

Speed change management for New Zealand roads

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Executive summary

The goal of the present research, carried out between July 2004 and June 2005, was to identify and develop research findings that would enable the development of speed management approaches for New Zealand roads akin to self-explaining and sustainably safe initiatives elsewhere. After the project was begun, the National Road Safety Committee and the Ministry of Transport articulated a National Speed Management Initiative which stated:

The emphasis is not just on speed limit enforcement, it includes perceptual measures that influence the speed that a driver feels is appropriate for the section of road upon which they are driving – in effect the 'self-explaining road.'

To meet the original goal, and provide information consistent with the implementation of the National Speed Management Initiative, the project began with an extensive review of published research in the areas of traffic calming, self-explaining roads, and perceptual countermeasures, which was then summarised in an annotated bibliography.

The review of the published literature on speed management identified two distinct types of speed management treatments based on different functions:

- speed change treatments that clearly indicate a change in speed,
- speed maintenance treatments that encourage drivers to maintain an appropriate speed in the zone.

The research literature associated with speed change treatments at village gateways or urban thresholds has shown that their location has important implications for their effectiveness; if they are not accompanied by downstream changes in road conditions such as decreases in road width or increases in urban density, the speed reductions produced by the gateway may dissipate within 250 m. At other speed change locations (typically within urban or village areas) visual treatments (e.g. signage & perceptual narrowing) appear to be more appropriate for higher-speed environments whereas physical treatments producing deflection or discomfort (chicanes, speed humps, and judder bars) may be unsuitable for speeds higher than 30–50 km/h.

A wider range of treatments for speed maintenance was identified in the research literature, in part because these designs are intended to reinforce appropriate speeds across a greater range of operating speeds. Some of the most effective treatments have manipulated lane width, the number of traffic lanes, and central medians to moderate vehicle speeds. Roadside features such as the proximity of angle parking and landscaping also have a perceptual narrowing effect and reduce drivers' speeds. Other treatments such as changes in road surface, centre lines, signage, cycle lanes, and footpaths have also been employed, but with lower levels of effectiveness. Physically restrictive measures such as periodic placement of speed humps and chicanes have been reported to be effective but much less desirable because of their low acceptability to road users and residents. The product of the literature review was:

- An annotated bibliography containing written summaries describing the speed management treatments evaluated, methods of investigation, and the pertinent findings or conclusions of 38 of the key published papers.
- Summary tables describing the speed maintenance and speed change treatments that have been found to be most effective in the literature. Examination of meta-analyses of the published research on speed management showed that speed change thresholds and speed maintenance treatments produce significant and stable reductions in vehicle speeds (by up to 27%), the number of injury crashes (average of 15%), and the number and severity of injuries (average of 11%).

New Zealand data on the effectiveness of the various types of speed management treatments were not readily available because of both the novelty of some of the treatments, and the admixture of treatments and data collection protocols employed when speed management treatments have been attempted here. In order to provide some indication of what effect speed management designs have on New Zealand roads, a brief observational sample examining various road widths, centre lines, and central medians was undertaken. The results of the New Zealand sample were consistent with predictions made from the speed management literature. In the open road environment, as lane width and number of lanes increased so did the average and 85th percentile (C85) vehicle speeds observed. In the urban (50 km/h) environment, the absence of centre line markings was associated with lower speeds when compared to lanes separated with a dashed white centre line. When lane delineation was achieved with a wide landscaped central median and accompanied by angled parking the lowest vehicle speeds were observed, presumably caused by a perceptual narrowing effect.

A sample of international researchers and practitioners was then surveyed to identify and refine the list of speed management designs identified from the literature and to supplement the information on their effectiveness (degree of speed compliance) with some indication of how long-lasting the effects were (their sustainability) and road users' subjective reactions to them (their acceptability). The results of the survey showed generally good internal agreement, and good agreement with the results of the literature review. For example, survey ratings and the effectiveness data in the literature showed that manipulations of lane width, number of lanes, and the use of a central median are consistently identified as having the some of the greatest effects on speed compliance. Similarly, the survey ratings of speed change or threshold designs agreed with the literature review in showing different recommendations depending on the speed profile:

- For lower speed transitions physical measures employing build-outs (curb extensions), speed tables (flat-topped speed humps), and changes in road surface texture and colour were identified as most effective, sustainable, and suitable.
- For speed change thresholds at higher speed profiles, perceptual measures using edge lines, hatching, angle parking, and landscaped central islands received the highest ratings.

Based on the survey responses and the literature review, we were able to identify some specific recommendations about road design characteristics for speed management which:

- manipulate a constrained set of road features,
- are designed to elicit the correct speeds from drivers,
- allow drivers to readily recognise the road category and distinguish it from others,
- will increase homogeneity of speeds (minimise individual differences),
- will resist habituation and behavioural adaptation.

The report also identifies four concrete steps toward implementation of a speed management approach in New Zealand:

- Road categorisation activities. Identification of road categories appropriate to the New Zealand roading system through consultation and information exchange with national and local road controlling authorities.
- Laboratory studies. Collection of drivers' subjective reactions (estimates of appropriate speed, appearance of safety, and aesthetic ratings) and objective responses (speed change and speed maintenance) to candidate speed management treatments.
- Field trials. Application of the road classification hierarchy and treatment designs on a selected area or region, accompanied by systematic data collection on the effects of the various treatments on an area-wide (rather than blackspot) basis.
- Speed management design guide. Following one or more successful area-wide trials, a speed management design guide for New Zealand roads can be developed incrementally through a series of Traffic Notes and guidelines.

Abstract

The goal of the present research, carried out between July 2004 and June 2005 was to identify and develop New Zealand speed management approaches that influence drivers' speed choices by manipulating road features that evoke correct expectations and driving behaviours from road users.

The research first reviewed the available published research in the areas of traffic calming, self-explaining roads, and perceptual countermeasures. A range of speed management designs were identified for threshold treatments that clearly indicate a change in speed, and treatments that encourage drivers to maintain an appropriate speed in the zone.

A sample site survey of driver speeds was conducted to compare vehicle speeds at several locations and provide an indication of whether the variables reported in the overseas literature would have equivalent effects on New Zealand roads. A questionnaire was then prepared to obtain road safety researchers' ratings of the effectiveness (speed compliance), sustainability (resistance to habituation), and suitability (road user acceptance) of road designs for speed change and speed maintenance. The results of the questionnaire were summarised and used to develop a list of speed management designs with the greatest promise for implementing sustainably safe, self-explaining roads in New Zealand.

1. Introduction

Road safety researchers and road controlling authorities in many countries have identified inadvertent speeding (where motorists are unaware that they are exceeding the speed limit) as a significant safety issue. Speed is a well-documented error mode for New Zealand drivers, with high speeds and speed variability being associated with increased probabilities of crashes and serious injuries (Frith & Patterson 2001). Research in New Zealand and overseas has suggested that inadvertent speeding is particularly problematic in speed change situations such as entrances to urban areas, arterial roads, rural schools, and motorway off-ramps. Speeding in these situations presents an increased risk not only to other motorists, but also to other road users such as pedestrians and cyclists. The subject of the present research is the investigation of engineering treatments that can assist drivers to select the correct speed, and maintain it, in speed change situations.

Many motorists appear to find it difficult to slow down from highway or open road speeds when entering an urban or semi-urban area. Commonly, the driver is faced with a situation where they are required to decelerate to 70 km/h or 50 km/h after having travelled at 100 km/h or faster for an extended amount of time. In order to address speed change problems at these sites, a range of village gateway and rural-urban threshold treatments (generally referred to as urban thresholds) have been implemented in many countries including New Zealand. Urban threshold treatments have ranged from simply increasing the size of speed roundel signs, to complex treatments involving a combination of road narrowing, cross-hatching, traffic islands, and large welcome signs. While some of these urban thresholds have been quite successful in producing reductions in average drivers' speeds up to 21% (Traffic Advisory Unit 1997a), similar treatments at other locations have had only temporary or negative effects on speed. For example, an urban threshold treatment consisting of large format speed signs, vertical poles, and a central flush median installed on SH 2 on the eastern threshold of Ngatea in the Waikato District (New Zealand) resulted in an 8% increase in the speeds of west-bound traffic. Research undertaken with laboratory simulations and field trials has demonstrated that many of the temporary and contrary effects of speed thresholds stem from perceptual after-effects of thresholds that are sited before low-density urban streetscapes (Charlton et al. 2002). A significant proportion of the speed reductions produced by urban thresholds result from implicit perceptual effects that can dissipate 250 m after passing the threshold, causing drivers to return to their pre-threshold speeds, or even higher speeds, if the threshold is not followed by an increase in the density of traffic and roadside development (Charlton et al. 2002).

Historically, the most common method of alerting drivers to a change in speed zone has been through the use of road signs. The placement and design of road signs has a substantial history of research and there are a number of well-established standards for their use such as the United States' Manual on Uniform Traffic Control Devices, the International Organisation for Standardisation (ISO) Public Information Symbols Standard 7001, and New Zealand's Manual of Traffic Signs and Markings. Unfortunately, research indicates that road signs are noticed and recalled by a relatively low proportion of drivers

(Hughes & Cole 1986, Charlton 2006). An alternative approach for bringing drivers into compliance with a desired speed has been to introduce physical restrictions or forcing functions that make it difficult or unpleasant to exceed the designated speed. Some of the earliest attempts at introducing speed management through physical restrictions occurred nearly 30 years ago in the Netherlands and Germany where measures such as chicanes, speed humps, neckdowns (curb extensions), planters and other traffic-calming devices were added to the streetscape to reduce motor vehicles' speeds in residential areas and villages. Although these traffic-calming techniques frequently have an immediately beneficial effect on speed change, they can be viewed quite negatively by road users (Martens et al. 1997).

