shown in Figure 2.1 and Figure 2.2 respectively.

Figure 2.1: Examples of high-speed rural roads

Source: Austroads (2010a), based on Austroads (2003, superseded).

Figure 2.2: Examples of intermediate-speed rural roads

Source: Austroads (2010a), based on Austroads (2003, superseded).

2.2 Safe System Approach

The Safe System approach has been formally adopted by Austroads, and forms a key component of the Australian National Road Safety Strategy (Australian Transport Council 2011) and New Zealand's Safer Journeys Strategy (Ministry of Transport 2010).

The Safe System approach accepts that humans will make errors and take risks and, as such, crashes will continue to occur. In addition, humans are physically vulnerable, and are only able to withstand limited change in kinetic energy (e.g. during the rapid deceleration associated with a crash) before injury or death occurs (Austroads 2013a).

A key aspect of the Safe System approach is that speed should be managed, taking account of the risks on different parts of the road transport system. Research to date has identified that speed is a significant contributor to death and serious injuries on rural roads in both Australia and New Zealand. Speed contributes to around 28% of all fatal rural crashes in Australia, and 31% in New Zealand (Austroads 2014a).

2.3 Speed Reduction and Speed Maintenance Treatments

In order to consider treatments that should be applied in higher-speed environments, it is important to consider speed reduction and speed maintenance. Depending on the segment of road being considered, it may be necessary to consider:

- speed reduction – aid drivers in responding to a changing speed environment due to a transition (e.g. high to low-speed) or a hazard on a road
- speed maintenance – assist drivers in maintaining a desired speed in line with the posted speed limit or design speed applicable to a section of road.

The project has considered treatments applicable to both situations. At intersections, horizontal curves, transitions from high-speed to low-speed environments or other hazards and measures to aid drivers to reduce their speed to respond to the changing speed environment need to be considered. Section 3 of the report discusses a number of promising speed reduction treatments that may merit further consideration for application in higher-speed environments.

For mid-block situations on higher-speed roads, roads should be designed to aid drivers with maintaining an appropriate speed for a section of road. Section 4 discusses road features that influence speed in mid-block road sections in high-speed environments.

2.4 Self-explaining Roads

In recent years, the concept of a ‘self-explaining’ road has been developed (e.g. Schermers 1999; Theeuwes & Godthelp 1992, Wegman & Aarts 2006). Application of the concept of self-explaining roads seeks to provide road features and characteristics that encourage speed choices consistent with the safe speed for the function and design of a road. The ultimate self-explaining road is one for which the road elements inform motorists as to the required safe speed.

In order to recognise the current road function and to predict road elements, the following features are required (World Bank 2005):

- clear design, marking and signing
- recognisable road categories
- design elements for each road category that are uniform.

Self-explaining roads are further discussed in Section 3.2 in relation to developing treatments to support self-explaining roads and in Section 4, which discusses research that has been conducted on self-explaining roads to identify road features that may influence speed and assist in making roads more self-explanatory.

3. Speed Management Treatments in Higher-speed Environments

3.1 Review of Speed Reduction Treatments

The project reviewed speed reduction treatments applicable to high-speed environments. An earlier literature review identified a number of possible treatments; this report provides details on some of the more promising options identified. The project has considered engineering-based treatments that were at a stage where they had potential for developing guidance that could supplement the Austroads *Guide to Road Design* or other relevant Austroads guidance.

Treatments identified included:

- treatments to support development of road hierarchies in line with the concept of self-explaining roads
- perceptual countermeasures
- transverse rumble strips
- vehicle activated signs
- gateway treatments
- route-based curve treatments
- wide median centrelines
- sight distance adjustments on intersection approaches.

3.2 Treatments to Support Development of Road Hierarchies and Self-explaining Roads

Research conducted to develop and implement self-explaining roads (Section 2.4) considered how combinations of road features could support road categorisations with different speed environments.

Further research may wish to consider how the concept of self-explaining roads could be developed in an Australasian context. However, there is a substantial amount of work that would be required. It is likely that this would require staging to fully consider aspects of this topic. This may include:

- first stage: developing a self-explaining road hierarchy and identifying the features associated with hierarchical categories
- second stage: allocating roads to categories of the self-explaining road hierarchy
- third stage: conducting a trial application of the self-explaining road hierarchy on an area of the road network.

The development of Austroads guidance on this topic could only occur after these stages were completed.

Austroads guidance may also consider treatments that apply the principles of making roads more self-explanatory. This may help to further establish the case for this type of approach, but through a more limited application. Treatments identified during the review conducted as part of the project that support the self-explaining roads concept include gateway treatments (Section 3.6), route-based curve treatments (Section 3.7) and wide median treatments combined with reduced posted speed limits (Section 3.8).

3.3 Perceptual Countermeasures

Perceptual countermeasures are used to alter the drivers' perception speed, or the road environment. Methods may consist of making a road appear narrower or a curve appear more severe. By altering the driver's perception, it is hoped that the driver will slow down to match the perceived conditions rather than the actual ones.

3.3.1 Previous Research

Research undertaken in Australia and New Zealand has evaluated the effectiveness of different types of perceptual countermeasures. This has included transverse pavement markings and perceptual guide-post treatments. Neither treatment is commonly used in Australia or New Zealand, although transverse pavement markings have been applied at some sites. Overseas, transverse pavement markings have been trialled in a number of road applications including curves, work zones, intersection approaches and transition zones (gateways).

A study by Macaulay et al. (2004) investigated a perceptual countermeasure on curves. The treatment consisted of laterally diverging guide posts with ascending heights, applied on the outside of a curve, to create the perceptual illusion of the curve being tighter than it is in reality (Figure 3.1). The treatment was applied to six curve sites in New South Wales and Victoria.

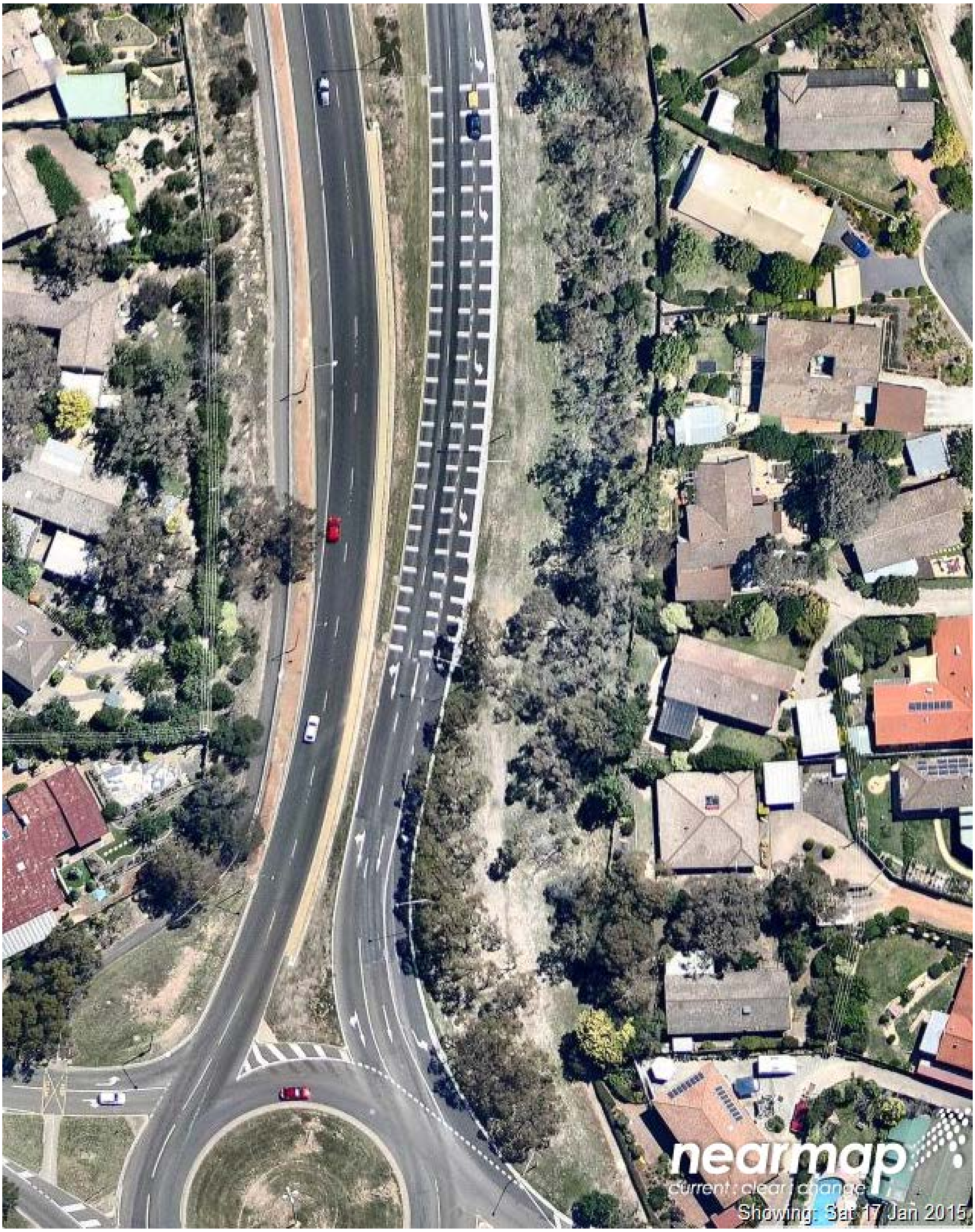
Figure 3.1: Perceptual guide-post treatment on a curve

Source: Macaulay et al. (2004).

Trial outcomes included that enhanced edge-post spacing with ascending post heights for curves (to provide an impression of curve severity) produced mixed results (Macaulay et al. 2004). A significant decrease in speeds was found at three sites, with no change at two, and an increase at one. Individual differences were identified at these sites that were not able to be fully explored as part of the trial. These required further assessment to determine whether in the long term such measures could have a consistent effect on speeds at curves, and on subsequent crashes. The trial did not evaluate the effect of this treatment on crashes.

Transverse markings have been applied on the approaches to intersections. These have been used to give the perception that drivers are travelling faster than they are, or that the road narrows to encourage slowing on an intersection approach. Some road agencies in Australia have installed this type of treatment. An example on a roundabout approach with transverse pavement markings is shown in Figure 3.2.

Figure 3.2: Transverse marking treatment on a roundabout approach in the ACT



Source: ©Nearmap (2015), 'ACT', map data, Nearmap, Sydney, NSW.

In the UK, yellow transverse bar markings have been applied on high-speed approaches to roundabouts, including main carriageways and exit slip roads. The spacing between markings is reduced for markings located closer to the roundabout, in order to give the illusion to drivers of faster travel. An example of these markings located on a dual-carriageway approach to a roundabout is shown in Figure 3.3.

Figure 3.3: Yellow transverse bar markings

Source: Department for Transport (2001).

A trial of yellow transverse bar markings markings at 42 at-grade roundabouts found an overall crash reduction of 57% in comparison with control locations (Department for Transport 2001, citing Hilliar-Symons 1981). Another trial of the markings on 44 motorway exit slip roads to roundabouts observed a 15% reduction in injury accidents relative to control sites (not statistically significant) (Department for Transport 2001, citing Haynes et al. 1993). Neither of the trials reported on the impacts of the markings on travel speeds.

In Australia, Macaulay et al. (2004) investigated the effects of a perceptual treatment on vehicle speeds on intersection approaches consisting of peripheral pavement markings (Figure 3.4). The treatment consisted of short yellow transverse markings located on the edges of the lane that gave the impression of narrowing in order to reduce speeds. Markings were provided with equal spacing between the lines. Advantages of the peripheral pavement markings when compared with full transverse bar markings included decreased skid resistance, particularly for motorcyclists in wet conditions, and reduced capital cost due to the use of shorter pavement markings.

The markings were found to have a positive effect on speeds approaching intersections (approximately a 2–4 km/h reduction observed during follow-up period).

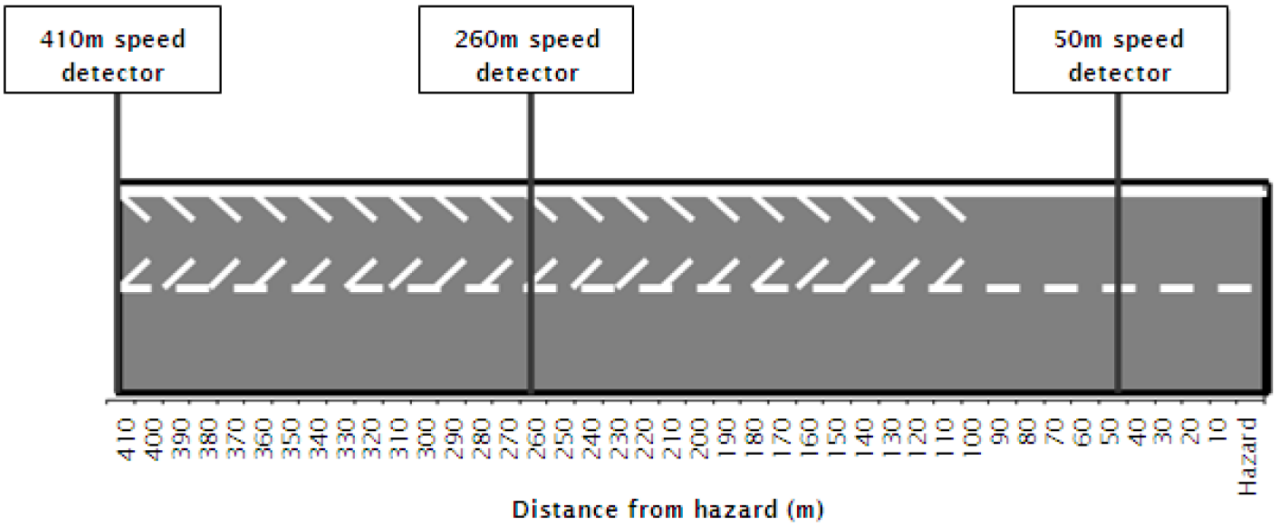
Figure 3.4: Peripheral markings on intersection approach

Source: Macaulay et al. (2004).

In New Zealand, Martindale and Urlich (2010) conducted a trial of peripheral pavement markings at two sites, one on the approach to an intersection and another on the approach to a bridge. Each site included horizontal curvature. The approach to the intersection site was prior to an unsignalised intersection where the right-turn movement was given priority, thus introducing an out-of-context curve. The approach to the bridge included a right-hand curve on the approach to a bridge abutment. The approaches at both locations were in 100 km/h posted speed zones.

The markings applied in the trial consisted of evenly spaced peripheral bars extending 1 m from the edge lines at 60° angles. Figure 3.5 shows a conceptual layout of the markings and the locations where speed measurements were conducted to assess their effectiveness.

Figure 3.5: Layout of peripheral markings installed in NZ Trial



Source: Martindale and Urlich (2010).

The trial found that the primary effect of the lane markings was to reduce vehicle speed at the start of the treatment (410 m from the hazard), which the authors implied was due to the transverse lines creating an alerting function, resulting in drivers entering the marked area at a lower speed as a precaution. Investigation was also conducted to determine whether the treatment was more effective on differing days of the week (e.g. weekday versus weekend drivers) and vehicle type (light versus heavy vehicles). However, the study found changes in mean vehicle speed unrelated to these factors.

In North America, Hallmark, Hawkins and Smadi (2013) summarised the effectiveness of transverse pavement markings at reducing speed in different locations and speed environments (Table 3.1). Treatments included:

- optical speed bars (i.e. peripheral white markings, Figure 3.6)
- on-pavement chevrons (Figure 3.7)
- transverse lines (Figure 3.8).

Noted advantages of these treatments included that they were low cost, did not affect vehicle operation or impact on emergency vehicles or drainage. Disadvantages identified included additional maintenance requirements and reduced effectiveness during winter conditions.

Table 3.1: Reported speed reductions from US trials of transverse pavement markings

Treatment	Type of sites	Speed environment		Change in speed[1]			Source, cited in Hallmark, Hawkins and Smadi (2013)
		Posted speed	Advisory speed	Speed metric	Miles/h	Km/h	
Optical speed bars (peripheral markings)	Rural two-lane tangent section	55 mph (89 km/h)	Not applicable	Mean	–2.0 to 4.2	–3.2 to 6.8	Latoski (2009)
				85th percentile	–5.0 to –2.0	–8.0 to –3.2	
	Freeway curve	50 mph (80 km/h)	Not applicable	Mean	–5.0 to –1.1	–8.0 to –1.8	Gates et al. (2008)
				85th percentile	–1.0	–1.6	
	Rural curves	65 mph (105 km/h) and 45 mph (72 km/h)	40 mph (64 km/h)	Mean	–5.9 to 2.3	–9.5 to 3.7	Katz et al. (2006)
				85th percentile	–5.0 to 2.4	–8.0 to 3.9	
Converging chevrons	Freeway-to-freeway connector	65 mph (105 km/h)	50 mph (80 km/h)	Mean	–15.0 to 1.0	–24.1 to 1.6	Drakopoulous and Vergou (2003)
				85th percentile	–17.0 to 1.0	–27.4 to 1.6	
	Curve	Not specified	Not specified	85th percentile	–6.0	–9.7	Shinar (1980)
Transverse lines	Various	Not stated	Not stated	Mean	–2.0 to –1.0	–3.2 to –1.6	Griffin and Reinhart (1995)
				85th percentile	–15.0	–24.1	
Transverse lines	Work zone	70 km/h (work zone)	Not applicable	Mean	–2.1	–3.4	Hildebrand et al. (2003)
				85th percentile	–2.4	–3.9	

1 *Negative values indicate a decrease in speed.*

Source: Based on Hallmark, Hawkins and Smadi (2013).

Figure 3.6: Optical speed bars

Source: Hallmark, Hawkins and Smadi (2013), citing Hallmark (2007).