Because drivers may select alternative routes to avoid speed change and speed maintenance treatments based on physical restrictions, localised traffic-calming strategies have been replaced by an area-wide traffic calming or speed management focus in countries such as Austria, Finland, the Netherlands, Sweden, and Switzerland (Gårder et al. 2002). Many of these area-wide speed management schemes have been quite successful, producing significant reductions in speed and road traffic injuries (Bunn et al. 2003, Elvik 2001). In order to cope with a greater range of operating speeds and traffic characteristics, however, area-wide speed management relies on a substantially greater variety of treatments than the original physically restrictive speed humps, chicanes, and street closures. Unlike the earlier localised traffic-calming initiatives, the goal is not just to reduce speeds, but instead to manage speeds in a sustainable way by making use of physical interventions, visual treatments, and drivers' own learned driving habits. This approach, known variously as sustainable safety, self-explaining roads, or self-enforcing roads, first identifies an appropriate operating speed for a given road (given its desired function), identifies road designs that afford that operating speed, and then applies those road designs consistently to all roads having that function (van der Horst & Kaptein 1998, Theeuwes & Godthelp 1995).

The logic behind sustainable safety or self-explaining roads (SERs) is the use of road designs that evoke correct expectations and driving behaviours from road users. In cognitive psychological terms, people develop mental schemata and scripts that allow them to gain maximum information with the least cognitive effort possible (cognitive economy). With repeated exposure to similar situations, the development of schemata and scripts allows an individual to anticipate likely events and produce appropriate responses. With extended practise, scripts and schemata allow people to perform complex tasks more or less automatically, without explicit or conscious attention to the task. As with other well-practised behaviours, a considerable proportion of vehicle control actions while driving may be performed automatically. Importantly for the present research, drivers' speed selection in particular appears to depend on explicit attention in some situations, and on implicit perceptual cues associated with road and traffic characteristics in others (Charlton 2004, Recarte & Nunes 1996). The SER approach recognises this situation and advocates road designs that assist drivers in forming appropriate schemata for various categories of road (including the desired speed), promoting successful categorisation, and as a result, correct behaviour for that road.

The sustainable safety/self-explaining roads concept focuses on the three key principles of functionality, homogeneity, and predictability (Janssen 2000, van Vliet & Schermers 2000). In practice, functionality requires the creation of a few well-defined categories of mono-functional roads (e.g. through-roads, distributor roads, and access roads) and ensuring that the use of a particular road matches its intended function. Multifunctional roads lead to contradictory design requirements, confusion in the minds of drivers, and incorrect expectations and inappropriate driving behaviour. Clearly defined road categories promote homogeneity in their use, preventing large differences in vehicle speed, direction, and mass. Finally, predictability, or recognisability, means keeping the road design and layout within each category as uniform as possible and clearly differentiated from other categories so that the function of a road is easily recognised and will elicit the correct behaviour from road users.

Sustainably safe or self-explaining roads are designed to include specific geometric, marking, paving, and roadside elements that can be readily used by drivers to categorise road types and serve as implicit (unconscious) controls on driver behaviour. These road elements can include the use of median and edge line treatments, access controls, road markings, pavement surfaces, and roadside furniture. The key is to select the combination of features that will afford the desired driver speeds and to ensure the consistent use of these features throughout the speed zone(s). While many of these treatments have been employed in isolation, research findings indicate that the combination of treatments and consistency of their use is the key to making their effects long-lasting (van der Horst & Kaptein 1998, Martens et al. 1997).

The goal of the present research was to identify and develop research findings that would enable the development of New Zealand speed management approaches akin to self-explaining and sustainably safe initiatives elsewhere. After the project was begun, the National Road Safety Committee and the Ministry of Transport articulated a National Speed Management Initiative which stated:

The emphasis is not just on speed limit enforcement, it includes perceptual measures that influence the speed that a driver feels is appropriate for the section of road upon which they are driving – in effect the 'self-explaining road' (Ministry of Transport 2004).

To meet the original goal, and provide information consistent with the implementation of the National Speed management Initiative, the project began with an extensive review of published research in the areas of traffic calming, self-explaining roads, and perceptual countermeasures, which was then summarised in an annotated bibliography. The review focused on the identification of speed management designs for both:

- speed change treatments that clearly indicate a change in speed
- speed management treatments that encourage drivers to maintain an appropriate speed in the zone.

Following the literature review, a brief observational sample of driver speeds was collected to compare vehicle speeds at several locations and provide an indication of whether the variables reported in the overseas literature would have equivalent effects on

New Zealand roads. A questionnaire was then prepared to obtain road safety researchers' ratings of the effectiveness (speed compliance), sustainability (resistance to habituation), and suitability (road user acceptance) of road designs for speed change and speed maintenance. The results of the questionnaire were summarised and used to further refine a list of speed management designs with the greatest promise for implementing sustainably safe, self-explaining roads in New Zealand. The results of the literature review, sample site survey, and experts' questionnaire were used to prepare design recommendations which:

- manipulate a constrained set of road features,
- are designed to elicit the correct speeds from drivers,
- allow drivers to readily recognise the road category and distinguish it from others,
- will increase homogeneity of speeds (minimise individual differences),
- will resist habituation (behavioural adaptation) and possess good road user acceptability.

Additional recommendations for further research (including field trials), development of design guidelines, and implementation were also prepared and presented in this report.

2. Literature review

The research related to engineering treatments for speed management spans several broad areas including: traffic calming (Martens et al. 1997), self-explaining roads (Theeuwes 1998), and perceptual countermeasures (Godley et al. 1999). A wide-ranging search of the recent literature in these areas yielded 104 published journal articles and technical reports. From these published findings, it was desirable to select a subset of the most relevant papers to summarise and review. Three sorts of criteria were used to select the papers included in the literature review.

1. Eighteen papers reporting the results of laboratory or field trials that provided enough methodological detail to be evaluated critically (i.e. contained full descriptions of the countermeasure configurations and data obtained before and after countermeasure implementation) were selected and comprised 44% of the papers reviewed.
2. Eleven review articles that summarised and critiqued portions of the relevant speed management research literature were included and comprised 27% of the papers included in the present review.
3. Twelve papers that outlined key speed management principles or implementation strategies were included and represented 29% of the papers reviewed.

For 38 of the 41 papers in the resulting subset, a brief written summary was prepared describing the speed management treatments evaluated, methods of investigation, and the pertinent findings or conclusions offered by the researchers. The summaries of these articles are presented in the annotated bibliography contained in this report (Appendix A). The three remaining papers described meta-analyses of the findings from other research papers and a somewhat fuller description of them is included in Section 2.3 of this report.

Cataloguing the types of speed management treatments and their effects on driver behaviour can be difficult because of the broad range of treatments tested and the range of functions and contexts for which they were attempted. For example, traffic-calming engineering measures are often grouped according to their topology: into horizontal measures (e.g. road narrowing) and vertical measures (e.g. speed humps). Alternatively, speed management treatments have been classified according to their level of coercion:

- informative measures that alert road users (e.g. a maximum speed sign),
- suggestive measures that encourage or afford appropriate behaviour through visual suggestion or illusion (e.g. road narrowing by using lines),
- persuasive measures that make it more convenient for drivers to behave in a certain way (e.g. speed humps),
- obstructive measures that make higher speeds physically impossible (e.g. chicanes) (van Schagen 2003).

For the purposes of this review, speed management treatments reviewed were first functionally categorised into treatments associated with speed transitions (changes from one operating speed to another) and speed maintenance (maintenance of a desired speed). This categorisation was adopted inasmuch as the present review examined both speed management and speed change management, whereas many previous reviews concentrated on only one domain or the other.

Within each of these functional categories, the treatments were then sorted according to their method of control: whether they used visual guidance, physical obstacles, tactile feedback, etc. For example, a road can be physically narrowed by adding a raised central median or be made to appear narrower by virtue of moving the longitudinal edge lines further away from the road edge. Similarly, chicanes and road humps are a form physical impediment while painted lines or strips of coloured pavement transversely oriented to the flow of traffic form a visual impediment or threshold.

Finally, the various treatments within each control method are organised according to their topological features, road surface, road width, medians, road edges, etc. The principal findings associated with speed management treatments are thus summarised and presented according to their function and method of control in the sections that follow.

2.1 Speed change treatments

Various urban threshold treatments have been tried in an attempt to reduce drivers' speeds when entering an urban area or village. The visual complexity of the threshold design appears to be positively related to the amount of speed reduction produced and it is not uncommon for thresholds at the entrance to an urban area to incorporate a range of physical and visual design elements. Further, the terms 'thresholds' and 'gateways' are often used interchangeably, although 'threshold' more correctly refers to the specific location where a speed limit changes and practically speaking a threshold treatment can be applied at any point where a change in speed limit occurs (e.g. within urban or village boundaries). Where possible this report reserves the term 'gateway' to refer to speed change countermeasures located at the entrance of an urban or village area and uses thresholds in its more general sense but also to refer to countermeasures applied within an urban or village boundary. For example, a gateway treatment employing speed countdown signs, dragon's teeth pavement markings, and a red pavement roundel at the entrance of a village reduced drivers' mean speeds by 21% (9 mph or 14.5 km/h) and their 85th percentile (C85) speeds 19%, as compared to drivers' speeds before installation. Speeds of drivers crossing the threshold in the other direction (outbound drivers seeing the red pavement roundel only) were also reduced; mean speeds were reduced by 17% and C85 speeds by 19% (Traffic Advisory Unit 1997a).