Figure 3.7: Converging chevrons

Source: Hallmark, Hawkins and Smadi (2013), citing Hallmark (2007).

Figure 3.8: Transverse lines

Source: Hallmark, Hawkins and Smadi (2013), citing Arnold and Lantz (2007).

3.3.2 Austroads Guidance

Part 4B of the *Guide to Road Design* (Austroads 2011a) briefly noted the application of perceptual markings. The Guide identified ‘pavement markings across carriageway’ and ‘guideposts at decreasing spacing on the approach to a roundabout’ as treatments that may be considered to encourage drivers to approach a roundabout at an appropriate speed (Section 4.5.3, Austroads 2011a). However, no additional guidance was provided on what specifically such a treatment entails or its effectiveness.

Perceptual countermeasures and the research undertaken by Macaulay et al. (2004) were briefly noted in the *Guide to Road Safety Part 5: Safety for Rural and Remote Areas* (Austroads 2006).

For existing Austroads guidance, there is merit in developing guidance or providing cross-references (e.g. Austroads 2014a) to further details on perceptual countermeasures and their effectiveness.

3.4 Transverse Rumble Strips

Rumble strips are provided to encourage motorists to reduce their speed and alert drivers approaching a hazard. Audio-tactile treatments have been applied transversely, or across driving lanes, to warn motorists approaching curves or intersections.

3.4.1 Previous Research

Transverse audio-tactile treatments have been applied in advance of intersections, including railway level crossings.

Harwood (1993) reviewed a number of studies that assessed the effectiveness of rumble strips. The study concluded that transverse rumble strips appeared to be effective in reducing the number of collisions at intersections with results varying from 14–100%. However, the author expressed concerns regarding the validity of almost all the evaluations reviewed.

A Victorian trial assessed the effectiveness of transverse rumble strips on high-speed approaches in advance of passive rail level crossings and on minor approaches to T-intersections (Hore-Lacey 2008). A total of 28 sites were assessed, with 14 at rail crossings and 14 at intersections. The mean speed at rail crossings was reduced by around 4 km/h (with reductions up to 12.5 km/h). Mean speed at intersections was reduced at a point 200 m in advance of the intersection (4.8 km/h), but not 50 m prior to the intersection.

Radalj and Kidd (2005) reported on the use of rumble strips that were trialled on high-speed rural roads at railway level crossings controlled by stop and give-way signs. The study concluded that the design used did not appear to be effective in reducing mean speeds at give-way-controlled sites, but speeds were reduced at stop-controlled crossings (5 km/h). It was concluded that the number of groups of rumble strips installed had a large influence in terms of speed reduction effectiveness.

A review by Thompson, Burris and Carlson (2006) of rumble strips on high-speed approaches to nine rural stop-controlled intersections in the USA found a small but significant reduction in speeds. Most sites recorded speed reductions of around 1.6 km/h, although some locations had slightly greater reduction (3–5 km/h). The study concluded that such small reductions in speed were not of practical significance, suggesting that speed reductions of at least 4 mph (6.4 km/h) would be required to have a positive influence on safety.

Implementation considerations for transverse rumble strips include that (Austroads 2014a, Charman et al. 2010):

- the profile for the rumble strips needs to be suitable so as not to present a hazard to motorcyclists
- rumble strips are noisy and should not be placed near residential areas, although at higher speeds the noise effects are less severe
- rumble strips need to be combined with signing that indicates the reason for reducing speed.

Transverse rumble strips have been used in a number of applications on the approaches to curves. However, little objective information is available on their effectiveness in speed or crash reduction at curves. McGee and Hanscom (2006) reported that there is no conclusive evidence of rumble strip effectiveness in reducing crashes at curves, but that they do tend to reduce speed, in most cases, but not to a practical level.

The Department for Transport (2005) described a trial of a variant of rumble strips called 'rumblewaves'. These are a quieter alternative to conventional rumble strips, creating noise and vibration within the vehicle, but not significantly increasing external noise levels. Rumblewaves have been tested on the approach to rural bends, but were found to have minimal impact on speed reduction (less than 1 km/h at the trial location). The trial included sites with high-speed approaches, but effectiveness was similar in different speed environments.

3.4.2 Austroads Guidance

The *Guide to Road Design Part 4B* (Austroads 2011a) identifies rumble strips as a potential treatment on high-speed approaches to roundabouts. Commentary 3 in Part 10 of the *Guide to Traffic Management* (Austroads 2009a) provides guidance on the application of transverse rumble strips. No cross-reference is provided between the two *Guides*, which may merit consideration in future updates. Austroads (2014a) also provides details on the effectiveness of transverse rumble strips.

3.5 Vehicle Activated Signs

Vehicle activated signs (VAS) are a form of emerging speed reduction treatment that have been trialled in Australia and New Zealand. The purpose of VAS is to encourage travel at lower speeds and to warn of changes in road conditions. Commonly used types of VAS include speed enforcement and hazard warning signs (Figure 3.9).

Speed-enforcing VAS are speed and safety-related dynamic roadside signs that display a message when an approaching vehicle exceeds a predetermined speed (referred to as a threshold speed). They are mainly installed at locations with speeding problems or a speed-related crash history or in instances where the use of standard speed and warning signs has not been effective in lowering travelling speeds or altering driver behaviour (Department for Transport 2003).

Vehicle activated hazard warning signs are installed on the approaches to hazards (e.g. curves and intersections). They advise drivers of changing road conditions and the need for safer speed for the prevailing conditions. They are triggered when a vehicle exceeds a predetermined speed, displaying either the hazard type and recommended speed or a message to slow down along with the hazard type. The types of VAS used differ based on site-specific conditions and requirements, and the underlying reasons for the implementation. They are mainly used to target the proportion of drivers exceeding the speed limit or safe speeds for the prevailing conditions. The message type, display times and threshold speeds vary for each jurisdiction.

Figure 3.9: Examples of vehicle activated signs

Source: Makwasha and Turner (2014), citing Burbridge et al. (2010) and Connell Wagner (2009).

Source: Austroads (2014a), citing Warwickshire County Council.

3.5.1 Previous Research

To more broadly consider the effectiveness of VAS on speed and crashes, Austroads (Makwasha & Turner 2014) conducted research that pooled data from earlier trials (Victoria, Queensland, South Australia and New Zealand), in addition to data from these locations that had previously not been considered.

The study conducted a retrospective assessment at 70 sites to evaluate speed and crash effects. The project considered the effects of different types of VAS including speed roundels and curve and intersection warning signs. The study included a range of sites and was not limited to high-speed environments.

Results of the study found reductions in both mean and 85th percentile speeds for all sign types assessed. Reductions for 85th percentile speeds were greater, which was expected as VAS generally target excessive speeds or drivers exceeding the speed limit.

With regard to the effects of VAS on speed, the findings included:

- reductions in mean speeds were greatest at speed roundels (3.9%) compared to the other types of VAS (3.0–3.6%)
- 85th percentile speed reductions were greatest at curve warning signs (6%)
- the sign configuration that yielded the greatest reduction in mean speed was a 100 km/h speed roundel (7%)
- a slow-down roundel and a right curve with slow-down warning sign yielded the greatest reduction in 85th percentile speed (8%).

Statistically significant overall crash reductions were found, with the greatest observed at intersection warning signs, with a crash reduction factor (CRF) of 70%, followed by speed roundels (CRF of 39%). Overall, net reductions ranged from 37–70%.

While the results indicated considerable reductions in crashes and lower speeds, the authors noted that the study was unable to include control sites and had a limited sample size. This could have led to overestimating the net impact of VAS.

The results of the Austroads study were consistent with the findings from previous studies such as Winnett and Wheeler (2002), which assessed the impact of VAS at more than 60 sites across the UK. The results suggested that VAS can form an effective treatment to reduce speed and crashes in different speed environments, including high-speed roads.

3.5.2 Austroads Guidance

Part 8 of the *Guide to Road Safety* (Austroads 2009b) refers practitioners to the *Road Safety Engineering Toolkit*, which includes guidance on the application of VAS.

Guidance on vehicle activated signs was not identified in the *Guide to Road Design*. For example, in Part 4B (Austroads 2011a), VAS are not identified as a potential speed reduction treatment on high-speed roundabout approaches.

Developing practitioner guidance on the application of VAS for inclusion in the Austroads Guides merits further consideration. Reference to Austroads (2014a) or the *Road Safety Engineering Toolkit* (Austroads & ARRB Group 2010) may be considered in future Guide updates, such as for Part 4B (Austroads 2011a).

3.6 Gateway Treatments

Gateways are a type of treatment that has been applied to slow speeds where a vehicle is travelling from a higher-speed environment to a low-speed environment. They may consist of a single treatment (e.g. speed limit signs only) or a combination of treatments.

Combined treatments may include traffic islands, lane narrowing, coloured pavement, road markings and vertical elements (e.g. planting of trees or shrubs). Examples of gateway treatments are shown in Figure 3.10 and further examples of types of gateways can be found in Appendix A.

Figure 3.10: Pinch point gateway treatments

Source: ARRB Group.

Source: Land Transport Safety Authority (2002).

3.6.1 Previous Research

Previous research (Austroads 2014a, Makwasha & Turner 2013, Taylor & Wheeler 2000) found that gateways, particularly pinch point gateways (Figure 3.10), were capable of lowering crash frequencies on rural-urban transitions (35% overall crash reduction for pinch point gateways). The findings also indicated that there were reductions in both mean and 85th percentile speeds.

Research (Austroads 2014a, Charlton & Baas 2006) identified important considerations for applying gateway treatments including:

- gateways are most effective if placed at the point where development begins
- the speed reduction of gateways will dissipate within 250 m unless additional treatments or supporting road features are positioned further downstream (e.g. decreases in road width or increases in urban density)
- for higher-speed changes, threshold designs that place a greater reliance on perceptual features such as signing, visual narrowing, flush medians and hatching and traffic medians may be more appropriate.

As part of research conducted on self-explaining roads in Europe, Cocu et al. (2011) conducted a series of workshops to obtain expert opinions regarding the effectiveness of speed reduction treatments. Gateway treatments were one of the measures identified as having the greatest potential for influencing speed and could play a critical role in influencing potential conflicts with vulnerable users following transitions into villages or semi-urban areas.

Feedback included:

- an effective gateway should include an interruption of the visual perspective
- interruption of the visual perspective could be obtained through a combination of measures, such as a central island with planting and staggered sections
- in some of the examples reviewed in the workshops, the road was noted as looking exactly the same before and after the gateway treatment and was not considered effective.

3.6.2 Austroads Guidance

Currently, the *Guide to Road Design* and other Austroads Guides do not provide practitioner guidance on gateway treatments. Based on the findings of the previous research, developing practitioner guidance on the design of gateway treatments merits further consideration in the Guides.

3.7 Route-based Curve Treatments

On high-speed roads, a variety of treatments have been installed to address the crash risk posed by horizontal curves. Treatments may involve various combinations (e.g. signs and markings), which have been installed over a period of time in an ad hoc manner. This may result in differing treatments being utilised on curves of similar severity, thereby presenting a confusing message to motorists.

3.7.1 Previous Research

Previous research developed a number of systems to support route-based curve treatments, which seek to match the level of treatment with curve severity. Such systems typically involve developing a series of risk categories that are used to identify the level of risk of curves. Combinations of treatments may than be applied to suit each level of risk.

An example of such a system is shown in Figure 3.11. As indicated, based on a drivers' approach speed and the speed on a curve, a series of categories were developed. These ranged from a category E representing the sharpest curves (substantial reductions in speed on the curve required) to category A representing the widest curves (only minor reductions in speed required). Another system for classifying the risk of horizontal curves was developed by Cardoso (2005) that created consistency classes based on speed reduction, rates of deceleration on a curve and type of road shoulder (i.e. sealed versus unsealed).

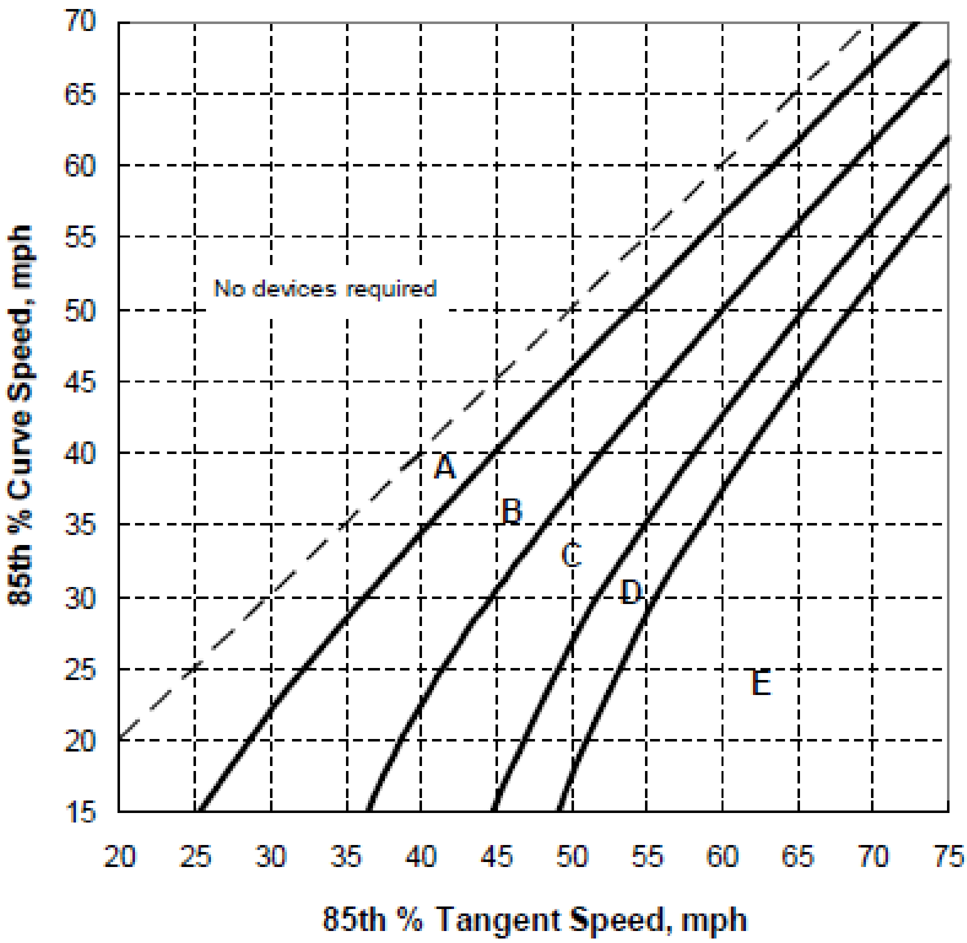
Using such systems, different combinations of treatments may be matched with the severity of a curve. An example of a system of curve treatments is shown in Figure 3.12.

For Cocu et al. (2011), route-based curve treatments were one of the measures identified as having the greatest potential for influencing speed and could play a vital role in influencing loss-of-control crashes on curves.

Workshop findings noted that:

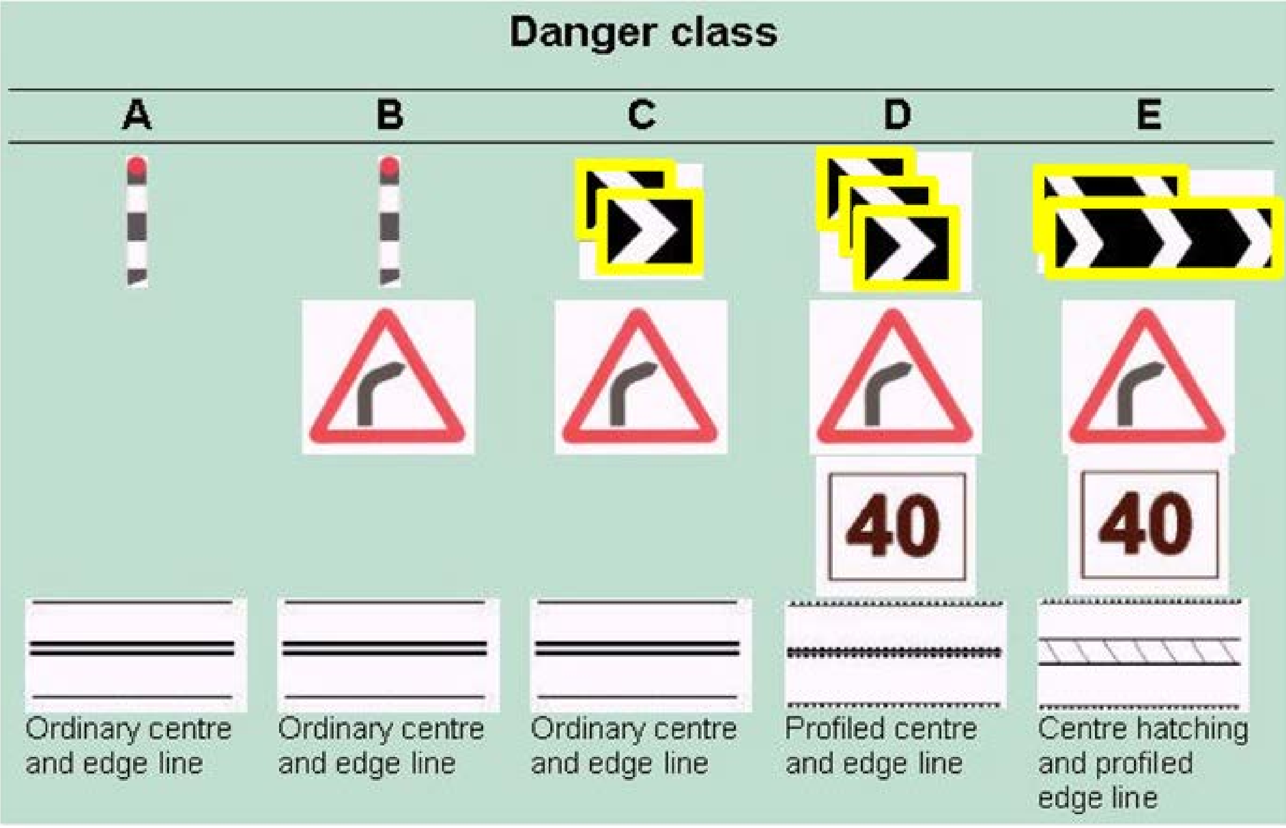
- Combinations of treatments presented on a curve should inform the road user about the severity (i.e. sharpness) of a curve, with a greater number of treatments being applied consistently to higher-severity curves and fewer to lower-severity curves.
- Consistent treatment was crucial to ensure that a road user's categorisation of a curve was correct and that the expectation of appropriate speed was accurate.