2.1.1 Gateway treatments

The majority of speed change countermeasures at urban and village gateways have included a combination of physical and visual features. Comparisons of different types of gateway treatments placed at the entrances to villages in England found that simple visual gateways (roadside signing and marking) reduced drivers' C85 speeds by 3 mph

(5 km/h). More elaborate treatments employing high visibility features on the roadside and road surface (e.g. coloured road surfacing, visual narrowing, large roadside signs) reduced C85 speeds by 7 mph (11 km/h), and gateways using physical restrictions as well as visual features (traffic islands and build-outs (curb extensions)) produced C85 reductions of 10 mph (16 km/h) (Traffic Advisory Unit 1994, Elliott et al. 2003). The slowing effect of gateway and threshold treatments, however, can be temporary and dissipate 250 m after passing the threshold (Charlton et al. 2002), and careful consideration must be given to conditions and countermeasures downstream from the treatment. The effects on drivers' speeds result from the momentary physical and visual properties of gateways and when road conditions downstream from a gateway do not reinforce the lower speeds with visual and/or physical road conditions (e.g. narrower lanes, increased traffic, roadside furniture, etc.) some drivers may return to their former speeds within 250 m. In some applications, the downstream speeds may actually exceed pre-threshold speeds because of a perceptual process called visual motion after effect, a form of habituation (Charlton et al. 2002). One example of this was the threshold located at Ngatea (described earlier in this report) in which the threshold was not accompanied by any appreciable downstream changes in road width, traffic density, or roadside furniture. Thus the placement of thresholds in relation to the built environment and road conditions is extremely important; placement of gateways at the first house of a village is much more effective than at the village boundary (Traffic Advisory Unit 1994). Similarly, Carsten et al. (1995) found that the combination of countdown speed signs and a speed limit painted on the road was effective at the start of a village, but speed reductions were not maintained through the village. When downstream effects of various gateways were compared, all of the threshold types (simple, high visibility, visible and physical) were found to have similar effects (reductions of 3.2 - 4.8 km/h). When the gateway treatments were combined with in-village road narrowing, however, the downstream effects were much greater: 9 mph (14.5 km/h) reductions at the gateway, and 10 mph (16 km/h) in the village. The effects of the three principal types of threshold or gateway treatment, as reported in the published literature, are shown in Table 2.1.

2.1.2 Physical thresholds

Speed change countermeasures that rely solely on physical restrictions or purely visual treatments have also been tested. The research literature indicates that threshold treatments with physical restrictions typically produce the largest speed reductions. For example, transverse rumble strips in groupings or rumble mats can reduce speeds by 3–6 mph (4.8–9.5 km/h), reduce accident rates, and produce uniform, moderate deceleration (Elliott et al. 2003, Traffic Advisory Unit 2005). Although some studies report a durable effect (up to 1 year) of transverse rumble strips (Martens et al. 1997), other researchers have noted that their effect may lessen over time since less discomfort occurs when traversed at higher speeds (Elliott et al. 2003). Other trials of planted speed control medians on arterial roads, effectively deflecting the path of traffic and narrowing the lane width, have obtained significant speed reductions on the order of 9% (Berger & Linauer 1998, Forbes & Gill 2000). Similarly, placement of a monument in the centre of the road was found to reduce speeds by 5 mph (8 km/h) (Elliott et al. 2003). When the physical restriction causes a greater amount of deflection or driver discomfort, as in the case of chicanes and road humps, even lower speeds can be achieved. Chicanes with path angles

of 15–20° reduce mean speeds to less than 20 mph (32 km/h) with C85 speeds of 20–25 mph (32–40 km/h) and path angles of less than 10° allow mean speeds of 25 mph (40 km/h) or more and C85 speeds over 30 mph (48 km/h) (Traffic Advisory Unit 1997b). Speed humps and speed cushions have also been used as threshold treatments for low speed zones and the amount of speed reduction produced is influenced by adjusting the height and length of the speed hump. For example, narrow speed cushions, with red pavement roundels reduced mean speeds 21% to 36% resulting in mean speeds of 27 km/h and C85 speeds of 35 km/h (Traffic Advisory Unit 1997a). Round-topped speed humps produce even slower speeds; speed humps 75 mm high have been found to reduce C85 speeds to 30–32 km/h (Martens et al. 1997, Traffic Advisory Unit 1996). Because of the very low speeds produced by chicanes, speed cushions, and speed humps, they are perhaps appropriate only for speed change thresholds where drivers are moving from a low to moderate speed to an area associated with even lower speeds.

2.1.3 Visual thresholds

The traditional approach of placing simple speed restriction signs at speed change thresholds, or even large speed countdown signs, does not significantly reduce speeds by itself, but may be effective in conjunction with other measures, such as gateways (Elliott et al. 2003). Although the speed reductions associated with purely visual threshold treatments are not as large as those reported for treatments incorporating various kinds of physical restrictions, many types can produce significant effects. For example, vehicle-activated speed signs that display speed messages when a vehicle exceeds a set speed have been found to reduce mean speeds up to 11 km/h and have a lasting effect (up to 3 years) (Elliott et al. 2003). Similarly, vehicle-activated speed limit roundel signs installed at a variety of speed change locations reduced mean traffic speeds by an average of 11%, reducing the proportion of vehicle exceeding the speed limit in all cases ranging between 7 and 51 percentage points (Winnet & Wheeler 2002). Other threshold treatments incorporate various strategies based on visually narrowing the road width. At one site where yellow poles were placed to give a road narrowing impression, combined with a strip of coloured pavement, a central island 140 m before the gateway, and a 50 km/h sign, resulted in a decrease in mean speed from 77 km/h to 66 km/h (although still over the 50 km/h speed limit) (Martens et al. 1997). In cases where poles and plantings are used to produce visual narrowing, researchers have noted that, in order to maximise speed reductions at thresholds, the vertical elements should be higher than the width of the road (van Schagen 2003).

Other visual treatments to produce optical narrowing, such as cross-hatching, flush medians, and edge lines, have been shown to reduce C85 speeds by 7–10 mph (11–16 km/h) when used at gateways (Chinn & Elliott 2002, Traffic Advisory Unit 1994). Simple transverse lines have also significantly reduced speeds at the beginning of villages producing reductions of 4 mph (6.5 km/h) in mean speeds and 7 mph (11 km/h) in C85 speeds (Carsten et al. 1995). Changing the colour of pavement surfaces may serve as reminders of speed limit, but do not produce any speed reductions by themselves (Carsten et al. 1995, Traffic Advisory Unit 1994). As described above, thresholds employing more complex combinations of visual characteristics can produce significant reductions in speeds. For example, a gateway with countdown signs, dragons' teeth, and

a red pavement speed roundel reduced mean speeds 21% (14.5 km/h) and C85 speeds by 19% (Traffic Advisory Unit 1997a). Like other threshold treatments however, the slowing effect of visual thresholds can be temporary; a transverse line treatment based on the Wundt Illusion worked at beginning of village but not at later points (Carsten et al. 1995). The effects of the various types of visual threshold treatment, as reported in the published literature, are summarised in Table 2.1.

Table 2.1. Treatments for speed change.

Treatment type		% reduction	Avg speed (km/h) post-installation	C85 speed (km/h) post-installation
 <p>Gateways & urban thresholds</p>	Signing & pavement marking	0 – 3%	67.2	89.6
	High visibility	7.5%	64	76.8
	High visibility + physical features	15-27%	52.8-66	70.4
 <p>Physical treatments</p>	Transverse rumble strips & mats	0.1-6%	43-62	48-72
	Traffic medians	9%	49.3	57.3
	Chicanes 10° path angle	26%	36.8	44.8
	15-20° path angle	–	40	> 48
	Speed cushions 75mm high	9.3%	27.2	35.2
 <p>Visual treatments</p>	Speed signs	0	Depends on speed limit	Depends on speed limit
	Speed roundels	0	Depends on speed limit	Depends on speed limit
	Oversized signs	0-3%	67.2	89.6
	Dynamic signs	11%	Depends on speed limit	Depends on speed limit
	Visual narrowing	11-20%	Depends on speed limit	Depends on speed limit
	Transverse lines	8-14%	57.5 - 65	77.5-82.8
	Coloured pavement	0%	–	–
Note: empty cells above indicate that no published data were found for that measure.				

In generalising the findings presented in the tables it is important to recognise that the many outcomes will be somewhat site-specific with regard to the absolute speeds

obtained. Thus the data presented are intended to provide the magnitude of effects reported in the literature and it is the ordinal relationship between treatment types that may be of greatest use, rather than any precise predictions about speed differentials produced in a specific application.

2.1.4 Summary of effects

All the above threshold treatments share the common goal of prompting drivers to decrease speeds, but researchers' interpretations of which threshold elements work best, and how they work, have differed. Early researchers suggested that the presence of large signs and physical restrictions produced a level of driver intimidation that effectively prompted drivers to pay more attention to their speed (Fildes & Jarvis 1994). Other researchers focused on the ability of large signs, pavement markings, and even physical restrictions to enhance the attention-capturing capability of the speed signage (Godley et al. 1999). More recently, research has shown that threshold treatments produce a slowing effect, even when no speed restriction is present (Charlton et al. 2002), suggesting that implicit perceptual cues also play a role in the speed reductions produced by threshold treatments. What is clear from the studies cited above is that the best results typically occur when thresholds and gateways employ a combination of physical and visual measures and when they are accompanied by downstream changes in the roadway and/or built environment that serve to maintain or manage the speed change.