Figure 3.11: Curve risk categorisation



Source: Bonneson et al. (2007).

Figure 3.12: Route-based curve treatments



Source: TRL and Department for International Development (2001).

- Sjörgen et al. (2012) conducted a simulator study to evaluate the effectiveness of route-based curve treatments on speed adaptation. This was used to help establish combinations of treatments on curves that could assist drivers in correctly establishing the severity of a curve in advance of a curve and adapt their speed appropriately. Treatments included curve warning signs, slow markings, chevron signs, coloured surfacing and vehicle activated signs. Examples of the different levels of curve treatments that could be applied to a simulated curve are shown in Figure 3.13.

The key finding of the study was that consistent combinations of treatments at curves, which were in line with the severity of the curves, contributed to greater speed reductions. A consistent level of treatment was found to result in lower mean speeds through curves with medium or severe curvature (Figure 3.14). The difference was found to be greatest for severe curves, for which mean speeds were found to be 3 km/h slower when a consistent curve treatment was applied.

Figure 3.13: Examples of levels of curve/bend treatments applied in simulator study

No treatment

Curve/bend warning sign and edge line markings

Curve/bend warning sign, edge line markings and slow markings

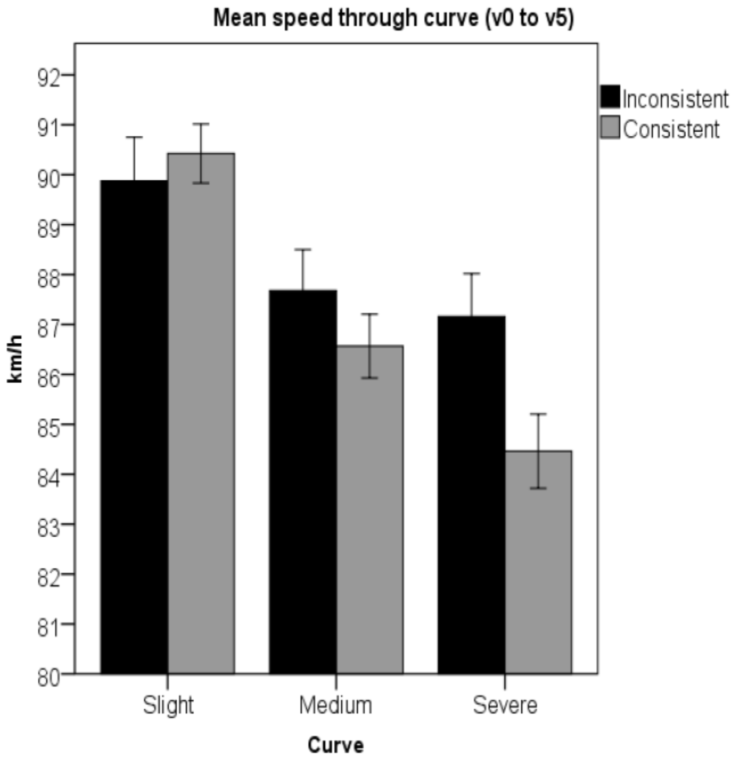
Curve/bend warning sign, edge line markings, slow markings and chevron sign

Curve/bend warning sign, edge line markings, slow markings, chevron sign and coloured surface

Curve/bend warning sign, edge line markings, slow markings, chevron sign, coloured surface and vehicle activated sign

Source: Sjörgen et al. (2012).

Figure 3.14: Mean speed through curves for consistent versus inconsistent route-based curve treatments



Source: Sjörgen et al. (2012).

A trial of route-based curve treatments is currently being conducted by VicRoads (Jurewicz et al. 2014). Table 3.2 identifies the treatment types proposed for the different types of curves. The curve types were based on a number of risk factors including curve direction, approach speed and change in speed, sealed pavement width and grade.

Table 3.2: Proposed treatment packages for each curve risk category

Curve type	Treatments
Low risk	Guideposts Edge line (only if pavement width allows) Centreline (only if pavement width allows)
Medium risk	Raised retroreflective pavement markings (only if linemarking exists or is possible) Audio-tactile (only if pavement width allows) Curve warning and advisory speed signs for isolated or group of curves
High risk	Chevron alignment markers Pavement widening, hazard removal, safety barriers (site-conditional)

Note: Higher risk curve treatments are in addition to those identified for lower risk curve types.

Source: Jurewicz et al. (2014).

3.7.2 Austroads Guidance

The review did not identify any existing Austroads guidance on this type of treatment. However, the developments and outcomes of the VicRoads trial may help to inform the effectiveness of this type of treatment. In order to further consider this topic, this trial should be monitored to consider any implications for further Austroads research and guidance.

3.8 Wide Median Centrelines

3.8.1 Lane Width

Roadway width has been identified as a feature of roads that influenced travel speeds based on the outcomes of a number of Australasian and overseas studies. In recognising this influence, several types of speed reduction treatments have been developed.

3.8.2 Previous Research of Lane Narrowing Treatments

Lane narrowing treatments typically involve physical narrowing of the road by using extended kerbs or raised medians. Alternatively, this may involve narrowing using road markings and wide, painted medians. In some overseas cases, a low-volume two-lane road was converted to a one-lane road, by removing the centreline and providing broken edge lines. Examples include the ‘2–1’ (two minus one) system used in some European countries. However, this type of system has typically been installed on lower-speed rural roads.

One type of treatment that has been investigated on high-speed roads involves using wide median centreline treatments. These treatments typically involve installing a wide median centreline that ‘perceptually’ narrows a road whilst keeping the road seal width constant. Godley et al. (1999) investigated this type of treatment using driver simulation to assess the effectiveness of a 2.3 m hatched centreline median and lanes narrowed to 2.5 m on a two-lane rural road with a 100 km/h speed limit. Results of the study found that the narrowed perceptual lanes increased the amount of effort devoted towards steering, resulting in less lateral position variability and slower speeds.

Trials in Australia and New Zealand have investigated wide median centreline treatments on high-speed roads and considered their potential for reducing crashes, altering the lateral positioning of vehicles and impact on speed (Figure 3.15).

Figure 3.15: Road narrowing via wide median centreline

Wide median centreline trial, New South Wales

Source: Connell et al. (2011).

Painted median strip trial, Queensland

Source: Whittaker (2012).

Connell et al. (2011) reported on a trial of widely spaced audio-tactile centrelines installed on the Newell Highway in New South Wales. The markings consisted of a combination of a 100 mm lane line, a 100 mm audio-tactile line, an 800 mm gap, followed by another 100 mm audio-tactile line and a 100 mm lane line, resulting in a total median width of 1.2 m between opposing directions of travel (Figure 3.15(a)).

The study evaluated the line markings at two sites to assess their influence on vehicle positioning and speed. Outcomes of the trial found large reductions in the proportions of vehicles crossing onto or over the edge line or centreline, which suggested that the linemarking greatly improved lane discipline. The trial also found that the line markings influenced speed (Table 3.3). Mean speeds were observed to decrease, with the exception of heavy vehicles at the Parkes trial site.

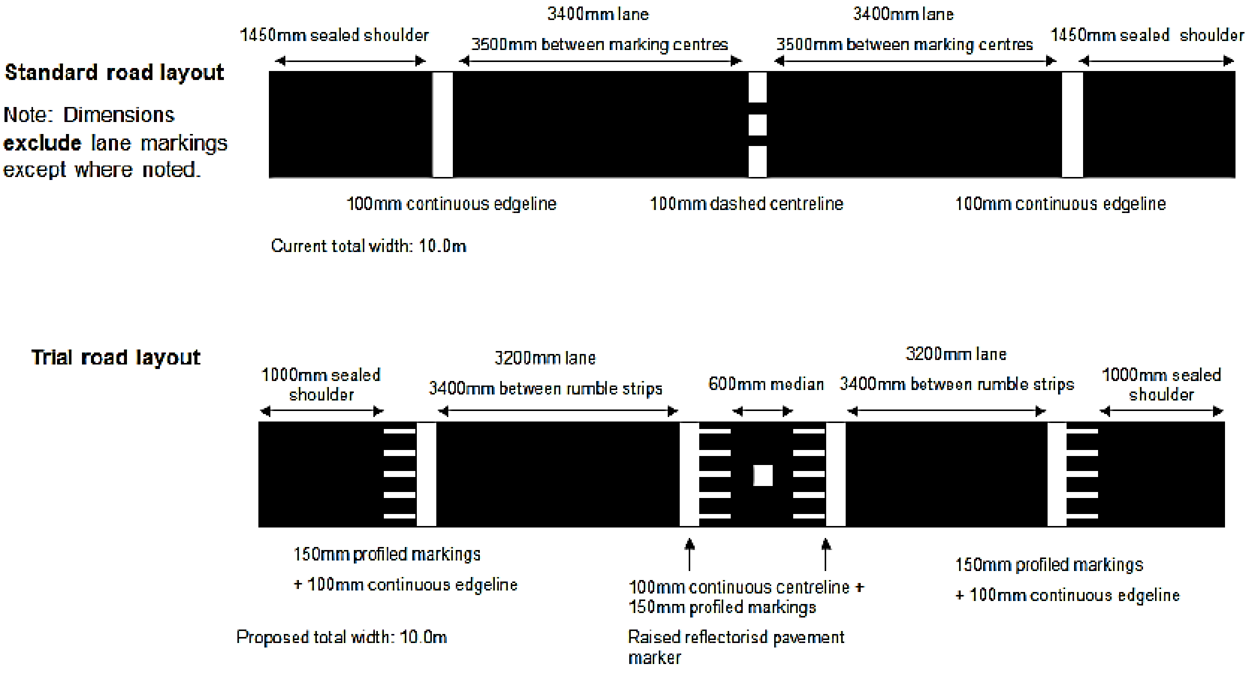
Table 3.3: Effect of wide median centreline on average speed, Newell Highway trial

Site	Vehicle type	Average speed (km/h)	
		Before	After
West Wyalong	Light vehicles	102.8	99.7
	Heavy vehicles	101.0	99.1
Parkes	Light vehicles	100.5	99.8
	Heavy vehicles	101.0	102.7

Source: Connell et al. (2011).

The New Zealand Transport Agency conducted a wide median centreline trial at four locations to measure the impact of the markings on reducing head-on crash risk (Beca 2011). The trial road layout and a standard layout are shown in Figure 3.16. As shown, the overall carriageway width remained consistent with both layouts, but the lane width between the edge line and centreline was reduced from 3.4 to 3.2 m.

Figure 3.16: New Zealand wide median centreline layout



Source: Beca (2011).

The trial found that across all sites, lateral vehicle positioning from the centreline increased (statistically significant) by 0.3 m (from 1.2 to 1.5 m). A slight overall reduction in traffic speeds was also observed across the four sites (Table 3.4). However, assessment of speed was not a focus of the study and the statistical significance of speed changes was not reported. Influences were noted that were likely to have influenced the results, such as the removal of a passing lane at the Pukekohe site (where a 5.6 km/h reduction in speed was observed). Outcomes of the trial found that there was no increase in speed within or downstream of the sites, but there was no conclusive evidence that the wide median centreline reduced speeds.

Table 3.4: Observed change in 85th percentile speed, New Zealand wide median centreline trial

Site	Change in 85th percentile speed (km/h)		
	Upstream	Within trial area	Downstream
Waikanae	1.25	–1.8	–1.8
Pukekohe	–2.95	–5.6	–0.775
Woodend	–7.4	0.65	–0.65
Huntly	0.59	1.4	2.5

Source: Based on Beca (2011).

A trial of a painted median strip was conducted in Queensland (Whittaker 2012). The trial involved installing a painted median strip on a 35 km segment of the Bruce Highway in 2011. The median had an overall dimension of 1.0 m, which was outlined by two 100 mm lane lines and two rows of 150 mm raised ribs, as shown in Figure 3.15(b). The treatment reduced lane widths to 3.0 m and complemented changes implemented prior to the painted median strip (2008) to reduce the posted speed limit from 100 km/h to 90 km/h on this segment of highway.

Whittaker noted there had been very little change in crash trends in the two years after the posted speed limit was reduced (i.e. between 2008 and 2010). Crash trends included a decreasing total crash rate and fatal and head-on crashes that continued to occur at a similar rate during this time period.

Whittaker assessed the effects of the painted median line markings on crashes, based on analysis of crash data for a two-year period prior to and a one-year period after installation. All crash data was taken from the time period after the posted speed limit was reduced. Outcomes of the analysis found that the painted median strip led to a 75% reduction in head-on and cross-over-the-centreline crashes and reduced run-off-road-left and total crashes by 59%.

It was also noted that other safety treatments implemented at the treatment sites (including the reduced posted speed limit, variable message signs and enhanced signage) may have influenced the results. However, as the treatments had been installed prior to the beginning of the trial before period, there was only expected to be a marginal influence.

The trial did not assess vehicle speeds, but the author suggested that further work to consider the implications on speed would be of value due to the potential effects of perceptual lane narrowing. Although not noted by the author or evaluated as part of the Queensland trial, considering the effect on speed of combining a reduced speed zone with a painted centreline median may be an area of further investigation. In line with the concept of a self-explaining road, painted centreline medians may assist drivers with recognising reduced posted speed limit zones.

In the UK, research by Jamson, Lai and Jamson (2010) investigated the use of median and peripheral treatments on two-lane two-way rural road segments with a speed limit of 60 miles/h (96 km/h) using a driver simulator (Figure 3.17). The roadway assessed was 7.3 m in width. The median treatments consisted of introducing a 1.35 m wide hatched central area that effectively reduced each carriageway by 0.675 m.

The study considered the speed reductions that could be obtained on a straight segment of rural road by increasing a driver’s risk perception. It did not assess other performance measures such as lateral vehicle positioning. Speed was assessed by defining an ‘impact zone’ that began at the road segment where a driver received the first cue regarding the presence of a treatment and continued through the length of roadway where the treatment was installed. Performance measures included the resulting average speed change recorded per metre within the impact zone due to the treatment.

Results of the simulation found that the central hatching with coloured pavement resulted in the greatest speed change (average of 4 km/h per m). This was greater than the change due to the central hatching treatment (average of 2.4 km/h per m). The peripheral treatments were also found to reduce speed (average of 3.5 km/h per m for both types of treatment). All changes were statistically significant.

Based on the simulation, it was concluded that speed reductions were achievable by installing treatments that increased a driver's risk perception. The authors also explored other types of treatments that alerted drivers, which were identified as being more effective at junctions.

Figure 3.17: Median and peripheral treatments assessed

Central hatching

Central hatching with coloured pavement

Peripheral hatching

Peripheral hatching with coloured pavement

Source: Jamson, Lai and Jamson (2010).

3.8.3 Austroads Guidance

No existing guidance was identified in the Austroads Guides applicable to wide median centreline treatments. However, the *Road Safety Engineering Toolkit* (Austroads & ARRB Group 2010) identified painted medians supplemented with rumble strips or pavement markers as a treatment to alert motorists that they are leaving their lane. The toolkit did not identify use of this type of treatment for reducing speed.

Further assessment of the impact on speed of wide median centreline treatments has merit. Results of the trials reviewed found that wide median centrelines had an impact on lateral vehicle positioning and reducing crashes. The effect on speeds was less clear. Assessing the effect on speed of a combined treatment with wide centreline medians and reduced posted speed limit zones may also merit further consideration.

3.9 Sight Distance Adjustments on Approaches to Intersections

3.9.1 Previous Research

Previous research has investigated the reduction of sight distance on the approach to an intersection via the use of screens or hedges (Charlton 2003; Leicestershire County Council 2010). This prevented drivers from anticipating gaps at an upstream location from an intersection that might not still be present when they arrive at the intersection stop or give-way line. Examples of these treatments are shown in Figure 3.18. The treatments have been found to result in speed and crash reductions, but are relatively untested in Australia and New Zealand. The treatments are likely to be limited to locations that have excessive sight distance on the approach to an intersection.

Figure 3.18: Examples of sight distance reductions on approaches to intersections

Approach to a T-intersection

Source: Charlton (2003).

Approach to a roundabout

Source: Leicestershire County Council (2010).

Charlton (2003) evaluated this type of treatment at one approach to a staggered T-intersection in New Zealand where there was an unrestricted view of traffic travelling from one direction on the main route. It was hypothesised that drivers were anticipating gaps in traffic at the intersection as far as 100 m in advance, which was supported by very short stop times at the intersection. Additionally, 24 of the 25 crashes during the previous five-year period at the intersection were due to crossing or turning movements.

Hessian screens were installed restricting sight visibility until 25 m prior to the intersection (Figure 3.18(a)). This was found to reduce mean approach speeds from 38 to 29 km/h and 85th percentile speeds from 50 to 39 km/h. The study only reported on a short follow-up period (37 weeks), during which crashes ceased. The trial was noted as a success and the screens were to remain in place until a more permanent solution (a rural roundabout) could be installed.

In a broader study, the New Zealand Transport Agency investigated the relationships between crashes, speed, traffic volume and sight distance at roundabouts (Turner et al. 2009). Drawing on a large dataset of roundabouts across New Zealand, the authors developed a number of models that attempted to predict crash numbers at various roundabout types. One of the key findings of the study was that crashes increased with increased visibility of vehicles approaching from the right, largely due to the fact that higher visibility was correlated with higher speeds. The authors recommended that further research be undertaken to evaluate the role of visibility in determining negotiation speed through a roundabout.

3.9.2 Austroads Guidance

No existing Austroads guidance was identified that discussed this type of treatment.

This treatment has been applied at limited locations and further assessment would be required to consider it. Application at roundabout sites may merit further assessment, due to the crash benefits associated with roundabouts and the challenges identified with approach speeds at roundabouts in high-speed environments.

4. Road Features and Higher-speed Environments

4.1 Introduction

The second year of this project focused on mid-block sections of roads. On mid-block sections where the speed environment remains consistent, drivers are required to maintain a desired speed in line with the posted speed limit or design speed applicable to a section of road.

There are a number of road features from which drivers obtain cues that may influence their speed. Two important aspects include:

- the perceived risk of a feature (e.g. narrow lanes, Section 4.2.5)
- features that indicate a perceived function and/or quality of a road (e.g. separation of driving directions, Section 4.2.7).

In some situations, these aspects may overlap, which may create differing impacts on driver behaviour and poses challenges for understanding the impact on speed.

Research related to these features is discussed in this section. This includes research that has considered the influence of individual features, as well as studies that have evaluated the combined effect of different road features. Austroads guidance that discusses the effect of road features is also identified where applicable.

4.2 Individual Road Features

4.2.1 Horizontal Alignment

There is a large amount of research on the influence of horizontal alignment on speed, with a firm relationship established between the amount of horizontal curvature on a road and the influences on speed. Martens, Comte and Kaptein (1997) noted that driving through curves requires extra effort in lane keeping. Horizontal curves may also limit visibility distances along a road, which influences a driver’s capability to anticipate the course of the road or upcoming traffic situations.

Part 3 of the *Guide to Road Design* (Austroads 2010a) provides an operating speed model for rural roads. The model was developed to predict the operating speed of cars along a rural road, where speed is largely controlled by horizontal curvature. It provides designers with a tool to estimate the changes in speed as vehicles travel through a horizontal curve (or a series of curves) of a given radius and at a particular approach speed. The model will also estimate the changes in speed at locations downstream from a curve.

4.2.2 Vertical Alignment

Vertical gradients will have an influence on speed. Martens, Comte and Kaptein (1997) noted that gravity will reduce the speed of vehicles on uphill gradients and increase vehicle speed on downhill gradients. Forward visibility is also restricted on uphill gradients, which may lead to driver uncertainty contributing to slower speeds.

Austroads (2010a) provides guidance on designing vertical alignment on roads. Section 8.5 discusses the impact of vertical grades on operating speed including the guidance shown in Table 4.1. The Guide also provides general maximum grades that are based on vehicle performance (Table 4.2). As shown, for high operating speeds (100 km/h or faster), the general maximum grades are recommended as 3–5% for flat terrain, 4–6% for rolling terrain and 6–8% in mountainous terrain for a 100 km/h operating speed.

Table 4.1: Effect of grade on vehicle type and speed

Grade %	Reduction in vehicle speed as compared to flat grade				Road type suitability
	Uphill		Downhill		
	Light vehicle	Heavy vehicle	Light vehicle	Heavy vehicle	
0–3	Minimal	Minimal	Minimal	Minimal	For use on all roads.
3–6	Minimal	Some reduction on high speed roads	Minimal	Minimal	For use on low-moderate speed roads (incl. high traffic volume roads).
6–9	Largely unaffected	Significantly slower	Minimal	Minimal for straight alignment. Substantial for winding alignment	For use on roads in mountainous terrain. Usually need to provide auxiliary lanes if high traffic volumes.
9–12	Slower	Much slower	Slower	Significantly slower for straight alignment. Much slower for winding alignment	Need to provide auxiliary lanes for moderate – high traffic volumes. Need to consider run-away vehicle facilities if proportion of commercial vehicles is high.
12–15	10–15 km/h slower	15% max negotiable	10–15 km/h slower	Extremely slow	Satisfactory on low-volume roads (very few or no commercial vehicles).
15–33	Very slow	Not negotiable	Very slow	Not negotiable	Only to be used in extreme cases and be of short lengths (no commercial vehicles).

Source: Austroads (2010a), based on Queensland Department of Main Roads (2002).

Table 4.2: General maximum grades (%)

Operating speed (km/h)	Terrain		
	Flat	Rolling	Mountainous
60	6–8	7–9	9–10
80	4–6	5–7	7–9
100	3–5	4–6	6–8
120	3–5	4–6	–
130	3–5	4–6	–

Notes: Values closer to the lower figures should be aimed for on primary highways. Higher values may be warranted to suit local conditions. For unsealed surfaces the above value should be reduced by 1%.

Source: Austroads (2010a).

Based on the guidance provided, grades will have a minimal effect on light vehicles in high-speed environments when roads are designed consistent with the recommended maximum grades. However, heavy vehicles travelling uphill and downhill in mountainous terrain (100 km/h operating speed) or with a winding alignment will be affected by vertical gradient.

4.2.3 Access Points

The number of access points has been found to influence vehicle speeds on roads (Martens, Comte & Kaptein 1997, Charlton & Baas 2006).

Part 3 of the *Guide to Traffic Management* (Austroads 2013b) provides guidance on the analysis of uninterrupted traffic flow for different types of roadways including two-lane two-way roads, multi-lane roads and freeways. The methods of analysis included in Austroads (2013b) are based on procedures described in the *Highway Capacity Manual* (Transportation Research Board 2010).

For two-lane two-way roads and multi-lane roads, Austroads (2013b) notes that increasing the frequency of access points reduces the free-flow speed. On motorways, interchange spacing of less than 3 km is identified as decreasing free-flow speed.

Issues related to access management are discussed in Parts 5 of the *Guide to Traffic Management* (Austroads 2014b) and Part 4 of the *Guide to Road Design* (Austroads 2009c).

4.2.4 Road Surface

Rough or irregular road surfaces may decrease driver comfort, thereby resulting in slower vehicle speeds.

Research

Elliott, McColl and Kennedy (2003) noted that rough road surfaces were effective in reducing speeds, citing a study (Slangen 1983) that found a 14–23% reduction in speed due to rough road surfaces. Martens, Comte and Kaptein (1997) identified other research that had assessed the impact of road surface on speed noting that:

- a rough road that followed a smooth section of road reduced speeds by 5%, citing Te Velde (1985)
- following resurfacing of a rural road with speeds of 70–80 km/h, speeds increased by up to 2.6 km/h, citing Cooper et al. (1980).

Charman et al. (2010) noted that poor road surfaces may reduce speeds, but may introduce safety issues when negotiated at speed. In addition, the overuse of surface treatments may diminish their effectiveness.

Austroads Guidance

Part 3 of the *Guide to Road Design* (Austroads 2010a) identifies pavement surface conditions as a road feature that may influence operating speed. However, the Guide notes that there is insufficient research available to accurately understand its impact.

Commentary 4 in Austroads (2010a) provides some limited guidance applicable to calibrating the operating speed model for observed conditions. It notes that roads with poor broken surfaces can be considered to reduce operating speeds by 5–10 km/h.

Part 5 of the *Guide to Pavement Technology* (Austroads 2011b) provides roughness values applicable to different speed environments (Table 4.3). The Guide identifies maximum desirable roughness counts for various classes of newly constructed or rehabilitated roads.

Table 4.3: Maximum desirable levels of roughness

Road function	Level of roughness[1]		
	Typical maximum desirable roughness for new construction or rehabilitation (length > 500 m)	Indicative investigation levels for roughness (counts/km)	
		Isolated areas	Length > 500 m
Freeways and other high-class facilities	To 40 counts/km	110	90
Highways and main roads (100 km/h)	To 50 counts/km	140[2]	110
Highways and main roads (less than 80 km/h)	To 50 counts/km	160	140
Other local roads (sealed)	No limits defined[3]	No limits defined[3]	No limits defined[3]

1 *Roughness measures are in equivalent National Association of State Road Authorities (NAASRA) roughness counts/km, for further guidance refer to Austroads (2011b).*
2 *Lower levels may be appropriate where total traffic or heavy vehicle volumes are high.*
3 *Roughness levels depend on local conditions and traffic calming measures.*

Source: Table 4.1 of Austroads (2011b).

4.2.5 Road, Lane and Shoulder Width

Road, lane and shoulder width has been identified as influencing speed. Martens, Comte and Kaptein (1997) noted that narrower roads and lanes required increased driver effort towards lane keeping and steering, which contributed to slower speeds. However, although narrower roads and lanes may reduce speeds in high-speed environments, this may contribute to an increase in road crashes. Austroads (2015c) noted that the risk of run-off-road casualty crashes was 2.7 times higher on roads with narrow pavements (< 6 m) when compared to roads with 9–10 m pavements.

Charman et al. (2010) noted that reducing lane width may have a negative impact on safety, due to a reduction in the lateral room for correction and that in a rural situation it was unlikely that lane width would be reduced for the sole purpose of influencing speed.

Research

A study in the USA (Harwood et al. 1999) investigated the relationship between traffic lane and shoulder width on free-flow speed as part of the development of the *Highway Capacity Manual: HCM 2000* (Transportation Research Board 2000). The relationship was retained in the 2010 edition of the manual. The research by Harwood et al. (1999) focused on two-lane highways. However, Transportation Research Board (2000 and 2010) also provided free-flow speed reductions due to lane width for multi-lane highways and freeways. This relationship was discussed in Section 4.2 of the Austroads *Guide to Traffic Management – Part 3: Traffic Studies and Analysis* (Austroads 2013b).

In order to determine the free-flow speed on a two-lane two-way highway, Harwood et al. (1999) developed an equation to determine the free-flow speed under base conditions. Base conditions were expected to exclude factors such as restrictive geometric, traffic or environmental factors. For two-way two-lane highways, base conditions included widths of 3.6 m for traffic lanes and 1.8 m for shoulders. The relationship also included a factor to adjust speeds based on the number of access points.

The equation developed for this relationship is shown in Equation 1.

$$FFS = BFFS - f_{LS} - f_A \qquad 1$$

where

FFS = estimated free-flow speed (km/h)

$BFFS$ = estimated free-flow speed (km/h) for base conditions (i.e. widths of 3.6 m for traffic lanes and 1.8 m for shoulders)

f_{LS} = adjustment factor for lane and shoulder width

f_A = adjustment factor for access points

A field study was conducted to derive the adjustment for lane and shoulder width by analysing data from two-lane highways in California and Missouri upstream and downstream of shoulder and lane width transitions. The effects on mean speed for lane and shoulder width individually are shown in Table 4.4. These were used to determine the adjustment factor for lane and shoulder width (f_{LS}) in Equation 1.

Table 4.4: Individual reductions in mean speed due to lane and shoulder width for two-way two-lane highways

Effect of lane width		Effect of shoulder width	
Lane width (m)	**Reduction in mean speed (km/h)**	**Shoulder width (m)**	**Reduction in mean speed (km/h)**
3.6	0.0	1.8	0.0
3.3	0.7	1.2	2.1
3.0	1.7	0.6	4.2
2.7	3.5	0.0	6.8

Source: Harwood et al. (1999).

A more recent study (Melo et al. 2012) examined the relationship between free-flow speed, lane and shoulder widths determined by Harwood et al. (1999). The study considered the effects of variations in lane and shoulder widths by using a driving simulator. The simulator considered two types of roads. Both were two-way two-lane rural roads located in Portugal. One was a winding road with a design speed of 40 km/h and the other a less demanding road with a design speed of 80 km/h.

Results of the study differed from those included in the *Highway Capacity Manual* (Transportation Research Board 2000) and are shown in Table 4.5. Differences included:

- The 'base' lane and width combination (i.e. largest combination of lane and shoulder width that reduced speed) was a 3.6 m lane and a 0.6 m shoulder, and not a 1.8 m shoulder. This was observed in the results for both the 40 and 80 km/h speed environments.
- The combined effect of lane and shoulder width were not additive, particularly the combinations of a narrow lane and a wide shoulder or a wide lane and narrow shoulder which were found to have a small reduction in free-flow speed (e.g. 3.6 m lane and no shoulder, or 2.7 m lane and a 1.8 m shoulder).
- The influence of cross-section on free-flow speed was dependent on the speed environment, with greater reductions observed on the less demanding 80 km/h road than the winding 40 km/h road.

The research did not consider speed environments greater than 80 km/h which limited the application of the findings to higher-speed roads. However, the findings merit consideration into how the combined effect of lane and shoulder width can influence speed. The results of the research also suggested that on less demanding high-speed roads, shoulder width would be expected to have a minor influence on speed where lane width was in the vicinity of 3.6 m.

Table 4.5: Reduction in free-flow speed based on lane and shoulder widths

Lane width (m)	Shoulder width (m)											
	General values Harwood et al. (1999)				Winding road, 40 km/h design speed Melo et al. (2012)				Less demanding road, 80 km/h design speed Melo et al. (2012)			
	0.0	0.6	1.2	1.8	0.0	0.6	1.2	1.8	0.0	0.6	1.2	1.8
2.7	10.3	7.7	5.6	3.5	6.8	3.7	2.3	1.0	9.9	5.4	3.4	0.5
3.0	8.5	5.9	3.8	1.7	4.6	2.3	1.4	n/a	6.7	3.4	2.1	n/a
3.3	7.5	4.9	2.8	0.7	2.5	1.1	0.6	n/a	3.7	1.7	0.8	n/a
3.6	6.8	4.2	2.1	0.0	0.6	0.0	n/a	n/a	0.9	0.0	n/a	n/a

Notes: Values shown are reduction in free-flow speed (km/h) based on lane and shoulder width combination. Based on two-way two-lane highways.

Source: Harwood et al. (1999) and Melo et al. (2012).

Austroads Guidance

Part 3 of the *Guide to Road Design* (Austroads 2010a) provides guidance on determining road and lane width. For rural roads, the Guide suggests a desirable lane width of 3.5 m. For single-lane carriageways, widths of 3.5 m are recommended with narrower widths applied for lower-volume roads (Table 4.6). Values for total shoulder, minimum shoulder seal and total carriageway width are also provided in the table. As shown in the table, the recommended total carriageway width increases as the design annual average daily traffic (AADT) increases.

Table 4.6: Single carriageway rural roads widths (m)

Element	Design AADT				
	1–150	150–500	500–1000	1000–3000	> 3000
Traffic lanes[(1)]	3.7 (1 x 3.7)	6.2 (2 x 3.1)	6.2–7.0 (2 x 3.1/3.5)	7.0 (2 x 3.5)	7.0 (2 x 3.5)
Total shoulder	2.5	1.5	1.5	2.0	2.5
Minimum shoulder seal[(2), (3), (4), (5), (6)]	0	0.5	0.5	1.0	1.5
Total carriageway	8.7	9.2	9.2–10.0	11.0	12.0

1 *Traffic lane widths include centre lines but are exclusive of edge lines.*
2 *Where significant numbers of cyclists use the roadway, consideration should be given to fully sealing the shoulders. Suggest use of a maximum size 10 mm seal within a 20 km radius of towns.*
3 *Wider shoulder seals may be appropriate depending on requirements for maintenance costs, soil and climatic conditions or to accommodate the tracked width requirements for large combination vehicles.*
4 *Short lengths of wider shoulder seal or lay-bys to be provided at suitable locations to provide for discretionary stops.*
5 *Full width shoulder seals may be appropriate adjacent to safety barriers and on the high side of superelevation.*
6 *A minimum 7.0 m seal should be provided on designated heavy vehicle routes (or where the AADT contains more than 15% heavy vehicles).*

Source: Austroads (2010a).

Austroads (2010a) notes that travel speed will be influenced by the lane width of a rural road. The Guide states that ‘Drivers tend to reduce their travel speed, or shift closer to the lane/road centre (or both) when there is a perception that a fixed hazardous object is too close to the nearside or offside of a vehicle’.

Other effects of lane width include:

- lane width and road surface have substantial influences on the safety and comfort of the users of a roadway
- narrow lanes result in more wheel concentrations in the vicinity of the pavement edge which forces vehicles to travel laterally closer to one another than would normally happen at the design speed.

The operating speed model for rural roads included in Austroads (2010a) also recognises the influence of narrower lane widths. Section 3.5.3 of the Guide identifies cross-section as a road feature that may influence speed and suggests that when applying the operating speed model to segments with lane widths narrower than 3 m, operating speeds can be reduced by up to 3 km/h. Similar guidance is provided in Section 2.4.2 of Part 2 of the *Guide to Road Design* (Austroads 2015a).

Guidance provided on the analysis of uninterrupted traffic flow in Part 3 of the *Guide to Traffic Management* (Austroads 2013b) also considers the effects of lane width on free-flow speed. Based on Transportation Research Board (2010), Austroads (2013b) notes that free-flow speeds will be reduced where lane width is less than 3.6 m.

4.2.6 Number of Lanes

In Europe, the ERASER project investigated the influence of different combinations of road features (Houtenbos et al. 2011). The objective of the project was to identify road features that influenced speeding behaviour and consider how universal the effects were on driver behaviour in different European countries. The project considered the influence of the number of lanes on speed, and found that drivers perceived slightly faster speed (2 km/h difference) on multilane roads when compared with single-lane roads.

A separate European project, the SPACE project, also considered the effect of the number of lanes on speed and found that speed in high-speed environments may be greater on roads with three or more lanes (Aarts et al. 2011).

Austroads (2013b), based on Transportation Research Board (2010), identifies the number of lanes as a road feature that will influence free-flow speed.

4.2.7 Separation of Driving Directions

The separation of driving directions has also been identified as a road feature influencing speed. Research has indicated that drivers perceived faster speeds on divided roads as opposed to undivided roads (Aarts et al. 2011, Houtenbos et al. 2011). Stelling-Konczak et al. (2011) noted that roads with physical separation (especially ones involving a central reservation) were more readily identified as high-speed through roads.