2.2 Speed maintenance treatments

Well-designed threshold and gateway treatments produce significant speed reductions, but the reductions can be transitory when the downstream roadway does not reinforce the lower speeds. A wide range of speed management techniques based on engineering measures such as chicanes, speed humps, neckdowns, planters and other devices have been in use for nearly 30 years. Because localised traffic calming measures such as these may prompt drivers to seek other routes through the road network they have increasingly been replaced by area-wide approaches, including main traffic arteries, villages, shopping streets and town centres (Gårder et al. 2002). These area-wide traffic-calming and speed management schemes have produced significant reductions in road traffic injuries ranging from 11% (Bunn et al. 2003) to 15% (Elvik 2001). When considering the effect of area-wide traffic speed management on low-speed streets the effect is even more dramatic, producing reductions in crashes ranging from 25% (Elvik 2001) to 30% (van Vleit & Schermers 2000).

Area-wide speed management must necessarily accommodate a greater range of operating speeds and traffic characteristics and thus cannot rely solely on speed humps, chicanes and other localised treatments. Instead, area-wide approaches employ a combination of physical interventions, visual treatments, and drivers' own learned driving habits to manage traffic speeds in a sustainable way. This approach, variously referred to as sustainable safety, self-explaining roads, or area-wide speed management begins with a hierarchy of desired road functions, identifies road designs that afford the desired operating speeds for each road function or level, and then applies those designs consistently to all roads having that function. One of the design features shown to have the most consistent effects in these area-wide speed management schemes has been

changes in road width. Road width manipulations have been proven to be effective in terms of managing speed, reducing vehicle crashes and pedestrian fatalities, and much more popular with residents and road users than speed humps and chicanes (Gårder et al. 2002, Macbeth 1998). Other treatments based on changes in edge line and centre line delineation, the use of central medians and various types of road surfacing, have also been quite effective and appear to work as explicit and implicit reminders to drivers as to the correct speed for the road. Speed signs are obviously still required throughout the network, but in some cases they have been supplemented or replaced with newer technologies such as vehicle-activated signs to increase their effectiveness. The visual and physical characteristics of the roadside environment also play an important role in area-wide speed management, and although less easily manipulated, they are considered, and in some cases modified, through the use of plantings and footpaths. Finally, physical obstacles such as speed humps and chicanes are still used for lower speed zones (e.g. 30 km/h areas). The effects of these speed management treatments, physical and visual, are described in the sections to follow.

2.2.1 Road width

Although measuring the effect of road width independently of other road design factors is difficult, manipulations of road width and number of lanes have been shown to have direct and long-lasting effects on drivers' speeds. An overall carriageway width of 6 m was found to produce mean speeds of 80 km/h and a width of 8 m increased speed to 90-100 km/h (van der Hoven 1997, cited in Martens et al. 1997). An even more extreme reduction was tested in England where the overall carriageway width was reduced 33% to 3 m (by creating a 1.5 m non-motorised lane). The treatment was highly effective, achieving significant 21% reductions in both mean and C85 speeds (mean speed of 25 mph, C85 of 30 mph) (Traffic Advisory Unit 2004). Vey & Ferreri (1968, cited in Martens et al. 1997) compared two nearly identical bridges and found that 3-m lanes produced significantly lower speeds than 3.4-m lanes. An analysis of rural two-lane roads found a significant positive correlation between pavement width and speed even though the speed limit was the same on all roads (Martens et al. 1997). Similarly, on urban arterials a significant relationship between lane width and speed was found, holding all other factors constant, in that during off-peak traffic hours speeds increased 0.96 km/h for every 0.3 m lane width and 1.6 km/h for every 0.3 m of lane width during peak traffic hours (Heimbach et al. 1983). In a study of four-lane arterials every 0.3 m of lane width over 3 m produced an increase of 4.64 km/h in C85 speeds (Fitzpatrick et al. 2000). In another review, road narrowing by itself, without any supplementary design measures, has been shown to produce speed reductions of 5.7 km/h for every metre of lane width reduction beyond 4 metres (Martens et al. 1997). One of the key findings in studies of the effects of road width is that the perceived width of the road is the important variable in determining drivers' speeds (Martens et al. 1997). Road narrowing has been found to reduce drivers' estimates of their driving speeds by as much as 11 km/h (Elliott et al. 2003). Highways with 3.5 m lanes are generally perceived as safer by drivers than 2.7 m lanes, and associated with higher chosen speeds, but interestingly rated lower in their aesthetic qualities (Zakowska 1997). The opposite pattern is found for narrow lanes of 2.7 m (higher aesthetics but lower safety and speed choice), but even a small increase in width (to 3 m) produces much higher speed choice with only slightly higher perceived

safety rating (Zakowska 1997). Finally, the method used to achieve reductions in lane width is important: when a vehicle-free central area between lanes was installed to reduce lane widths from 4.6 m to 3.6 m, speeds increased 7.5 km/h (van der Horst 1983, cited in Martens et al. 1997). The effects of road width on drivers' speeds are summarised in Table 2.2.

Table 2.2 Treatments for speed maintenance.

Treatment type		Avg speed (km/h)	C85 speed (km/h)
Road width 	Lane width (urban arterials)		
	3.0m	40	65
	3.25m	42	68
	3.5m	45	72
	3.75m	48	76
	4.0m	—	80
	4.25m	—	82
	Carriageway width (through roads)		
	6.0m	80	
	8.0m	90-100	
Number of lanes 	Number of lanes (arterial roads)		
	4	50	51
	2	45	45.85
	1	40	—
Centre & edge line delineation 	Through roads		
	Centre line marked		72.0
	No centre line		51.2
	Edge line marked		76.8
	No edge line		64.0
Note: empty cells above indicate that no published data were found for that measure.			

2.2.2 Number of lanes

A factor related to perceived road width is the number of lanes in the carriageway. Generally speaking, an increase in the number of lanes produces faster speeds, even if the width of individual lanes remains constant, perhaps because of increased overtaking opportunities or differences in perceived road width. In one study of urban arterials on which the number of lanes was reduced from four lanes to two, speeds were reduced by an average of 10% and crashes were reduced 47% (Gårder et al. 2002). Similarly, an urban arterial with four 3.35 m lanes carrying 24,000 vehicles per day which was re-stripped to produce two 3.35 m lanes separated by a 2.74 m turn lane obtained a 9% reduction in C85 speeds, dropping from 52 km/h to 46.7 km/h (Skene 1999). In another case, speeds were significantly reduced on a six-lane urban arterial carrying 30,000 vehicles per day by reducing the number of lanes from six to four and lane widths from 3.15 m to 3 m, and, while it was unpopular with bus operators, the number of crashes did not increase (Macbeth 1998).

2.2.3 Delineation

The perceived width of drivers' lanes can also be manipulated visually by changing edge lines and centre lines. Visual treatments to produce optical narrowing, such as moving edge lines closer to the centre of the road or adding cross-hatching have been shown to reduce C85 speeds by 3 mph (5 km/h) when used by themselves, or by 10 mph (16 km/h) when used in combination with gateways (Traffic Advisory Unit 1994). In a survey of visual lane-narrowing treatments (cross-hatching and edge lines) the average reduction in mean speeds was 7 mph (11 km/h), a 6 mph (9.7 km/h) reduction in C85 speeds occurred, and a reduction of 33 mph (53 km/h) in speed variance (Carsten et al. 1995). In a driving simulator study, longitudinal red strips with hatching placed on the edge and centre of a rural road were found to reduce speeds by 9 km/h (Elliott et al. 2003).

Another approach to making roads appear narrower has been to remove delineation on moderately narrow roads. For example, removing the centre line from rural roads has been shown to reduce speeds by 11 km/h (Elliott et al. 2003). However, as with the analysis of road width, it is often difficult to isolate the effects of the presence or absence of edge lines and centre lines from other design factors, and many researchers have noted inconclusive results (Elliott et al. 2003, van Driele et al. 2004). Another treatment, known as a Drenthe edge line, employs unpainted and intermittent edge lines made of gravel chippings in conjunction with relatively narrow (2.25 m) lanes (van der Horst & Hoekstra 1994). Drenthe treatments have been reported to reduce speeds by 3 km/h in an instrumented car (Elliott et al. 2003) and by 1.88 km/h in a simulator (as well as resulting in lateral positions closer to the centre line) (Godley et al. 1999). However, it has been reported that:

- Combining visual delineation treatments does not reduce speed in an additive fashion.
- The type of delineation or width of hatched areas does not affect speeds differentially for moderately narrow lane widths (between 3 m and 3.5 m).
- The effect of shoulder width did not differ for widths between 1.35 m and 2 m (Carsten et al. 1995).