Austroads (2013b) suggests this approach for determining the free-flow speed on multilane highways, where free-flow speed on an undivided road is noted as being 2.6 km/h slower than on a divided road with the same features.

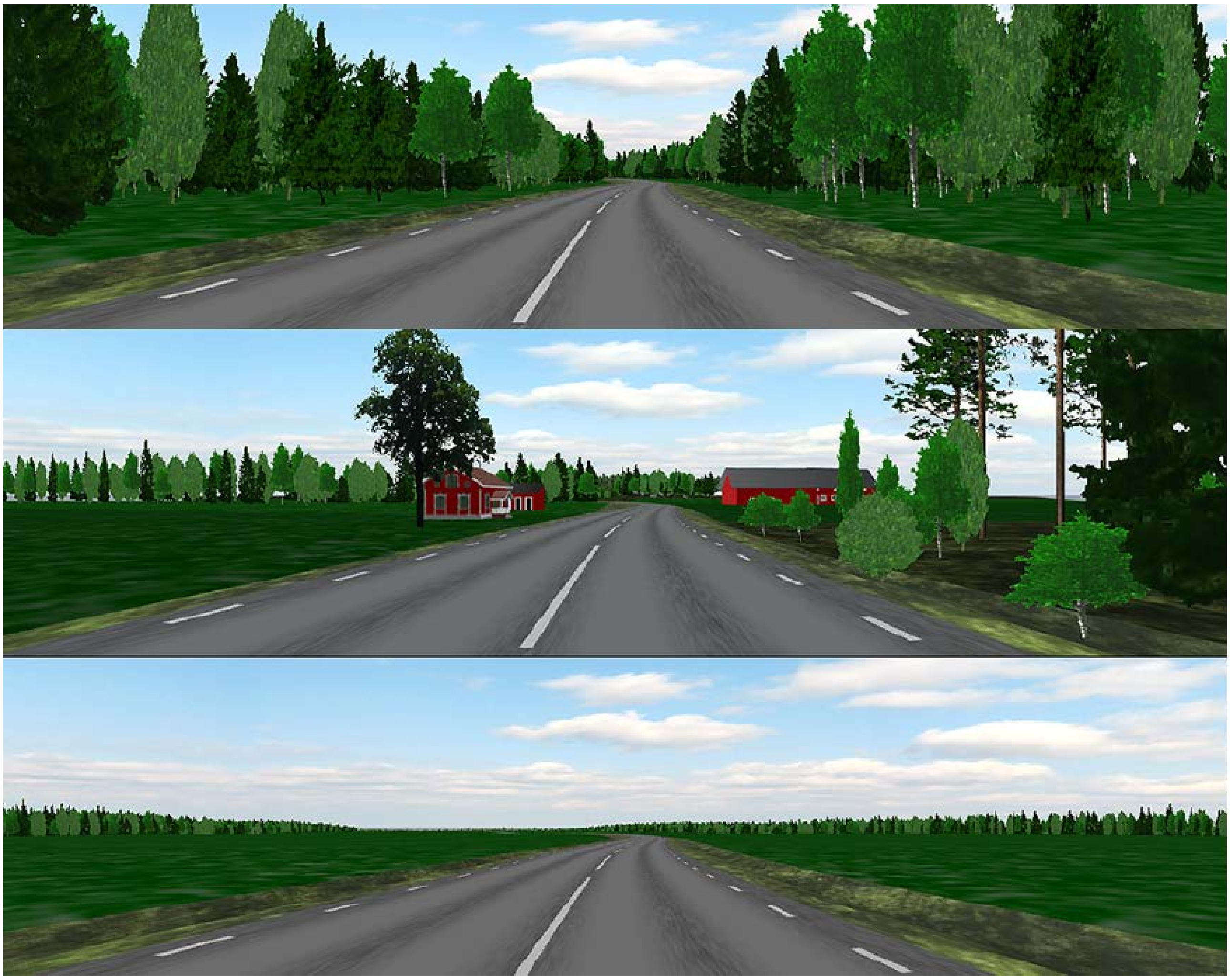
However, Elliott, McColl and Kennedy (2003) noted that speed may be reduced where central medians are present due to the effect of forward visibility being reduced, possibly increasing perceived risk. As noted in Section 4.1, the effect on speed may differ depending on the perceived effect of a feature and whether a feature increases perceived risk or is perceived as a higher-quality, higher-speed route.

4.2.8 Roadside Environment and Vertical Elements

Research has also considered the influence that roadside features have on speed in high-speed environments.

A Swedish study examined the effect of roadside landscape on driver behaviour (Antonson et al. 2009). The study used a driver simulator and a questionnaire of 18 drivers to consider the influence of landscape character (i.e. open, forested or varied) on driver behaviour. Examples of the computer-animated landscapes are shown in Figure 4.1.

Figure 4.1: Computer-animated roadside environments



Note: The roadside environments shown from top to bottom are forested, varying and open landscapes.

Source: Antonson et al. (2009).

The driver behaviours assessed included average speed, lateral vehicle position and road alignment. The topography and curvature of the computer-animated road were taken from a 10 km section of rural road in southern Sweden with a posted speed of 90 km/h.

Key findings of the study included:

- average speed was slower on road segments with varying landscape (89.3 km/h) than average speeds on landscapes that were forested (90.8 km/h) or open (92.9 km/h)
- the mean lateral position of vehicles was further away from the centreline of the road for open landscapes (1.46 m), which was greater than for forested (1.44 m) or varying landscapes (1.42 m).

In practical terms, the greatest difference in average speeds was between the varying and open landscapes (3.6 km/h difference).

This effect was smaller than the change identified by Houtenbos (2011) discussed in Section 4.3.2, which found differences of 8 km/h between an open and a more closed environment. It should be noted that the speed measurement methods were different between these studies. The results from Houtenbos et al. (2011) were based on driver perceptions, while Antonson et al. (2009) measured speed using a simulator.

Lauckner and Brandenburg (2014) conducted a driver simulation study on the effect of roadside and overhead features on driver behaviour. The study found that having road features on more planes of the peripheral vision (i.e. overhead, left side and right side) led to a decrease in speed. In addition, a greater combined number of features in any plane of the driver's peripheral visual field led to a decrease in speed.

Charman et al. (2010) noted that repetitive roadside objects (including street lighting poles, trees, walls or hedges) had a medium-low effectiveness at enabling appropriate speed choice (refer to Section 4.3.1). However, roadside objects were also identified as adversely influencing passive safety.

Part 6 of the *Guide to Road Design* (Austroads 2010b) provides design guidance on the mitigation of roadside hazards. Section 4.2.2 of this Guide identifies considerations for designing clear zones including recommended clear zone distances. Table 4.7 shows the recommended clear zone widths for high-speed environments.

Part 3 of the *Guide to Traffic Management* (Austroads 2013b) identifies lateral clearance as a road feature that influenced free-flow speed. However, in high-speed environments where the clear zone distances are met (Table 4.7), the research suggested that lateral clearance would have minimal influence on speed.

Table 4.7: Clear zone distances from edge of through travelled way – high-speed environments

Design speed (km/h)	Design ADT	Clear zone width (m)					
		Fill batter			Cut batter		
		6:1 to flat	4:1 to 5:1	3:1 and steeper[(2)]	6:1 to flat	4:1 to 5:1	3:1 and steeper[(2)]
100	< 750	5.5	7.5	[(2)]	5.0	4.5	3.5
	750–1500	7.5	10.0[(1)]	[(2)]	6.5	5.5	4.5
	1501–6000	9.0	12.0[(1)]	[(2)]	8.0	6.5	5.5
	> 6000	10.0[(1)]	13.5[(1)]	[(2)]	8.5	8.0	6.5
110	< 750	6.0	8.0	[(2)]	5.0	5.0	3.5
	750–1500	8.0	11.0[(1)]	[(2)]	6.5	6.0	5.0
	1501–6000	10.0[(1)]	13.0[(1)]	[(2)]	8.5	7.5	6.0
	> 6000	10.5[(1)]	14.0[(1)]	[(2)]	9.0	9.0	7.5

1 *Where a site specific investigation indicates a high probability of continuing crashes, or such occurrences are indicated by crash history, the designer may provide clear zone distances greater than the clear zone shown in Table 4.7. A jurisdiction may limit clear zones to 9 m for practicality and to provide a consistent roadway template if previous experience with similar projects or designs indicates satisfactory performance.*

2 *Since recovery is less likely on the unshielded, traversable 3:1 slopes, fixed objects should not be present in the vicinity of the toe of these slopes. Recovery of high-speed vehicles that encroach beyond the edge of the shoulder may be expected to occur beyond the toe of the slope. Determination of the recovery area at the toe of the slope should take into consideration available road reservation, environmental concerns, economic factors, safety needs, and crash histories. Also, the distance between the edge of the travelled lane and the beginning of the 3:1 slope should influence the recovery area provided at the toe of the slope. While the application may be limited by several factors, the fill slope parameters which may enter into determining a maximum desirable recovery area are illustrated in Figure 4.4 of Austroads (2010b).*

Source: Austroads (2010b), based on American Association of State Highway and Transportation Officials (2006).

4.2.9 Lateral Clearance

In addition to the research that has considered the effect on speed of different types of roadside features, other research has considered the influence of lateral clearance to roadside objects. Martens, Comte and Kaptein (1997) identified that decreased lateral clearance and obstacles placed directly along the side of the road reduced speed. Charlton and Baas (2006) found that roadside hazards 3 m or closer from the road edge reduced speed in an 80 km/h speed environment. However, Charman et al. (2010) noted that it was unlikely that roadside objects would be introduced for the sole purpose of influencing speed.

The procedures for determining free-flow speed that were developed by Transportation Research Board (2010) have been adopted by Austroads (2013b) and include lateral clearance as a factor:

- for freeways, free-flow speed is reduced where the right-side lateral clearance is less than 6 feet (1.8 m)
- for multilane highways, free-flow speed is reduced where total lateral clearance (i.e. the sum of the lateral clearance on left and right sides of road or carriageway) is less than 12 feet (3.6 m).

4.2.10 Road Tunnels

Calvi, De Blasiis and Guattari (2012) conducted a driver simulation study of the influence of road tunnels on speed and driver discomfort. The study found that average speeds were significantly lower in four of the six tunnel scenarios studied. Additionally, 60% of drivers reduced their speed upon entering a tunnel. These findings were consistent with those of Lauckner and Brandenburg (2014) who found that a road environment that created a tunnel-like impression helped to decrease speed significantly.

4.3 Combined Effect of Road Features

4.3.1 Road Features and Self-explaining Roads

In Europe, research on the development of self-explaining roads has considered the effects of road features on speed. The Speed Adaptation Control by Self-Explaining Roads (SPACE) project (Charman et al. 2010) conducted a review of individual treatments that could be considered as self-explaining and therefore had an effect on speed choice. Treatments were grouped into categories (including curves, transitions, intersections and links) and information was summarised on their effectiveness. This included a rating of their effectiveness in enabling appropriate speed choice.

For the links grouping, which considered the effect on speed choice of road features located on straight road sections, Charman et al. (2010) discussed the effect of a number of road features (Table 4.8). However, it was identified that many of the features were unlikely to be installed solely for the purpose of influencing speed, but may be present or installed for other purposes, such as improving passive safety. Illusory lane markings and median and edge treatments were identified as potentially effective treatments for enabling appropriate speed choice whilst having a neutral impact on passive safety. These treatments are further discussed Sections 3.3 and 3.8.

Table 4.8: Road features on links (straight road segments) that influence speed choice

Road feature	Effectiveness in enabling appropriate speed choice	Impact on passive safety	Other observations
Lane widths	• Medium-low (if lane width or number of lanes is reduced)	• Negative (if lane width or number of lanes is reduced)	• It is unlikely that, in a rural situation, lane width would be changed for the sole purpose of influencing speed. • Reducing lane width or the number of lanes may reduce the lateral room for correction.
Surface quality and treatment	• Medium for surface treatments (e.g. coloured surfacing) • Negative speed consequences for surface quality improvements	• Neutral	• Poor road surfaces (e.g. potholes) may reduce speeds, but may introduce safety issues when negotiated at speed. • Overuse of surface treatments may diminish their effectiveness if they are too common.
Illusory lane width markings	• Medium-high	• Neutral	• Give the perceptual impression that a lane is narrower. • Markings need to be skid resistant, e.g. to reduce risk to motorcycle safety. • Do not negatively impact on drivers' capability to correct when drifting out of lanes.
Median and edge treatments	• Medium	• Neutral	• Give the perceptual impression that a road is narrower. • Potential negative impacts on motorcycle safety. • Edge treatments may result in lateral positioning closer to opposing traffic.
Barriers	• Medium-low	• Positive	• The effect on speed of barriers varies depending on the situation. Barriers should be regarded as a safety feature rather than a speed management tool.
Shoulder	• Low	• Positive	• It is unlikely that shoulders will be added or removed for the sole purpose of influencing speed.
Repetitive roadside objects	• Medium-low	• Very positive (if trees are removed)	• May include street lighting poles, trees, walls or hedges. • It is unlikely that repetitive roadside objects will be introduced for the sole purpose of influencing speed.

Source: Based on Charman et al. (2010).

4.3.2 ERASER Project

In Europe, the Evaluation to Realise a common Approach to Self-explaining European Roads (ERASER) project investigated the influence of different combinations of road features (Houtenbos et al. 2011). The objective of the project was to identify road features that influenced speeding behaviour and consider how universal the effects were on driver behaviour in different European countries.

Features investigated included road width, separation of driving direction, roadside environment and the number of lanes per direction. The study was conducted using of an online questionnaire, which presented participants 24 pictures of rural distributor roads and asked them to indicate their own driving speed and a safe speed limit. Participants were included from six European countries (Austria, Germany, The Netherlands, Ireland, Sweden and the UK).

Findings of the study are shown in Table 4.9. It should be noted that the mean speeds are based on driver perceptions and were not based on actual field measurements of speed. Key results included that road width and vegetation of the roadside environment were found to influence speed with faster speeds reported by participants when a road was wider and there was relatively little vegetation at the roadside.

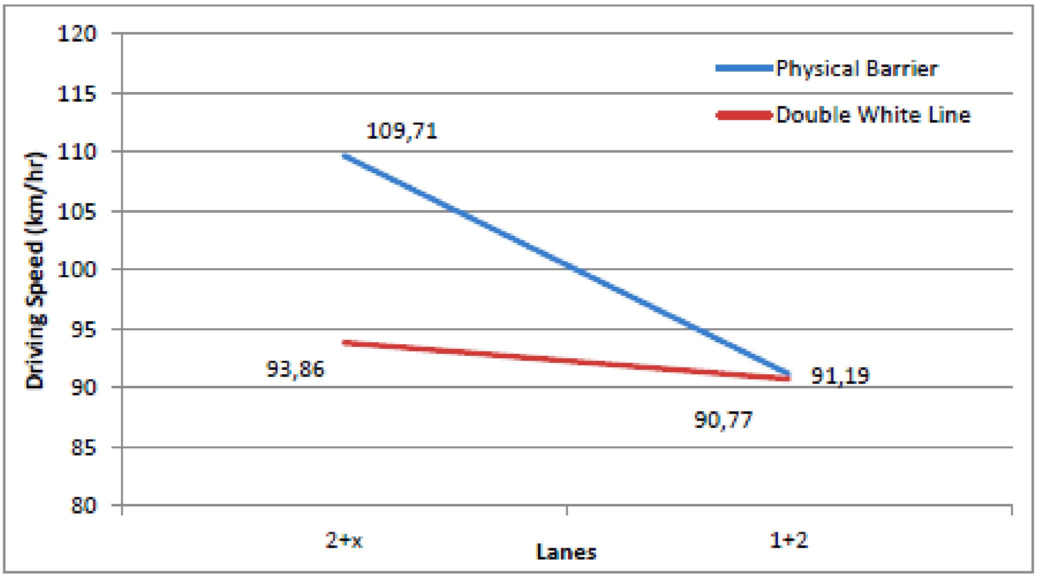
Table 4.9: ERASER project analysis of road features

Road feature	Findings
Roadside environment	• For multi-lane roads, reported mean speeds were considerably higher for roads with an open environment (100.50 km/h) than roads with a more closed environment (92.26 km/h). • For single-lane roads, reported mean speeds were considerably faster on roads with an open environment (92.91 km/h) than on roads with a more closed environment (84.75 km/h).
Lane width	• On multi-lane roads (i.e. 2 + 2 and 2 + 1 lane roads), reported mean speeds were slightly faster on wider roads (mean speed of 97.04 km/h) than on narrower roads (mean speed of 95.72 km/h). • On single-lane roads (i.e. 1 + 1 and 1 + 2 lane roads), reported mean speeds were slightly faster on wider roads (90.75 km/h) than on narrower roads (88.73 km/h). In some countries, differences in speed were not observed (Austria and Germany). • Narrow roads had lanes between 2.75 and 3.25 m. Wide roads had lane widths between 3.5 and 3.75 m.
Number of lanes	• Faster mean speeds were reported on 2 + 2 and 2 + 1 lane roads (101.78 km/h) than on 1 + 2 lane roads (90.98 km/h) in all countries. • Faster mean speeds were found on 1 + 2 lane roads (90.77 km/h) than on 1 + 1 lane roads (88.72 km/h).
Separation of driving directions: physical separation versus double continuous centreline	• Faster mean speeds were reported on roads with a physical barrier compared to roads with a double continuous centreline (mean difference of 8.14 km/h). • Results differed between countries with a greater difference observed in Germany, The Netherlands and Sweden (mean difference of 8.5 km/h) than in Austria, the UK and Ireland (mean difference of 5.5 km/h).
Separation of driving directions: double continuous centreline versus single broken centreline	• Overall, reported speeds on roads with a double centreline as a separation did not differ from those on roads with single broken centreline markings.