2.2.4 Medians

Central medians have been found to have a range of effects on speed. Although the use of planted medians to break a roadway into smaller paved expanses has been reported to decrease mean speeds, medians (raised & flush) usually increase speeds on urban arterials, unless they reduce the number of lanes, when they often calm speeds (Macbeth 1998). When medians have been added to reduce lane widths they have sometimes been associated with speed reductions of the order of 4.8 km/h (mean) and 6.4 km/h (C85) (Carsten et al. 1995, Elliott et al. 2003), but in other cases speed increases of up to 7.5 km/h (van der Horst 1983, cited in Martens et al. 1997). Interestingly, although raised medians are associated with higher speeds than no medians, two-way turn lanes and flush medians produce even higher speeds (Fitzpatrick et al. 2000). When medians result in deflection of traffic, however, their effects are more reliable. In one case, planted medians, 4 m wide with short approach tapers (10:1) deflecting traffic by 2 m, produced

a 9% drop in mean speeds (to 49.3 km/h) and a 20% reduction in the proportion of vehicles speeding (Forbes & Gill 2000). Similarly, short, wide, landscaped medians that deflected traffic with no loss of lane width were found to reduce speeds by 4.7 km/h (Elliott et al. 2003). The width of medians also appears to play a significant role in their effects on speed, raising C85 speeds by as much as 5-10% for every 3 m of median width (Fitzpatrick et al. 2000). The effects of medians on mean and C85 speeds as extracted from the published literature are presented in Table 2.3. Once again, however, it must be noted that the presence of medians is often confounded with other design features and thus their effects on speed must be considered cautiously.

Table 2.3. More treatments for speed maintenance.

		Treatment	Avg speed (km/h) post-treatment	C85 speed (km/h) post-treatment
		Medians 		Central medians no median
raised median	58.9			67.6
2-way turn lane deflecting median	-			70.8
	49.5			-
Median width 0 (local)				53.1
0 (arterial)				69.2
3m (local)				69.2
3m (arterial)				86.9
6m (local)				72.4
6m (arterial)				96.5
Road surface 		Treatment	% speed reduction	speed reduction (km/h)
		Roughness	14 – 23%	2.6 – 5.0
		Rumble devices	0 – 6%	0 – 9.6
		Transverse lines	2.1 – 13.7%	2 – 13
		Speed roundels	12%	4.8
Note: empty cells above indicate that no published data were found for that measure.				

2.2.5 Road surface

Researchers have noted that changes in road surface roughness, as when driving on bricks, cobbles or 'pot holes', have strong effects on drivers' speeds. Van de Kerkhof (1987, cited in Martens et al. 1997) stated that road roughness is one of the most important factors determining drivers' speeds and can explain 91% of the variation in mean driving speed. Similarly, Slangen (1987, cited in Elliott et al. 2003) reported that increases in roughness can produce a 14-23% reduction in mean speeds. Cooper et al. (1980) reported increases in drivers' mean speeds of 2.6 km/h at three test sites after resurfacing, whereas no change in speed was found at sites where surface roughness remained the same after resurfacing. Similarly, Parker (1997) found no change in speeds on two rural highways and a 5 km/h increase on two urban streets that were resurfaced. In a study of road surfaces of different kinds of roads, smooth road surfaces followed by

rough surfaces were associated with an immediate reduction in mean speeds of 5%; when a rough surface was followed by a smooth surface no immediate change in speed was noted (Te Velde 1985, cited in Martens et al. 1997). Transverse groupings of rumble strips, rumble areas, and other rumble devices can reduce localised speeds by up to 9.6 km/h but their effect between rumble areas is low, their immediate effects may lessen over time since less discomfort occurs when traversed at higher speeds, and they are typically not suitable within 200 m of residential dwellings because of the noise they generate (Elliott et al. 2003, Traffic Advisory Unit 1993, 2005).

Painted patterns such as herringbones and transverse lines designed to influence drivers' perception of speed have been shown to reduce speeds in several laboratory and field studies (Carsten et al. 1995, Godley et al. 1999, Macaulay et al. 2004, Martens et al. 1997). For example, a pattern based on the Wundt Illusion led to a 3.75 km/h speed reduction in a driving simulator, and a series of simple transverse lines reduced speeds by 2.03 km/h, but the speed reductions did not differ amongst the three patterns tested (Godley et al. 1999). A field trial of herringbone lines was found to decrease speeds at mid and end points of a village, but no added benefit was gained from combining them with other speed management treatments such as chicanes (Carsten et al. 1995). When transverse line patterns have been placed on approaches to dual carriageway roundabouts they have been associated with crash reductions of 50% and speed reductions ranging from 4 to 13 km/h (Elliott et al. 2003). Although the results of field trials have shown some short-term speed reductions produced by painted patterns, some doubt exists about the durability of their effectiveness, over time and over longer distances (Macaulay et al. 2004, Martens et al. 1997). Charlton (2003, 2004) has shown that they may hold promise as hazard warnings or speed change treatments, but their effectiveness declines over longer distances and with repeated exposures in a short interval. Painting coloured speed roundels directly on the road surface has produced mixed results: they may reduce speeds by 3 mph (4.8 km/h) in a 40 mph (64 km/h) speed zone (Carsten et al. 1995). Uniform changes in pavement colours and paint colours have not been shown to produce any reliable changes in speed (Carsten et al. 1995, Traffic Advisory Unit 1994).

2.2.6 Physical restrictions

Chicanes have been widely used to produce localised road narrowing and can produce and maintain significant speed reductions (Carsten et al. 1995). In a survey of a number of roads narrowed with chicane treatments, speeds between chicanes were found to average 29 mph (46.5 km/h) and C85 speeds averaged 31 mph (50 km/h) (Traffic Advisory Unit 1997b). The optimal spacing for chicanes based on a speed/spacing relationship could not be determined because of the rarity of intermediate speed data. Two types of chicanes have been implemented: single-lane working chicanes in which staggered build-outs narrow the road so that traffic from one direction has to give way to opposing traffic; and two-way working chicanes in which build-outs produce deflection but lanes are separated by road markings or a central median. Single-lane working chicanes are associated with the lowest speeds: with average speeds of 21 mph (33.8 km/h) and C85 speeds of 26 mph (41.8 km/h), 14 mph (22 km/h) lower than C85 speeds before chicanes. In comparison, the two-way working chicanes result in average speeds of 27 mph

(43.5 km/h) and C85 speeds of 31 mph (49.8 km/h), a reduction of 11 mph (17.7 km/h) in C85 speeds (Traffic Advisory Unit 1997b). When speeds were measured between chicanes the single-lane working treatments averaged 23 mph (37 km/h) and C85 speeds were 27 mph (43.5 km/h) (a reduction of 12 mph), while two-way working chicanes produced mean speeds of 31 mph (49.8 km/h) and C85 speeds of 34 mph (54.7 km/h), for an overall speed reduction of 6 mph (Traffic Advisory Unit 1997b). Speed humps and speed cushions have also been used to manage speeds on low-speed roads. Where speed cushions have been used with a spacing of 60 m, speeds between the cushions averages 33 km/h. When a spacing of 100 m is used, the mean speed between cushions is 39.8 km/h (Traffic Advisory Unit 1998). Similarly, the spacing between speed humps has a significant effect on speeds measured between the humps. Road humps spaced at 20 m intervals produce mean speeds between the humps of 30.6 m/h whereas 100 m intervals produce speeds of 35.4 km/h (Traffic Advisory Unit 1996). The authors of that study noted, however, that the vehicle speeds before installation of the road humps was significant in determining the resulting speed between humps; sites with 'before' speeds of 56 km/h produced 'after' speeds of 34 km/h with humps at 60 m intervals (Traffic Advisory Unit 1996).

2.2.7 Signs

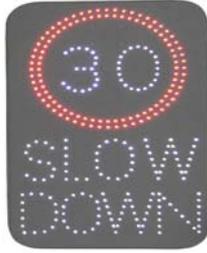
Historically the most common method of managing drivers' speed has been through the use of road signs. Considerable research has been dedicated to their legibility, symbology, and placement. Unfortunately, very few road signs are noticed and recalled by drivers (Hughes & Cole 1986, Charlton 2006). In a recent study of road sign conspicuity, participants reported noticing an average of only 15.3% of the speed roundels present on the roadside as they drove, as compared to 47.9% of all of roadside sign types or 42.6% of hazard warning signs (Charlton 2006). Summala & Hietamäki (1984) measured average vehicle speeds and speed changes at a 30 km/h speed sign and found that placing a flashing light on top of the sign, presumably increasing the signs' conspicuity, produced greater reductions in vehicle speeds. In a study of vehicle-activated signs, a warning was programmed to display the word 'SLOW' to vehicles exceeding the speed limit on an approach to a pedestrian crossing. The sign did not, however, result in any reduction of vehicle speeds, and was less effective than removable pedestrian islands and pedestrian crossing signs erected at a companion site (Kamyab et al. 2002). In contrast, vehicle-activated speed warnings in Great Britain were found to produce significant 11% reductions in mean vehicle speeds (6.5 km/h) at sites where there was no change in the speed limit (Winnet & Wheeler 2002). Opinion surveys of drivers in the areas where the signs were installed indicated 'overwhelming approval' of the signs and most had made the connection between their own speed and the signs being triggered. Vehicle-activated speed reduction warnings may be even more effective: when stopped approximately 2.5 km after passing a speed reduction variable message sign (VMS), an impressive 91% of drivers recalled the speed limit (Rämä 2001). However, some indication exists that the presence of VMS can reduce the number of drivers able to recall fixed warning signs located in the vicinity of the VMS (Rämä et al. 1999).