Source: Based on Houtenbos et al. (2011).

The project considered the combined effect of road features such as lane configuration and separation of driving directions (Figure 4.2). As shown, the presence of physical barriers on multi-lane (2 + x) roads influenced perceived speeds substantially (15.85 km/h difference), whilst only a small change in mean speed was observed on the 1 + 2 roads (0.42 km/h difference).

Figure 4.2: Combined effect of lane configuration and separation of driving directions



Note: Speeds shown are the mean speeds (km/h) based on driver perceptions from a questionnaire.

Source: Houtenbos et al. (2011).

Houtenbos et al. (2011) noted that the use of pictures to show the roadside environment had limitations in their ability to show texture in features such as trees and bushes, which may not have elicited the same feeling as the real environment. The study also only presented two extremes of roadside environment, completely open and dense forested, but was not able to explore more subtle changes in roadside environment. Other research which has considered the influence of roadside environment on speed is discussed in Section 4.2.8.

4.3.3 Credible Speed Limit Tool

To assist road agencies with implementing self-explaining roads, a further deliverable of the ERASER project was a draft version of a tool that could assist in speed-management-related decision making (Aarts et al. 2011). The aim of the tool was to make roads and their speed limits more credible or self-explaining, and also ensure that speed limits were safe.

The ERASER tool was based on the concept that various features of a road acted as accelerators or decelerators, thereby giving road users the impression of a faster or slower road. The tool required a user to input road feature data, then by conducting a credibility assessment of the features against the identified accelerators and decelerators, a 'safe speed limit' was calculated. Comparing the safe speed with the posted speed limit on a road provided an indication of whether the posted speed limit was credible (i.e. whether the desired speed fit with the intuitive speeds most drivers would prefer on a road). If the safe speed limit was less than the posted speed limit, then the tool identified potential measures that could be taken to improve the situation. It also provided a rating of the urgency of the situation.

The tool is available on the ERASER website (European Commission n.d.). The tool calculated a safe speed limit that could be compared with the existing posted speed limit. Also provided was additional information related to road features (accelerators and decelerators) that contributed to the assessment.

A summary of the scoring mechanisms underlying the ERASER tool are provided in Appendix B. The credible speed limit factors identified for 100 and 110 km/h environments are shown in Table 4.10.

Table 4.10: Credible speed limit factors identified for high-speed environments

Factor	100 km/h		110 km/h	
	Decelerator	Accelerator	Decelerator	Accelerator
Road width[(1)]	< 18 m	> 22 m	< 20 m	> 24 m
Lane width[(1)]	< 2.9 m	> 3.6 m	< 3.1 m	> 3.7 m
Number of lanes	< 2 per driving direction	3 or more	< 2 per driving direction	3 or more
Separation of driving directions	No separation of driving directions	–	No separation of driving directions	–
Horizontal alignment – length of tangents	< 170 m	> 460 m	< 210 m	> 550 m
Vulnerable road users	No restrictions	–	No restrictions	–
Type and frequency of intersections	At grade intersections Speed reducing measures at intersections	–	At grade intersections Speed reducing measures at intersections	–
Roadside environment	Dense or semi-open	–	Dense or semi-open	–

[1] *For undivided roads, road width was used as a factor. For divided roads, lane width was used.*

Source: Based on Aarts et al. (2011).

Aarts et al. (2011) noted that the initial version of the ERASER tool was considered simplistic and modifications were being explored to develop a more sophisticated version. For example, all accelerator and decelerator factors were given equal weighting, but results from the project suggested that some weightings had a greater influence than others and further research should consider applying weightings.

4.3.4 Roadway Features and Driver Discomfort

A US study (Stamatiadis et al. 2010) investigated roadway features on two-lane rural roads to gain an understanding of their influence on operating speed. This was conducted by assessing how strongly road design factors influenced perceived operator discomfort based on user ratings of virtual reality simulations. Driver discomfort was used as an indicator for operating speed, where increased driver discomfort was used to indicate reduced operating speeds.

The modelling and rating of visualisations permitted analysis of road features using scenarios representing five design elements: roadway width (which included the clear zone), vegetation type, roadside barrier type, horizontal curvature and vertical grade. The study was able to consider how these design elements influenced driver discomfort across a wide range of road layouts and assess the effect of combinations of design elements on driver discomfort.

With regard to assessing road design elements across different road layouts, key findings from Stamatiadis et al. (2010) were:

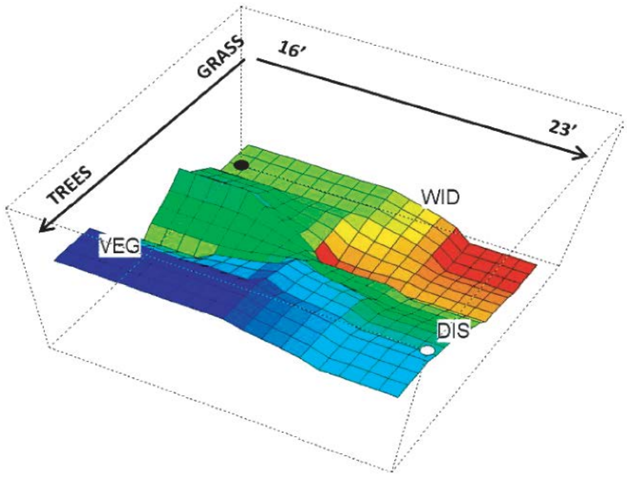
- Greater vegetation intensity (i.e. transition from lower to taller vegetation) contributed to greater driver discomfort across all combinations of road types.
- Roadside barriers also had a similar effect across all roadway types with
  - guardrail barrier resulting in greater driver discomfort than no barrier or cable barrier
  - guardrail barrier producing similar driver discomfort to stone or rock barriers.
- There was a distinct effect of roadway width across all combinations of vertical grades and horizontal curvature with discomfort increasing on narrower roads regardless of vegetation type and roadside barrier type.

A series of figures were developed to represent the influence of combinations of road design elements. Of interest was whether combined design elements had an additive effect, such that when combined they resulted in greater discomfort than for that of a single design element.

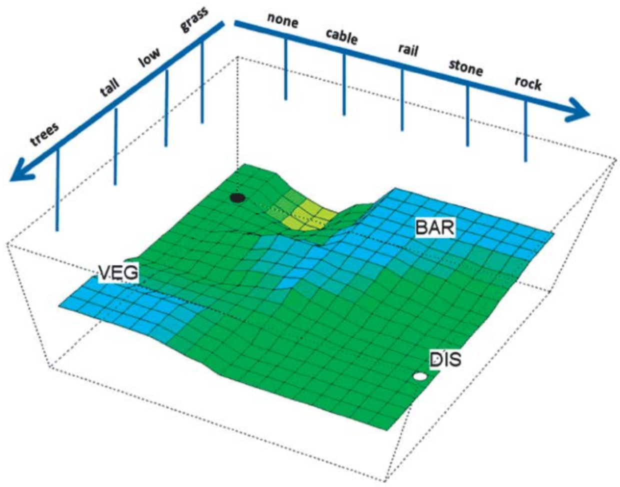
Figure 4.3 represents some of the key findings from this study including:

- Narrower roadways and greater vegetation intensity had an additive effect (Figure 4.3(a)). For example, roadway widths of 16 feet (4.9 m) and tree vegetation resulted in greater discomfort than roads of the same width with grass vegetation.
- The combined influence of barrier type and vegetation intensity (Figure 4.3(b)) did not result in an additive effect. Guardrail barriers with grass vegetation were observed to have slightly greater driver discomfort than guardrail barriers with tree vegetation.

Figure 4.3: Combined effect of road design elements on driver discomfort



Combined effect of vegetation type and roadway width (additive effect)



Combined effect of vegetation type and roadside barrier type (no additive effect)

Notes:
VEG = vegetation type, BAR = barrier type, WID = roadway width and DIS = driver discomfort.
Road width was expressed as the combined lane width plus clear zone.
Roadway width was expressed in feet.
Figure 4.3(a) was based on results for roadway with combined width greater than 18 foot (5.5 m) with 750 foot (229 m) horizontal radius.
Figure 4.3(b) was based on results for a straight road.

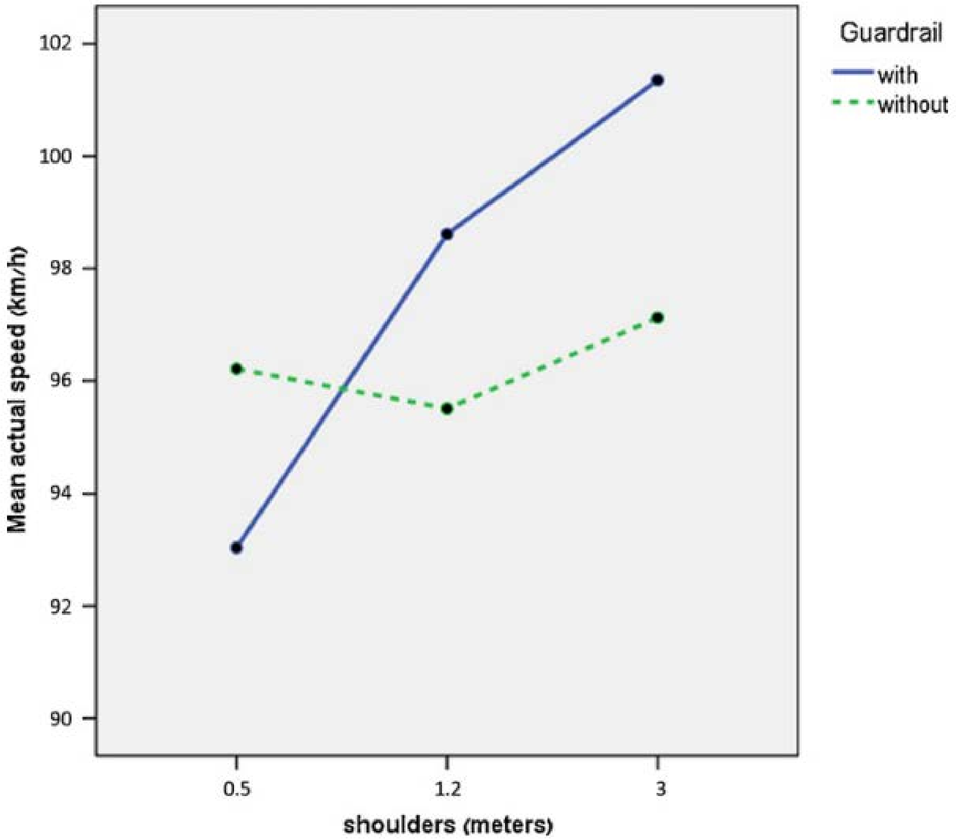
Source: Stamatiadis et al. (2010).

4.3.5 Effect of Shoulder Width, Guardrail and Roadway Geometry

Research by Ben-Bassat and Shinar (2011) in Israel considered the combined effects of shoulder width, guardrails and horizontal curvature on speed and lateral positioning based on a simulation of a four-lane highway. Opposing carriageways were separated by a concrete barrier and each direction was 4.5 m wide. The simulated terrain was flat and did not include houses, trees or other landscape elements. The study considered variations in shoulder width (0.5 m, 1.2 m or 3.0 m), presence of guardrail on the right-hand side of the carriageway (i.e. outer edge) and horizontal curvature (straight or four curve options including shallow or sharp left or right-hand curves). Study participants drove on the simulated highway, but were not shown a speedometer.

For the combined effect of guardrails and shoulder width, when a guardrail marked the edge of the shoulder, drivers increased their speed as the shoulders became wider (Figure 4.4). However, for roads without a guardrail, shoulders had a minimal influence on speed. The authors noted that when considering guardrails and shoulders, guardrails effectively increased speeds when a shoulder was wide and decreased speeds when a shoulder was narrow.

Figure 4.4: Effect of shoulder width with and without guardrail on mean speed



Source: Ben-Bassat and Shinar (2011).

When considering horizontal curvature and the presence of guardrail, the study found that the greatest average speeds were on the straight road section and the lowest on the sharp curves. When guardrails were present, the study noted that drivers travelled slightly faster on the straight road and shallow or sharp right-hand curves (i.e. the equivalent of left-hand curves in Australia and New Zealand). However, the guardrail had almost no effect on speeds on left-hand curves (right-hand curves in Australia and New Zealand).

A similar study by Bella (2013) in Italy assessed the impact of shoulders and guardrails using a driver simulator. However, this study focused on a two-way two-lane rural road with a posted speed limit of 90 km/h. The study considered two roadway cross-sections: one without a shoulder and one with a 1.5 m shoulder. These were considered typical of two-way two-lane rural roads in Italy. The simulation included trees positioned at regular 20 m intervals placed 1.5 m from the edge of the road. Roadside configurations were considered with and without guardrail and on straight and curved road segments.

Results of the study found that drivers adopted faster speeds when a shoulder was present. Mean differences in speeds were observed to be 3.8 km/h faster on road sections with a shoulder when compared with those without a shoulder. However, guardrails were not found to influence speed. This differed from the findings of Ben-Bassat and Shinar (2011), which were conducted on a four-lane highway. Bella (2013) noted that the differing results from the previous study may have been due to the presence of trees close to the edge of the road. These may have counteracted the effect of the guardrail. This finding was similar to those found by Stamatiadis et al. (2010) that suggested a mixed effect of barrier type and vegetation on driver discomfort.

5. Discussion and Conclusions

5.1 Speed Reduction Treatments

The review of speed reduction treatments in higher-speed environments identified information on a number of treatments. Based on the outcomes of this review, several treatments were identified which may merit further considerations for Austroads research and guidance as identified in Table 5.1.

Table 5.1: Speed reduction treatments identified that merit further consideration

Treatment	Road related area	Considerations for Austroads guidance
Treatments to support development of self-explaining roads	General	• Further research may consider implications of project findings for developing initial stage of a self-explaining road hierarchy.
Perceptual countermeasures including transverse pavement markings	Intersection approaches, sharp or out-of-context curve approaches	• May merit consideration for additional guidance on application, or referencing research that has considered the application and effectiveness of this treatment.
Transverse rumble strips	Intersection approaches and curves	• Discussed in Commentary 3 of the *Guide to Traffic Management – Part 10* (Austroads 2009a). This may merit cross-referencing from the *Guide to Road Design*. • May merit additional guidance on application, or referencing research that has considered the effectiveness of this treatment.
Vehicle activated signs	Intersection approaches, curves, transitions and other areas	• The effectiveness of this treatment was considered as part of previous Austroads research (Austroads 2014a). • May merit developing supplemental guidance on treatment for the *Guide to Road Design* or cross-reference to other Austroads Guides or reports.
Gateway treatments	Transition zones	• The application and effectiveness of this treatment was considered as part of a previous Austroads research (Austroads 2014a). • May consider developing standard design drawings and guidance for inclusion in the *Guide to Road Design*.
Route-based curve treatments	Curves	• Monitor developments and outcomes of VicRoads trial of route-based curve treatments to consider implications for Austroads guidance.
Wide median centrelines	Mid-block and route-based treatments	• May merit consideration for additional evaluation particularly where applied with a reduced posted speed.
Sight distance adjustments	Intersection approaches	• Application of treatment has been limited. • May merit further research to consider treatment due to the challenges with approach speeds at roundabouts in high-speed environments.

5.2 Road Features Influencing Speed

On mid-block sections of roads where the speed environment remains consistent, drivers seek to maintain a desired speed in line with the posted speed limit or design speed applicable to a section of road. There are a number of road features from which drivers obtain cues that may influence their speed.

The project considered the effect of a number of road features on speed in high-speed environments, which are identified in Table 5.2. For some road features, such as horizontal alignment, Austroads has developed a model that can assist in predicting the impact that the feature will have on speed. For other features, research has identified more broadly the influence that a road feature may have on speed in high-speed environments. In recent years, research has also examined the combined influence of different road features. However, further research is needed to gain a greater understanding of the combined influence of road features on speed.

5.2.1 Implications for Austroads Guidance

The review of road features identified a number of considerations for Austroads Guides. These include:

- Part 3 of the *Guide to Road Design* (Austroads 2010a) provides guidance on a number of the geometric design features identified in Table 5.2. The research identified and information provided in other Austroads Guides noted in the table may merit further consideration to enhance practitioner guidance on these road features.
- Parts 6 and 6B of the *Guide to Road Design* (Austroads 2010b and 2015b) provides guidance on roadside features and facilities. There is merit in developing further guidance that discusses the influence of the roadside environment and vertical features on speed.
- Parts 3 and 5 of the *Guide to Traffic Management* (Austroads 2013b and 2014b) provide guidance on access management and its influence on speed. Future review of the *Guide to Road Design* may consider guidance or enhancing cross-referencing between the Guides to consider this road feature.
- Part 5 of the *Guide to Pavement Technology* (Austroads 2011b) provides guidance on levels of roughness that are applicable to different categories of roads. There is merit in developing cross-linkages between this Guide and Part 3 of the *Guide to Road Design* to consider how road surfacing can assist in developing more self-explanatory roads.