2.2.8 Roadside features

Finally, a range of roadside features such as cycle lanes, pedestrian paths, parking strips, and edge posts have been used to influence drivers' speeds. In one field trial on several busy urban arterials (15,000-30,000 vehicles per day), cycle lanes and parking strips were used to narrow the overall road width and reduce the number of lanes, resulting in increased cyclist safety and lower vehicle speeds (Macbeth 1998). Widening footpaths may increase driving speeds, but if it is done in such a way that the carriageway becomes narrower, it can reduce speeds (Elliott et al. 2003). Entry points on a road (driveways, side roads, etc.) also have a significant effect on vehicle speeds with 13% higher speeds associated with roads possessing fewer than 29 access points per km (Elliott et al. 2003, Fitzpatrick et al. 2000). Changes to perceived lane width can easily be produced through the addition of on-street parking. The presence of parallel parking reduced drivers speed estimates by 5 mph (8 km/h) and right-angled parking reduced estimated speeds 7 mph (11 km/h) (Elliott et al. 2003). In one case where lane width was reduced from 5 m to 3.7 m by adding a white edge line to separate parked cars from the driving lane speeds were reduced 5% (Martens et al. 1997). Similarly, the addition of parking strips demarcated by modular traffic chicanes reduced C85 speeds by 10% (Macbeth 1998).

Lateral clearance between the edge of roadway and roadside objects also has a profound effect on drivers' speeds. A reduction of lateral clearance from 30 m to 15 m decreases speed by only 3%, but decreasing lateral clearance to 7.5 m reduces speed by 16% and can reduce the proportion of drivers exceeding the speed limit from 81% to 58%. (Martens et al. 1997). Buildings, trees, and parked cars immediately adjacent to the road have all been found to reduce speed by 12-14%, and the distance of housing from the road has been found to be positively correlated with urban car speeds. (Martens et al. 1997). Urban buildings affect estimates of drivers' own travel speed by 1.6-4.8 km/h and the amount of architectural detail has also been found to be strongly correlated with drivers' assessed speeds (Elliott et al. 2003). The effects of roadside trees have been more mixed, with one study showing 12-14% reductions in mean speed, another showing little effect on drivers' speed estimation (Elliott et al. 2003). It is possible that a continuous line of overgrowth can increase speeds by enhancing road delineation, as opposed to groups of bushes or trees which are more likely to be associated with decreases in speeds (Martens et al. 1997). A summary of the effects of various roadside features is presented in Table 2.4. As with the other summary tables, it is the relative ordinal relationship between treatments that is of greatest interest, rather than the precise speed differentials indicated.

Table 2.4 More treatments for speed maintenance.

Physical restrictions 	Treatment	Avg speed (km/h)	C85 speed (km/h)
Signs 	Sign type	Avg speed (km/h)	% speed reduction
Roadside features 	Feature		C85 speed (km/h)
	Chicanes Single-lane working Two-way working	46.5 37.0 49.8	50.0 43.5 54.7
	Speed cushions 60 m separation 100 m separation	32.9 39.4	38.6 48.3
	Speed humps 20 m separation 60 m separation 100 m separation 140 m separation	27.4 30.6 35.4 38.6	
	Static	Depends on speed limit	0%
	Flashing light	Depends on speed limit	10%
	Vehicle-activated	Depends on speed limit	11%
	Access density > 29 pts per km < 29 pts per km		74 83
	Parking No parking		51 77
	Road environment at 3 m from road edge clear yielding objects yielding & rigid isolated rigid isolated rigid continuous rigid continuous rigid	(arterial) (local) (arterial) (local)	50mph 45mph 38mph 42mph 33mph 47mph 27mph

Note: empty cells above indicate that no published data were found for that measure.

2.3 Meta-analyses

Meta-analyses are a method of systematically examining the published effects in a given research area, statistically comparing individual studies' effect sizes, and looking for trends across studies as well as any indication in publication bias. In the case of the present review, the review of the literature revealed two recent meta-analyses of area-wide traffic calming (Elvik 2001, Bunn et al. 2003), and a third meta-analysis of the literature associated with the effects of road markings on speed (Davidse et al. 2004). These articles merit some fuller discussion than provided for the other articles summarised and are described in the sections to follow.

2.3.1 Area-wide urban traffic schemes: a meta-analysis of safety effects

This recent study published by Elvik (2001) critically examined and summarised 33 studies evaluating the effects on road safety (accident rates) of area-wide urban traffic-calming schemes. The main questions discussed in the paper were:

- What are the essential elements of traffic-calming schemes?
- What is the best estimate of the effects on road safety of urban traffic-calming schemes?
- To what extent are the results of studies that have evaluated the safety effects affected by study design characteristics?
- To what extent can the results of the studies that have evaluated the safety effects of traffic-calming schemes, be generalised across countries and study decades?

The studies examined by Elvik were retrieved by means of a systematic literature review and were included only if they provided information about the number of accidents on which each study was based. The studies were then coded according to a number of characteristics, including:

- year of publication,
- country of origin,
- study design,
- traffic volume,
- crash severity,
- road type.

Each study was then assigned a validity score by weighting aspects of the study design on a seven-point validity scale. All the traffic-calming schemes that were described in these studies were found to have the following characteristics in common:

- The calmed area was generally a predominantly residential area, between 0.25 and 1.5 km²
- The street networks were not strictly differentiated according to traffic function.
- Commuters taking short cuts through residential streets was a common problem.
- On designated residential streets or local roads, measures were taken to reduce traffic volume (e.g. street closures), sometimes supplemented with speed-reducing devices (e.g. speed humps).
- Roads designated as main roads were upgraded to cope with a greater traffic volume.

Elvik then assessed the data set to determine whether there was any publication bias in the literature associated with area-wide traffic calming. Publication bias, selective reporting or preferential publication of results that are statistically significant or consistent with theory or expectation, is a significant challenge to the ability to draw robust generalisations from the published literature. Funnel graphs are scatter plots of effect size v sample size and when symmetrical (funnel shaped) are taken as indication of the absence of publication bias. The funnel graph from Elvik's analysis is shown in Figure 2.1

and, while considerable spread in estimates of safety effects was present, for both local and main roads, no indication of publication bias was found.

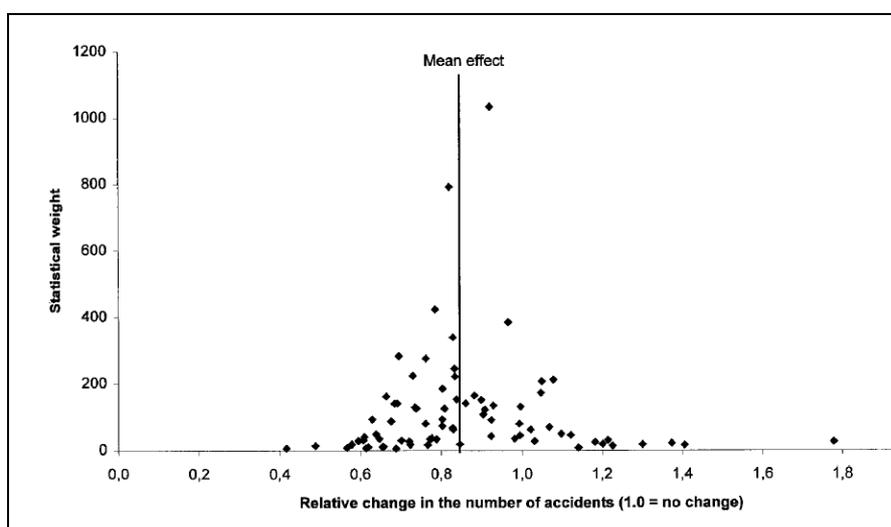


Figure 2.1 Funnel graph of the effects reported in 33 area-wide traffic-calming studies (Elvik 2001).

Elvik found that the results of the studies were quite similar in different countries. Statistically significant accident reductions were found in six countries, a non-significant accident reduction was found in one country, and a small non-significant increase in accidents occurred in one country. Elvik's analysis also considered the effects of traffic calming by study decade with the finding that the results appeared to be stable over time. Table 2.5 shows Elvik's weighted analysis of changes in the number of accidents, by accident severity and type of road. Elvik noted that many of the studies had some methodological shortcomings but nonetheless it was clear that a significant reduction in both property damage and injury accidents was evident in most of the published research. The analysis showed that area-wide traffic-calming schemes reduced injury accidents by an average of 15%. The reduction in accidents was greater on local roads (25-55%) than on main roads (about 8-15%), but Elvik noted that many of the schemes did not place calming treatments on main roads. Finally, the results indicated that the reported results of traffic calming were stable over time and of similar magnitude in the eight countries included in the analysis.

Table 2.5 Results of evaluation studies by accident severity and type of road (Elvik 2001).

Crash severity	Type of road	Percent change in the number of accidents			
		Fixed effects model		Random effects model	
		Best estimate	95% CI *	Best estimate	95% CI *
Injury crashes	Whole area	-15	(-17; -12)	-15	(-19; -10)
	Main roads	-8	(-12; -5)	-8	(-13; -2)
	Local roads	-24	(-39; -18)	-34	(-43; -23)
Property-damage-only crashes	Whole area	-16	(-19; -13)	-19	(-26; -12)
	Main roads	-11	(-16; -6)	-18	(-31; -3)
	Local roads	-29	(-25; -22)	-42	(-54; -26)
Severity not stated	Whole area	-19	(-25; -12)	-18	(-27; -9)
	Main roads	-14	(-21; -6)	-13	(-21; -4)
	Local roads	-57	(-68; -43)	-57	(-68; -43)

* Confidence interval

2.3.2 Traffic calming for the prevention of road injuries: systematic review and meta-analysis

This study published by Bunn et al. in 2003 focused on randomised control trials and controlled before-and-after studies of area-wide traffic-calming schemes. The schemes studied included a number of specific changes to the road layout, road hierarchy or road environment. A ratio of event rates before and after intervention in the traffic-calmed area divided by the corresponding ratio of event rates in the control area was used to calculate the reduction in the incident rate in the intervention area compared to that in the control area. Out of 586 reports considered by the authors, 12 reports (describing 16 controlled before-and-after studies) were used for the meta-analysis. Seven were done in Germany, six in the UK, two in Australia, and one in the Netherlands. All the studies were conducted in the 1970s and 80s. The authors calculated pooled rate ratios for studies reporting number of crashes (pooled rate ratio = 0.95, 95% confidence interval (CI) = 0.81 to 1.11); number of fatalities (pooled rate ratio = 0.63, 95% CI = 0.14 to 2.59); the total number of road traffic injuries (pooled ratio = 0.89, 95% CI = 0.80 to 1.00); and the number of pedestrian crashes (pooled rate ratio = 1.00, 95% CI = 0.84 to 1.18).

The analysis of the 16 controlled before-and-after studies found an 11% reduction in road traffic injuries, both fatal and non-fatal, and shows that area-wide traffic calming has the potential to prevent road traffic injuries. The ratio for road deaths should be regarded as imprecise because of the low number of reported road user deaths in the included studies.

2.3.3 The effect of altered road markings on speed and lateral position: a meta-analysis

The relationship between road markings and speed was chosen as the subject of this meta-analysis by Davidse et. al. published in 2004. Their meta-analysis aimed to determine the effect of different kinds of road markings on the speed and lateral position of drivers, with a particular emphasis placed on markings specifically related to sustainable safety (self-explaining roads). The road markings studied were confined to longitudinal lines at the centre or the edge of the pavement; materials considered were restricted to paint and raised pavement markers (RPMs); and only speed and lateral position as measured in unrestricted conditions were included in the meta-analysis.

The study first reviewed some of the road markings have been proposed for roads in a sustainably safe road network as shown in Table 2.6. For roads outside urban areas:

- Through roads should have a double continuous centre line with green paint between them (or a median or a guard rail) and continuous edge lines.
- Distributor roads should have a double continuous centre line (or a median) and broken edge lines.
- Access roads should have only broken edge lines.

For roads inside urban areas:

- Distributor roads should have a double continuous centre lines (or a median) and a broken edge line (or curbs).
- Access roads should have neither centre nor edge lines.

A total of 41 publications from the International Transport Research Database (ITRD), the SWOV library, databases of related research institutes, reference lists from articles, and suggestions of colleagues were used for the analysis. Experiments were independently coded by two coders according to background variables, research characteristics, characteristics of the (alterations in type of) markings, and information about the impact of the alterations and effect sizes. The 41 publications described 201 comparisons between different types of road markings.

Most of the experiments were published in reports (69%) and were carried out in the United States (52%) or the Netherlands (28%). Experiments took place between 1949 and 2000, with the US experiments taking place before 1992 and the Dutch experiments from 1992 onwards. Road markings were typically applied on roads outside urban areas (96%) with a speed limit of ~80 km/h (47%). Most of the investigations (80%) were before-and-after studies; 7% used sections of the same road while others (13%) used sections of two comparable roads. Driving simulator experiments (18%) were coded as before-and-after studies. The majority of studies (69%) used observers or measuring devices located at the side of the road. The graphs used to examine for publication bias are shown in Figure 2.2. None was evident.

Table 2.6 Proposed road markings for through roads, distributor roads, and access roads outside and inside urban areas (Davidse et al. 2004).

	Through roads	Distributor roads	Access roads
Outside urban areas			
Inside urban areas			

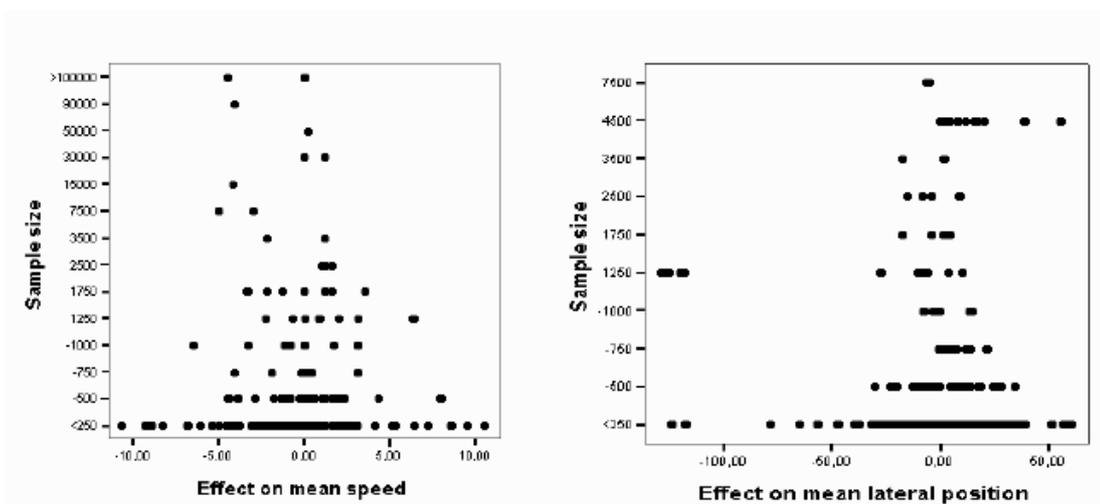


Figure 2.2 Funnel plots of publication bias (Davidse et al. 2004).

A total of 320 effect sizes were calculated for the effect of road markings on speed. In general, a lowering of the average speed (an effect size of less than zero) is regarded as an improvement in road safety. Reductions and increases ranged from -10.6 km/h to $+10.6$ km/h, as shown in Table 2.7. The alteration that led to the largest increase in speed was the adding of an edge line to a road that did not have any road markings, indicated by 'no edge lines => edge line (el)' (Table 2.7, type 2). Adding an edge line to a road without any road markings leads to a significant increase in mean speed ($p < 0.001$). Adding a centre line to an otherwise unmarked road, 'no lines => centre line (cl)', also leads to an increase in speed ($p < 0.05$). The addition of an edge line to a road that was already marked with a centre line ('cl => cl + edge line') or as replacement of a centre line ('cl => no cl + edge line') created significantly different effects from the adding of an

edge line to a previously unmarked road ($p < 0.001$) and the latter change even led to a significant decrease of the speed driven ($p < 0.01$).

Table 2.7 Effects on speed of different types of alterations of road markings (Davidse et al. 2004).

Type of alteration	N*	Range		Mean	Standard deviation
		Min	Max		
1 No lines => centre line (cl)	14	-1.9	9.6	3.0	4.6
2 No lines => edge line (el)	12	1.2	10.6	6.1	3.5
3 cl => cl + edge line	56	-5.0	8.1	0.4	2.7
4 cl => no cl + edge line	14	-4.0	1.0	-1.7	1.7
5 cl + el => cl + 'other type of el'	86	-9.3	6.5	-0.7	3.0
6 cl + el => no cl + 'other type of el'	4	0.0	1.2	0.7	0.6
7 cl + el => 'other type of cl' + el	32	-4.4	4.4	-0.1	2.8
8 cl + el => variation of both cl + el	4	-0.8	0.0	-0.4	0.5
9 alterations involving RPMs	56	-4.1	5.1	0.6	2.3
10 other alteration	42	-10.6	2.4	-2.5	3.3

* Since not all experiments have studied the effect on speed, the number of effect sizes can differ from the number of experiments

A total of 231 effect sizes were available for estimating the effect of altered markings on the variation in speed between road users. Both decreases and increases in speed variability were found with a maximum decrease in variability of 2.9 km/h and a maximum increase of 3.9 km/h. Interestingly both of the extremes were found in a single set of experiments that replaced post-mounted delineators with raised pavement markers on two-lane rural highways which also reported an increase of 4.2 km/h in drivers' mean speeds. We can infer from these data that, although mean speeds may show clear effects, the effect on the speed variability between drivers may differ substantially. Davidse et al. also noted that in some of the studies which reported little or no effect on mean speeds, changes in speed variability (up to 3 km/h) were obtained. They conclude that "in general, the effect of altered road markings on the variation in speed between road users is negligible" (p.23). A total of 369 effect sizes were calculated for the effects of road marking on lateral position. A range of changes in lane position (with a maximum of 124 cm to the centre and a maximum shift of 80 cm to the edge of the road) were found as shown in Table 2.8, but, in keeping with the present focus on speed management, they are not described in detail here.

This meta-analysis showed that adding an edge or centre line to a previously unmarked road can lead to an increase in speed. However, an increase in speed was not found when an edge line was added to a road that was already marked with a centre line or where a centre line was replaced with an edge line. The latter alteration led to a decrease in speed. Unfortunately the number of before-and-after studies specifically examining the alterations proposed for the sustainable safety programme (subsets of types 4, 5, & 7 in Table 2.7) were too few to draw reliable conclusions for through and distributor roads.

The proposed designs for access roads, however, was judged likely to reduce speeds by 2.4 km/h and shift mean lateral position 8-15 cm closer to the centre of the road.

Table 2.8 Effects on lateral position (cm from the centre of the road) of different types of alterations of road markings (Davidse et al. 2004).