Table 5.2: Research and guidance related to road features in high-speed environments

Road feature	Research and guidance on feature[(1)]	Impact on speed in high-speed environments[(1)]	Existing Austroads guidance[(1)]
Horizontal alignment	• The Austroads operating speed model for rural roads provides guidance on the impact of horizontal alignment on speed (AGRD Part 3). • The Austroads operating speed model suggests that on road segments with ranges of curve radii less than 350 m or isolated curves with radii less than 410 m, the section operating speed will be less than 100 km/h (AGRD Part 3).	May have a substantial impact on speed depending on horizontal curvature.	Section 3.5 of AGRD Part 3 (Austroads 2010a)
Vertical alignment	• Uphill gradients of 3–6% result in some speed reduction to heavy vehicles on high-speed roads. For high-speed roads in mountainous terrain, the speed of heavy vehicles will be slower on uphill and downhill gradients (Section 8.5 of AGRD Part 3). • For high-speed roads consistent with the general maximum grades identified in AGRD Part 3, the effect of gradients on the speed of light vehicles will be minimal (Section 8.5 of AGRD Part 3). • On rising gradients, visibility distance is restricted, which may lead to driver uncertainty and slower speed (Martens, Comte & Kaptein 1997). • Gravity also influenced speed on gradients and drivers were not found to effectively compensate for this factor (Martens, Comte & Kaptein 1997). • The combined effect of horizontal curvature and vertical grade on driver discomfort was not found to be additive (Stamatiadis et al. 2010).	May have a substantial impact on speed of heavy vehicles, depending on terrain. For roads designed consistent with AGRD Part 3, vertical gradients will have minimal influence on light vehicles on high-speed roads.	Sections 8.5.2 and 8.5.3 of AGRD Part 3 (Austroads 2010a) Section 4.3, 4.3 and 4.4 of AGTM Part 3 (Austroads 2013b) Section 2.4.2 of AGRD Part 2 (Austroads 2015a)
Access points	• For two-way two-lane or multilane roads, free-flow speed is reduced by 0.417 km/h per access point on a segment of road being analysed (Transportation Research Board 2010, cited in AGTM Part 3). • For freeways, free-flow speed is reduced by 2.16 km/h per on-ramp or off-ramp in a 10 km section of freeway (Transportation Research Board 2010, cited in AGTM Part 3). • 85^{th} percentile speed was reduced from 83 km/h to 74 km/h where there were more than 29 access points per km (Charlton & Baas 2006).	May have impact on speed where there are many access points. More likely to impact speed in urban or suburban areas with a greater access point density than in rural areas.	Sections 4.3, 4.3 and 4.4 of AGTM Part 3 (Austroads 2013b) Section 7 and Appendix A of AGRD Part 4 (Austroads 2009c) Section 2.2 of AGTM Part 5 (Austroads 2014b)

Road feature	Research and guidance on feature[1]	Impact on speed in high-speed environments[1]	Existing Austroads guidance[1]
Road surface	• Rough road surfaces were found to reduce speed (Elliott et al. 2003, Martens, Comte & Kaptein 1997). • Roads with poor broken surfaces reduced operating speed by 5–10 km/h (Appendix C and Commentary 4 of AGRD Part 3). • Poor road surfaces (e.g. potholes) may reduce speed, but may introduce safety issues when negotiated at speed (Charman et al. 2010). • Suggested levels of roughness applicable to different classes of roads are provided in AGPT Part 5.	Minor impact as high-speed roads are typically designed with smooth surfaces. Resurfacing of high-speed roads with poor quality surfaces may result in faster speeds.	Section 2.4.2 of AGRD Part 2 (Austroads 2015a) Appendix C and Commentary 4 of AGRD Part 3 (Austroads 2010a) Appendix B of AGPT Part 5 (Austroads 2011b)
Road width	• The *Highway Capacity Manual* identifies that the combination of lane and shoulder width influences free-flow speed (Harwood et al. 1999, Melo et al. 2012, Transportation Research Board 2010 cited in AGTM 3). • There was a distinct effect of roadway width across all combinations of vertical grades and horizontal curvature on driver discomfort increasing on narrower roads regardless of vegetation type and roadside barrier type (Stamatiadis et al. 2010). • Effective road width (i.e. the amount of pavement available for road users to drive on) was suggested as a feature that influenced speed. Smaller effective road widths were found to result in lower speed (Martens, Comte & Kaptein 1997). • Road width was identified as a factor for maintaining a credible speed for an undivided road, and lane width for the credible speed of a divided road (Aarts et al. 2011).	Minimal impact where high-speed roads are consistent with AGRD guidance.	The AGRD guidance identified focused on lane width as opposed to road width. Sections 4.2, 4.3 and 4.4 of AGTM Part 3 (Austroads 2013b)
Lane width	• Lane widths of less than 3.0 m may reduce speed by up to 3 km/h (AGRD Part 3). • For high-speed environments, lane widths of 2.9 m at 100 km/h and 3.1 m at 110 km/h were identified as decelerators for maintaining a credible speed limit (Aarts et al. 2011). • It is unlikely that, in a rural situation, lane width would be changed for the sole purpose of influencing speed (Charman et al. 2010). • Free-flow speed is reduced when lane widths are 3.3 m or less. Speed reduction values differed depending on lane and shoulder width combination (Transportation Research Board 2010, cited in AGTM Part 3). • Reductions in free-flow speed due to lane and shoulder width were identified for two-way two-lane roads, but the values differed from Transportation Research Board (2010), particularly for wide lanes (3.6 m) with no shoulders and narrow lanes (2.7 m) with wide shoulders (Melo et al. 2012).	Minimal impact where high-speed roads are consistent with AGRD guidance, which suggests that lane width should be 3.5 m or wider in high-speed environments. Lanes of this width would have minimal influence on speed. On high-speed roads, lane width is unlikely to be reduced solely for the purpose of influencing speed.	Appendix C and Commentary 4 of AGRD Part 3 (Austroads 2010a) Section 2.4.2 of AGRD Part 2 (Austroads 2015a) Sections 4.2, 4.3 and 4.4 of AGTM Part 3 (Austroads 2013b)

Road feature	Research and guidance on feature[1]	Impact on speed in high-speed environments[1]	Existing Austroads guidance[1]
Shoulder width	• Research suggested that shoulder width would have a minor influence on speed on less demanding roads with a lane width of 3.5 m or greater, where narrow shoulders reduced speed by 2 km/h or less (Melo et al. 2012). • Roads with shoulders resulted in faster speed on a 90 km/h two-way two-lane rural road (Bella 2013). • It is unlikely that shoulders would be added or removed for the sole purpose of influencing speed (Charman et al. 2010).	Minor impact on speed. Shoulders are unlikely to be installed or modified for the sole purpose of influencing speed.	Austroads guidance not identified
Number of lanes	• Drivers perceived slightly faster speed (2 km/h difference) on multilane roads when compared with single-lane roads (Houtenbos et al. 2011). • Speed in high-speed environments may be greater on roads with three or more lanes (Aarts et al. 2011).	Minor impact on speed.	Reference to Transportation Research Board (2010) provided in Sections 4.2, 4.3 and 4.4 of AGTM Part 3 (Austroads 2013b)
Physical separation of driving directions	• For multilane highways, AGTM Part 3 noted that free-flow speed on an undivided road is 2.6 km/h slower than on a divided road with the same features. • Undivided roads were identified as a decelerator for maintaining a credible speed limit in 100 km/h or 110 km/h speed environments (Aarts et al. 2011). • Drivers perceived faster speed on divided roads as opposed to undivided roads (Houtenbos et al. 2011). • Speed may be reduced where central medians are present due to the effect of forward visibility being reduced, possibly increasing perceived risk (Elliott, McColl & Kennedy 2003). • Roads with physical separation (especially ones involving a central reservation) were more readily identified as high-speed through roads (Stelling-Konczak et al. 2011).	Impact on speed may vary. Speed on divided roads may be faster than on undivided roads. However, some research has suggested that speed may be slower on divided roads where forward visibility is reduced.	Sections 4.2, 4.3 and 4.4 of AGTM Part 3 (Austroads 2013b)
Roadside environment and vertical features	• Section 3.3.2 in Part 6B of the AGRD (Austroads 2015b) notes that landscaping can be used for traffic calming, particularly on entrances to towns or when approaching areas with a lower posted speed. • Average speed was slightly lower on road segments with varying landscapes (89.3 km/h) and forested landscapes (90.8 km/h) when compared to open landscapes (92.9 km/h) (Antonson et al. 2009). • Greater vegetation intensity (i.e. transition from lower to taller vegetation) contributed to greater driver discomfort across all combinations of road types (Stamatiadis et al. 2010). • Dense or semi-open landscapes may reduce speed in high-speed environments (Aarts et al. 2011). • Drivers perceived faster speeds on roads with an open environment than roads with a more closed environment for both single-lane and multilane roads (Houtenbos et al. 2011). • A higher number of features in a driver's peripheral visual field leads to lower speeds (Lauckner & Brandenburg 2014). • Features in more planes of a driver's peripheral vision (i.e. left-side, right-side or overhead) lead to lower speeds (Lauckner & Brandenburg 2014).	Research suggests a minor influence of roadsides with dense, semi-open or varied landscapes on reducing speed when compared with open landscapes.	Briefly mentioned in AGRD Part 6B (Austroads 2015b)

Road feature	Research and guidance on feature[1]	Impact on speed in high-speed environments[1]	Existing Austroads guidance[1]
Lateral clearance	• For freeways, free-flow speed is reduced where the right-side lateral clearance is less than 6 feet (1.8m) (Transportation Research Board 2010) [2]. • For multilane highways, free-flow speed is reduced where total lateral clearance is less than 12 feet (3.6 m) (Transportation Research Board 2010) [3]. • Decreased lateral clearance and obstacles placed directly along the side of the road reduced speed (Martens, Comte & Kaptein 1997). • Roadside hazards 3 m or closer from the road edge were identified as reducing speed in an 80 km/h speed environment (Charlton & Baas 2006). • It is unlikely that roadside objects would be introduced for the sole purpose of influencing speed (Charman et al. 2010). • AGRD Part 6 provides guidance on clear zone distances. On roads in high-speed environments where the recommended clear zone distances are met, speed is unlikely to be influenced.	Minimal impact where clear zone distances are consistent with AGRD 6 guidance.	Section 4 of AGRD Part 6 provides guidance on clear zones (Austroads 2010b) Reference to Transportation Research Board (2010) provided in Sections 4.2, 4.3 and 4.4 of AGTM Part 3 (Austroads 2013b)
Road tunnels	• Features that create a tunnel-like impression of the roadside environment help to decrease speed significantly (Lauckner & Brandenburg 2014). • Drivers slow down when driving inside of a tunnel (Calvi, Blasiis & Guattari 2012).	For safety reasons, the posted speed in two-way tunnels is generally between 60 km/h and 80 km/h. High-speed environments in tunnels may be less common.	Austroads guidance not identified
Roadside barriers	• Roadside barriers were found to increase speed (Ben-Bassat & Shinar 2011). • Roadside barriers had minimal influence on speed when considered in combination with the effect of roadside obstacles (Bella 2013). • The combined influence of barrier type and vegetation intensity did not result in an additive effect on driver discomfort (Stamatiadis et al. 2010). • Guardrail barrier resulted in greater driver discomfort than no barrier or cable barrier (Stamatiadis et al. 2010). • The effect of barriers on speed varies depending on the situation. Barriers should be regarded as a safety feature rather than a speed management tool (Charman et al. 2010).	Unclear as results were mixed, which may have been due to whether the combined influence of roadside barriers and obstacles was considered. Roadside barriers are primarily installed for safety and not as a speed management tool.	Austroads guidance not identified

1 Austroads Guide to Road Design (AGRD), Austroads Guide to Traffic Management (AGTM), Austroads Guide to Pavement Technology (AGPT).
2 Right-side lateral clearance in North America is equivalent to left-side lateral clearance in Australia and New Zealand.
3 For multilane highways, Transportation Research Board (2010) defined total lateral clearance as the sum of the lateral clearance on the right and left sides of the carriageway.

References

Aarts, L, Pumberger, A, Lawton, B, Charman, S & Wijnen, W 2011, *Evaluation to realise a common approach to self-explaining European roads: road authority pilot and feasibility study,* deliverable no. 3&4, ERASER project, ERA-NET Road Programme, European Commission, Brussels, Belgium, viewed 17 September 2015, <http://eranetroad.org/index.php?option=com_docman&task=doc_download&gid=314&Itemid=53>.

American Association of State Highway and Transportation Officials 2006, *Roadway design guide*, AASHTO, Washington, DC, USA.

Antonson, H, Mårdh, S, Wiklund, M & Blomqvist, G 2009, 'Effect of surrounding landscape on driving behaviour: a driving simulator study', *Journal of Environmental Psychology*, vol. 29, no. 4, pp. 493-502.

Australian Transport Council 2011, *National road safety strategy 2011-2020*, ATC, Canberra, ACT.

Austroads 2006, *Guide to road safety part 5: safety for rural and remote areas*, AGRS05-06, Austroads, Sydney, NSW.

Austroads 2008, *Guide to traffic management part 8: local area traffic management,* AGTM08-08, Austroads, Sydney, NSW.

Austroads 2009a, *Guide to traffic management part 10: traffic control and communication devices,* AGTM10-09, Austroads, Sydney, NSW.

Austroads 2009b, *Guide to road safety part 8: treatment of crash locations,* AGRS08-09, Austroads, Sydney, NSW.

Austroads 2009c, *Guide to road design part 4: intersections and crossings: general,* AGRD04-09, Austroads, Sydney, NSW.

Austroads 2010a, *Guide to road design part 3: geometric design,* 2nd edn, AGRD03-10, Austroads, Sydney, NSW.

Austroads 2010b, *Guide to road design part 6: roadside design, safety and barriers,* 2nd edn, AGRD06-10, Austroads, Sydney, NSW.

Austroads 2011a, *Guide to road design part 4B: roundabouts,* 2nd edn, AGRD04B-11, Austroads, Sydney, NSW.

Austroads 2011b, *Guide to pavement technology part 5: pavement evaluation and treatment design,* 3rd edn, AGPT05-11, Austroads, Sydney, NSW.

Austroads 2013a, *Guide to road safety part 1: road safety overview*, 3rd edn, AGRS01-13, Austroads, Sydney, NSW.

Austroads 2013b, *Guide to traffic management part 3: traffic studies and analysis*, 2nd edn, AGTM03-13, Austroads, Sydney, NSW.

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

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

Austroads 2015a, *Guide to road design part 2: design considerations*, 2nd edn, AGRD02-15, Austroads, Sydney, NSW.

Austroads 2015b, *Guide to road design part 6B: roadside environment*, AGRD06B-15, Austroads, Sydney, NSW.

Austroads 2015c, *Road geometry study for improved rural safety*, AP-T295-15, Austroads, Sydney, NSW.

Austroads & ARRB Group 2010, 'Treatment type: curves: curve warning signs', Austroads road safety engineering toolkit software, ARRB Group, Vermont South, Vic, viewed 12 September 2015, <www.engtoolkit.com.au>.

Beca 2011, 'Wide centreline trial: interim report', NZ Transport Agency, Wellington, New Zealand.

Bella, F 2013, 'Driver perception of roadside configurations on two-lane rural roads: effects on speed and lateral placement', *Accident Analysis & Prevention*, vol. 50, pp. 251-62.

Ben-Bassat, T & Shinar, D 2011, 'Effect of shoulder width, guardrail and roadway geometry on driver perception and behavior', *Accident Analysis & Prevention*, vol. 43, no. 6, pp. 2142-52.

Bonneson, J, Pratt, M, Miles, J & Carlson, P 2007, *Horizontal curve signing handbook*, research report FHWA/TX-07/0-5439-P1, Texas Transportation Institute, Austin, Texas, USA.

Calvi, A, De Blasiis, MR & Guattari, C 2012, 'An empirical study of the effects of road tunnel on driving performance', *International congress: sustainability of road infrastructures, 5th, 2012, Rome, Italy*, Elsevier, Amsterdam, The Netherlands.

Cardoso, J 2005, 'Safety assessment for design and redesign of horizontal curves', *International symposium on highway geometric design, 3rd, 2005, Chicago, Illinois, USA*, Transportation Research Board, Washington, DC, USA, 20 pp.

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

Charlton, SG & Baas, PH 2006, *Speed change management for New Zealand roads*, report no. 300, Land Transport New Zealand, Wellington, NZ.

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: self-explaining roads literature review and treatment information*, deliverable no. 1, SPACE project, ERA-NET Road Programme, European Commission, Brussels, Belgium, viewed 14 September 2015, <www.eranetroad.org/index.php?option=com_docman&task=doc_download&gid=192&Itemid=53>.

Cocu, X, Casse, C, Volckaert, A & Van Geem, C 2011, *Speed adaptation control by self-explaining roads: technical note: report from workshop*, deliverable no. 3, SPACE project, ERA-NET Road Programme, European Commission, Brussels, Belgium, viewed 14 September 2015, <http://eranetroad.org/index.php?option=com_docman&task=doc_download&gid=280&Itemid=53>.

Connell, DJ, Smart, WJ, Cleaver, M, Job, RFS, de Roos, M, Hendry, T, Foster, J, Levett, S & Saffron, D 2011, 'Trial evaluation of wide, audio-tactile, centreline configurations on the Newell Highway', *Australasian road safety research, policing and education conference, 2011, Perth, WA*, Insurance Commission of Western Australia, Perth, WA, 7 pp.

Department for Transport 2001, *A road safety good practice guide for highway authorities*, DfT, London, UK.

Department for Transport 2003, *Vehicle activated signs*, traffic advisory leaflet 1/03, DfT, London, UK.

Department for Transport 2005, *Rumblewave surfacing,* traffic advisory leaflet 2005-01, DfT, London, UK.

Elliott, MA, McColl, VA & Kennedy, JV 2003, *Road design measures to reduce drivers' speed via 'psychological' processes: a literature review*, report no. 564, Transport Research Laboratory, Crowthorne, Berkshire, UK.

European Commission n.d., *ERASER tool for self-explaining roads: safe speeds and credible speed limits*, ERA-NET Road Programme, European Commission, Brussels, Belgium, viewed 13 September 2015, <www.swov.nl/enquete/Eraser/Tool.php>.

Godley, S, Fildes, B, Triggs, T & Brown, L 1999, *Perceptual countermeasures: experimental research,* CR 182, Australian Transport Safety Bureau, Canberra, ACT.

Hallmark, S, Hawkins, N & Smadi, O 2013, *Toolbox of countermeasures for rural two-lane curves,* Minnesota Department of Transportation, St. Paul, MN, USA, viewed 27 September 2015, <www.intrans.iastate.edu/research/documents/research-reports/rural_two-lane_curves_toolbox_w_cvr2.pdf>.

Harwood, DW 1993, *Use of rumble strips to enhance safety*, National Cooperative Highway Research Program (NCHRP) Synthesis of Highway Practice, no. 191, Transportation Research Board, Washington, DC, USA.

Harwood, DW, May, AD, Anderson, IB, Leiman, L & Archilla, AR 1999, *Capacity and quality of service of two-lane highways*, National Cooperative Highway Research Program, Transportation Research Board, Washington, DC, USA.

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

Houtenbos, M, Weller, G, Aarts, L, Laureshyn, A, Ardö, H, Svensson, A & Dietze, M 2011, *Evaluation to realise a common approach to self-explaining European roads: testing the self-explaining nature of roads: the effects of combinations of road features in different European countries*, deliverable no. 2, ERASER project, ERA-NET Road Programme, European Commission, Brussels, Belgium, viewed 14 September 2015, <http://web317.login-14.hoststar.at/web/eraser/downloads/ERASER_WP02_Deliverable_Road_User_Pilot.pdf>.

Jamson, S, Lai, F & Jamson, H 2010, 'Driving simulators for robust comparisons: a case study evaluating road safety engineering treatments', *Accident Analysis & Prevention*, vol. 42, no. 3, pp. 961-71.

Jurewicz, C, Chau, T, Mihailidis, P & Bui, B 2014, 'From research to practice: development of rural mass curve treatment program', *Australasian road safety research policing education conference, 2014, Melbourne*, *Vic,* Australasian College of Road Safety, ACT, Canberra, 12 pp.

Land Transport Safety Authority 2002, *Guidelines for urban-rural speed thresholds*, RTS 15, Land Transport Safety Authority, Wellington, New Zealand, viewed 17 September 2015, <www.nzta.govt.nz/resources/road-traffic-standards/docs/rts-15.pdf>.

Lauckner, M & Brandenburg, S 2014, 'Influence of basic environmental characteristics on driving speed', *Human Factors and Ergonomics Society annual meeting*, *2014, Chicago, Illinois, USA*, HFES, pp. 353-62.

Leicestershire County Council 2010, *Road safety in Leicestershire 2010*, Leicestershire County Council, Leicester, UK.

Macaulay, J, Gunatillake, T, Tziotis, M, Fildes, B, Corben, B & Newstead, S 2004, *On-road evaluation of perceptual countermeasures*, report no. CR 219, Australian Transport Safety Bureau, Canberra, ACT.

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, Qld*, Australasian College of Road Safety, Canberra, ACT, 9 pp.

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

Martens, MH, Comte, S & Kaptein, NA 1997, *The effects of road design on speed behaviour: a literature review*, TNO Human Factors Research Institute, The Netherlands, viewed 9 September 2015, <http://virtual.vtt.fi/virtual/proj6/master/rep231.pdf>.

Martindale, A & Urlich, C 2010, *Effectiveness of transverse road markings on reducing vehicle speeds*, research report no. 423, NZ Transport Agency, Wellington, New Zealand.

McGee, HW & Hanscom, FR 2006, *Low-cost treatments for horizontal curve safety*, FHWA-SA-07-002, Federal Highway Administration, Washington, DC, USA.

Melo, P, Lobo, A, Couto, A & Rodrigues, CM 2012, ‘Road cross-section width and free-flow speed on two-lane rural highways’, *Transportation Research Record,* no. 2301, pp. 28–35.

Ministry of Transport 2010, *Safer journeys: New Zealand's road safety strategy*, Ministry of Transport, Wellington, NZ.

Queensland Department of Main Roads 2002, *Road planning and design manual: chapter 12 vertical alignment*, 1st edn, Department of Main Roads, Brisbane, Qld.

Radalj, T & Kidd, B 2005, ‘A trial with rumble strips as a means of alerting drivers to hazards at approaches to passively protected railway level crossings on high speed Western Australia rural roads’, *Road safety research, policing education conference, 2005, Wellington, NZ*, Ministry of Transport, Wellington, New Zealand, 11 pp.

Schermers, G 1999, *Sustainable safety: a preventative road safety strategy for the future*, Transport Research Centre, Ministry of Public Works and Water Management, The Hague, The Netherlands.

Sjörgen, L, Anund, A, Charman, S, Ahern, A, Pumberger, A, Cocu, X, Van Geem, C, Grayson, G & Helman, S 2012, *Speed adaption control by self-explaining roads: final report*, deliverable no. 6, SPACE project, ERA-NET Road Programme, European Commission, Brussels, Belgium, viewed 14 September 2015, <http://eranetroad.org/index.php?option=com_docman&task=doc_download&gid=313&Itemid=53>.

Stamatiadis, N, Bailey, K, Grossardt, T & Ripy, J 2010, ‘Evaluation of highway design parameters on influencing operator speeds through casewise visual evaluation’, *Journal of Transportation Research*, no. 2195, pp. 143–9.

Stelling-Konczak, A, Aarts, L, Duivenvoorden, K & Goldenbeld, C 2011, ‘Supporting drivers in forming correct expectations about transitions between rural road categories’, *Accident Analysis & Prevention*, vol. 43, no. 1, pp. 101-11.

Taylor, M & Wheeler, A 2000, ‘Accident reductions resulting from village traffic calming’, *European transport conference, 2000, Cambridge, UK*, PTRC Education and Research Services Ltd., London, UK, vol. P 444, pp. 163-74.

Theeuwes, J & Godthelp, H 1992, ‘Self-explaining roads’, *Proceedings of the first world congress on safety of transportation*,*1992, Delft, the Netherlands*, Delft University Press, Delft, The Netherlands.

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.

Transportation Research Board 2000, *Highway capacity manual: HCM 2000,* TRB, Washington, DC, USA.

Transportation Research Board 2010, *Highway capacity manual: HCM 2010,* TRB, Washington, DC, USA.

TRL & Department for International Development 2001, *Horizontal curves*, highway design note 2/01, Transport Research Laboratory, Crowthorne, UK.

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

Wegman, F & Aarts, L 2006, *Advancing sustainable safety: national road safety outlook for 2005-20*, SWOV Institute for Road Safety Research, Leidschendam, The Netherlands.

Whittaker, A 2012, 'The safety benefit of continuous narrow painted median strips: continuous narrowing painted median trial: preliminary findings', Department of Transport and Main Roads, Brisbane, Qld.

Winnett, MA & Wheeler, AH 2002, *Vehicle-activated signs: a large scale evaluation*, report no. 548, TRL, Crowthorne, UK.

World Bank 2005, *Sustainable safe road design*, World Bank, Washington, DC, USA.

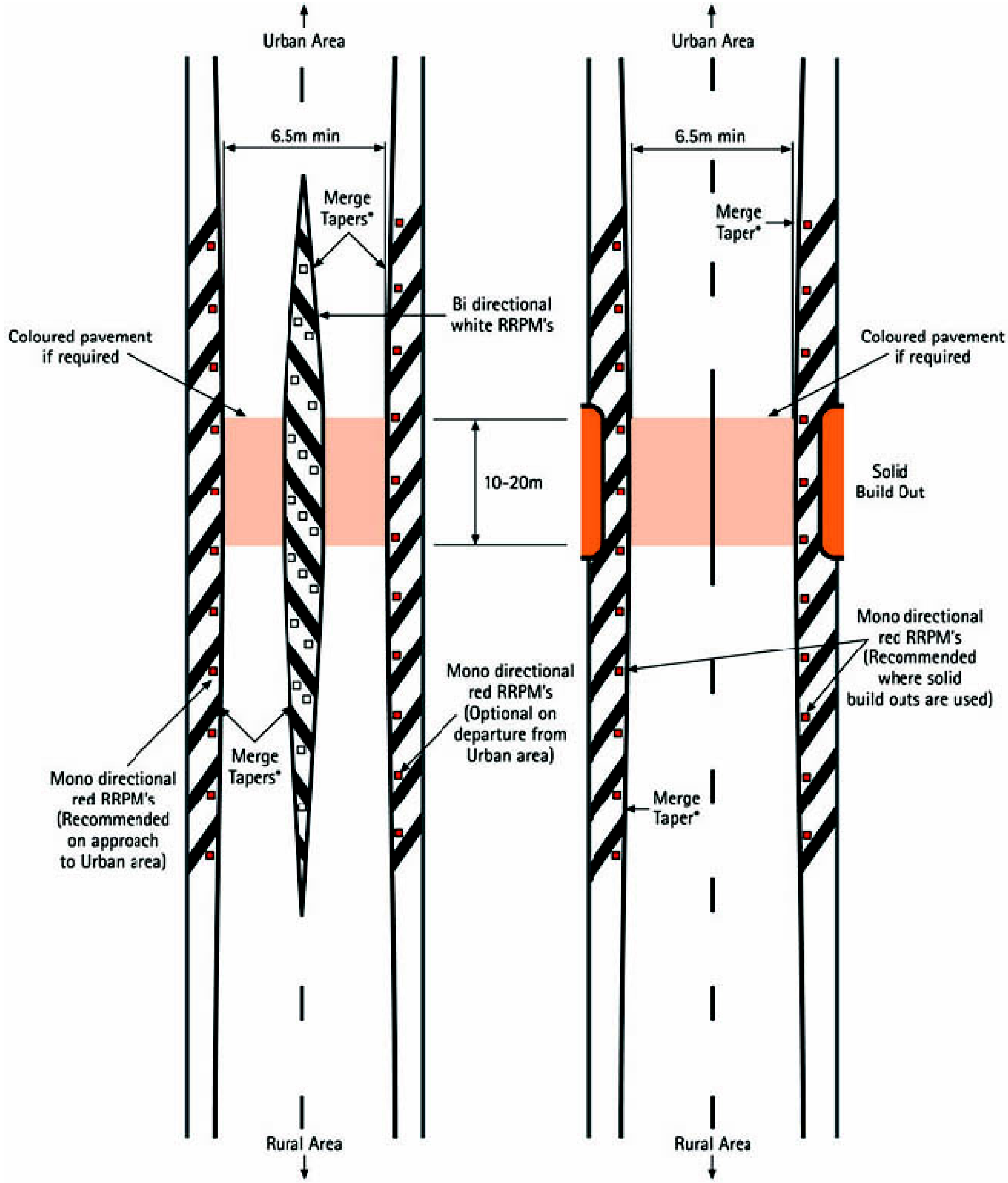
Superseded Austroads Publications

Austroads 2003, *Rural road design: a guide to the geometric design of rural roads,* AP-G1-03, Austroads, Sydney, NSW.

Appendix A Examples of Gateway Treatments

Examples of gateway treatments combining multiple types of treatments are shown in Figure A 1 and Figure A 2.

Figure A 1: Gateway treatments without solid islands

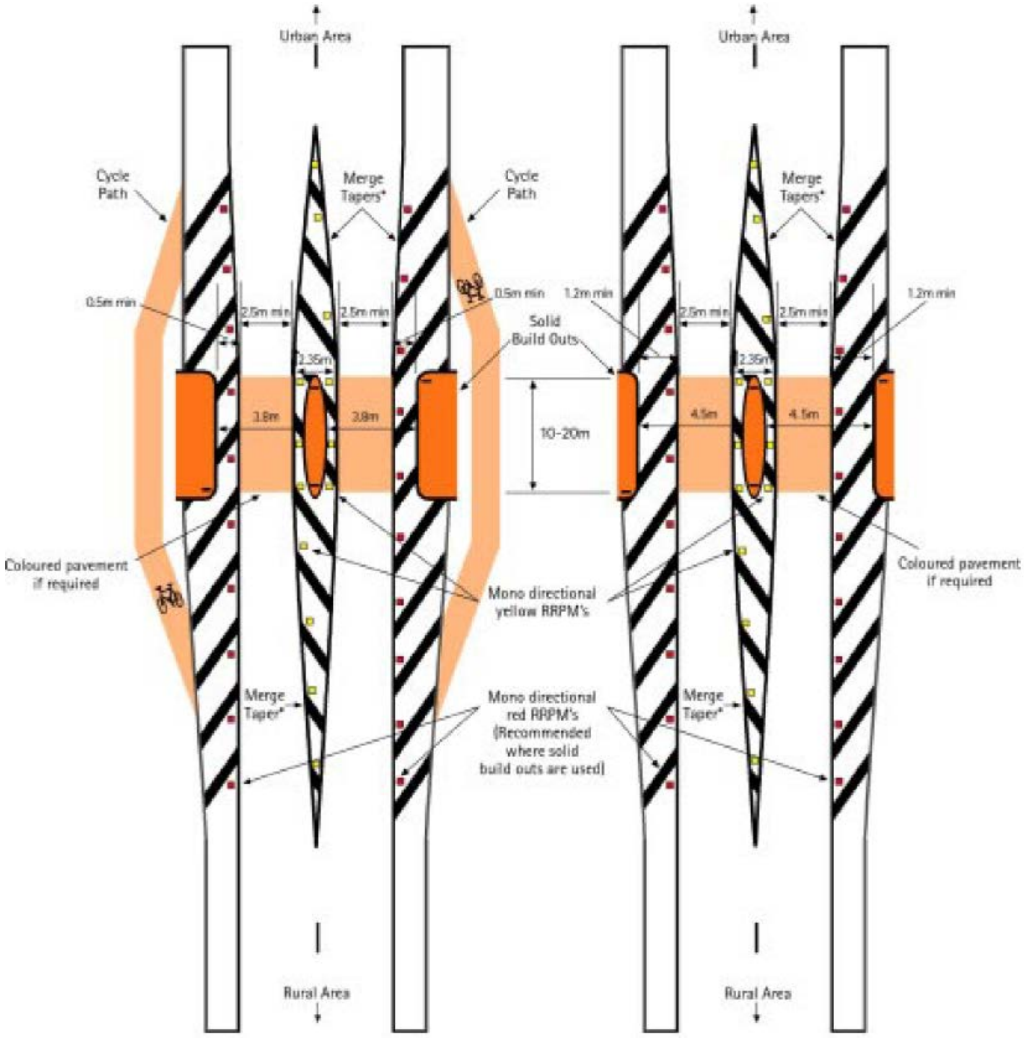


Flush median and hatched markings for a narrow road situation

Solid build outs, centreline and hatched markings

Source: Land Transport Safety Authority (2002).

Figure A 2: Gateway treatments with solid islands



Solid median island, build outs and markings where bicycle paths are used.

Solid median island, build outs and markings were cycles travel through the pinch point.

Source: Land Transport Safety Authority (2002).

Appendix B Credible Speed Limit Factors

The ERASER project (Aarts et al. 2011) developed a tool to assess the credibility of a speed limit to assist with the development of self-explaining roads in the European Union. The assessment was performed by considering a series of features that were known to act as a decelerator or accelerator depending on the speed limit. A final score was derived by summing the accelerators (1 point added) and decelerators (1 point subtracted). The implications of the credibility outcomes are shown in Table B 1.

Table B 1: ERASER tool speed limit credibility assessment outcomes

Final score	Implications
0	Road has more or less a credible speed limit
Less than 0	Speed limit is high Drivers might tend to drive slowly
Greater than 0	Speed limit is low (not credible) Drivers might tend to speed

Source: Based on Aarts et al. (2011).

The ERASER tool gave equal weighting to each factor. The factors considered in the assessment are shown in Table B 2 through Table B 7 for roads with speed limits of 80 km/h or faster.

Table B 2: Road and lane width and number of lanes

Speed limit (km/h)	Factor[(1)]	Decelerator	Accelerator
80	Road width	< 7.0 m	> 8.0 m
	Lane width	< 2.5 m	> 3.0 m
	Number of lanes	–	2 or more
90	Road width	< 12 m	> 15 m
	Lane width	< 2.7 m	> 3.3 m
	Number of lanes	–	2 or more
100	Road width	< 18 m	> 22 m
	Lane width	< 2.9 m	> 3.6 m
	Number of lanes	< 2 per driving direction	3 or more
110	Road width	< 20 m	> 24 m
	Lane width	< 3.1 m	> 3.7 m
	Number of lanes	< 2 per driving direction	3 or more

1 *For undivided roads, road width was used as a factor. For divided carriageways, lane width was used.*

Source: Based on Aarts et al. (2011).

Table B 3: Separation of driving directions

Speed limit (km/h)	Decelerator	Accelerator
80	No separation of driving directions	–
90	No separation of driving directions	–
100	No separation of driving directions	–
110	No separation of driving directions	–

Source: Based on Aarts et al. (2011).

Table B 4: Horizontal alignment: length of tangents

Speed limit (km/h)	Factor	Decelerator	Accelerator
80	Tangent length	< 105 m	> 300 m
90	Tangent length	< 135 m	> 380 m
100	Tangent length	< 170 m	> 460 m
110	Tangent length	< 210 m	> 550 m

Source: Based on Aarts et al. (2011).

Table B 5: Vulnerable road users – access restrictions

Speed limit (km/h)	Decelerator	Accelerator
80	No restrictions	–
90	No restrictions	–
100	No restrictions	–
110	No restrictions	–

Source: Based on Aarts et al. (2011).

Table B 6: Type and frequency of intersections

Speed limit (km/h)	Decelerator	Accelerator
80	Speed reducing measures at intersections	No at-grade intersections
90	At-grade intersections Speed reducing measures at intersections	–
100	At-grade intersections Speed reducing measures at intersections	–
110	At-grade intersections Speed reducing measures at intersections	–

Source: Based on Aarts et al. (2011).

Table B 7: Roadside environment

Speed limit (km/h)	Decelerator	Accelerator
80	Dense	Open
90	Dense	Open
100	Dense or semi-open	–
110	Dense or semi-open	–

Source: Based on Aarts et al. (2011).

Austroads

Level 9, 287 Elizabeth Street
Sydney NSW 2000 Australia

Phone: +61 2 8265 3300

austroads@austroads.com.au
www.austroads.com.au