Type of alteration	N*	Range		Mean	Standard deviation
		min	max		
1 no lines=>centre line (cl)	30	-19	48	12	20
2 no line =>edge line (el)	22	-15	48	10	16
3 cl => cl + edge line	85	-27	35	-1	11
4 cl => no cl + edge line	20	-42	21	-12	21
5 cl + el => cl +'other type of el'	80	-117	80	-3	30
7 cl + el => 'other type of cl' +el	38	-30	58	2	18
8 cl + el =>variation of both cl + el	4	-18	8	-5	15
9 alterations involving RPMs	52	-41	52	4	21
10 other alterations	38	-124	29	-10	38

* Since not all studies have studied the effect of lateral position, the number of effect sizes can differ from the number of studies reported

2.4 Summary

The review of the published literature on speed management revealed two distinct functions for speed management treatments: road designs to indicate speed changes, and designs to aid drivers' maintenance of appropriate speeds. Speed change designs employed at gateways have commonly contained a combination of design features, some physical and some visual. The location of gateways and the road environment immediately downstream appears to be very important to their effectiveness in reducing speeds. Speed reductions at gateway locations can be momentary (resulting from the physical and visual properties of the gateway) unless the road conditions downstream of a gateway reinforce the lower speeds with visual and/or physical road conditions (e.g. narrower lanes, increased traffic, roadside furniture, etc.). Thus placement of gateways at the first house of a village or urban area is much more effective than at the village boundary because the increased visual complexity and presence of other road users in a village or urban area reinforces the reduced speed initially produced by the gateway. Gateway treatments that are located well away from urban development or are not accompanied by any appreciable downstream changes in road width, traffic density, or roadside furniture will have only transitory effects and in some cases downstream speeds may actually exceed pre-threshold speeds because of a perceptual process called visual motion after effect.

At other speed change threshold sites within an urban area, the designs may be simpler, consisting of either predominantly physical or visual countermeasures, depending on the speed change profiles at the threshold site. For example, physical measures producing deflection (chicanes & build-outs) or discomfort (speed humps, judder bars, and transverse rumble strips) have robust effects but may be unsuitable for speeds higher

than 30-50 km/h because of safety concerns and road user frustration. For higher speed changes, thresholds with a greater reliance on perceptual design features such as signage, visual narrowing, flush medians and hatching, and traffic medians appear to be more appropriate.

Speed maintenance designs are intended to reinforce the appropriate speed in the area rather than initiate a change in speed at a specific site. Some of the most effective speed maintenance treatments have manipulated lane width and the number of traffic lanes to moderate vehicle speeds. Lane widths have been manipulated physically by adding landscaped or raised medians as well as perceptually by moving the painted edge line. Roadside features such as the proximity of angle parking and landscaping also have a perceptual narrowing effect and reduce drivers' speeds. The use of physically restrictive measures such as periodic placement of speed humps and chicanes, although effective, appears less desirable because of their low acceptability to road users and residents. The presence of central medians, flush or raised, appears to have a detrimental effect on drivers' speeds in direct proportion to the width of the median. That is, central medians appear to increase drivers' speeds so that wider medians typically result in faster speeds. The exception to this is when the medians produce deflection (e.g. a speed control median or small roundabout) or serve to reduce the width of the lanes.

Finally, the meta-analyses of published research show that speed management designs do work, even in the absence of the clear differentiation of road categories that is implicit in the self-explaining roads and sustainable safety design philosophies. Speed change thresholds and speed maintenance designs produce significant and stable reductions in vehicle speeds (by up to 27%), the number of injury crashes (average of 15%), and the number and severity of injuries (average of 11%).

3. Sample site survey

The next objective of the research was to collect a limited observational sample in order to provide an indication of whether some of the variables reported in the overseas literature have equivalent effects on New Zealand roads. The speed observations were not intended as a comprehensive speed survey; the aim was to provide a simple ordinal comparison of vehicle speeds at sites with different lane widths and centre line markings (two of the most robust speed management variables identified in the literature) and compare them to the ordering found in the published literature. As regards lane width, three rural open-road (100 km/h) sites where lane width ranged from 3.0-3.5 m and the number of lanes from 2 to 4 were identified along a 25 km segment of SH 1. Similarly, three urban locations with 50 km/h speed limits were found with either 1 or 2 lanes, with one site having no centre line marking, another with a dashed centre line, and a third with a landscaped central median separating the lanes. These particular sites were selected primarily because of the convenience and comparability afforded by their close proximity. The proximity of the three open road sites to one another meant that the characteristics of the traffic, pavement condition, and roadside environment would be relatively similar and speeds could be sampled close together in time. The three urban sites also had some similarities caused by their close proximity (within 5 km of each other), but some of their characteristics (i.e. traffic density, presence of parked cars, and landscaping) displayed more variability than the rural sites.

3.1 Method

Field observation of driving behaviour at six locations in the Waikato district were undertaken using a Marksman LTI 20-20 laser speed gun (Laser Technologies Ltd). Speeds were recorded at three open road sites along State Highway 1 and three sites in urban Hamilton. Data were collected in a convenience sample of 60 drivers per site, with the stipulation that speeds of only freely moving (non-platooned) vehicles were recorded. Data were collected by unobtrusively positioning a vehicle off the carriageway and recording vehicle speeds from within the vehicle. All observations were collected between 0900 and 1400 hours with clear visibility and dry conditions.

3.2 Results

The speeds recorded for each of the three open road sites, from a total of 180 vehicles, are shown in Figure 3.1. The speeds generally increase along with lane width and number of lanes, as predicted by the speed maintenance literature. The 3.0 m-wide lane¹ was associated with the lowest average speed (88.32 km/h), followed by the 3.5 m lane (93.35 km/h) and the four-lane (2+2) road (98.67 km/h). The 2+2 road consisted of four 3.5 m lanes with northbound and southbound traffic separated by a 4 m median with barrier, and thus it is not possible to say whether the higher speeds at that site were the result of the greater number of lanes, the greater overall road width, or the presence of

¹ This site had a 3.0 m lane southbound (the direction from which vehicle speeds were observed) and a 3.5 m lane northbound with an overall paved surface of 6.9 m.

the median barrier. The presence of any or all of these properties, however, would be predicted to lead to higher speeds. The C85 speeds for the three sites were also as predicted, increasing from 100.15, to 102.15, and to 108.15 km/h. One other point of note is the wider range of speeds recorded for the 3.0 m lane (SD=10.99) and for the four-lane site (SD=10.46) relative to the site with two 3.5-m lanes (SD=7.96). The reason for this difference was not immediately apparent from the observations or notes recorded at the sites.

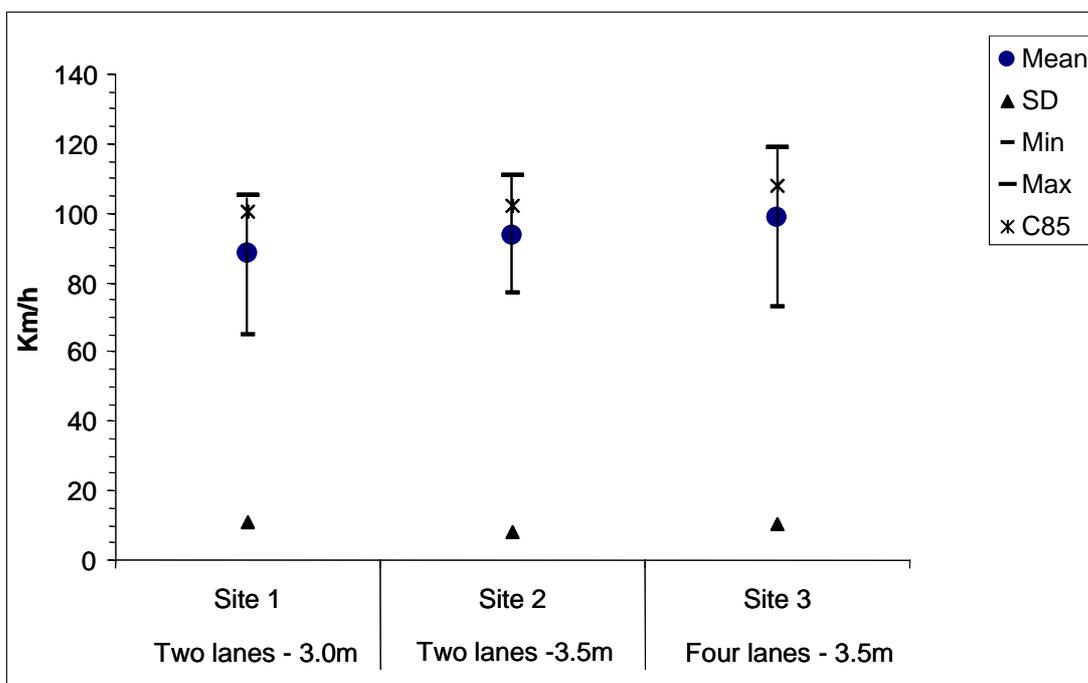


Figure 3.1 Speed profiles at three open road sites.

Speeds recorded from three urban sites are shown in Figure 3.2. These sites were all in 50 km/h speed zones but differed in regard to the delineation of the roadway centre. Site 4 had no centre line markings, Site 5 had a dashed white centre line, and Site 6 had a landscaped centre median. Vehicle speeds associated with the undelineated road (Site 4) were slower (mean of 49.75 km/h) than those recorded for Site 5 (mean of 53.62 km/h) as would be predicted from the research literature.

The finding that the speeds were lowest for Site 6 (average of 43.02 km/h) was, however, somewhat at odds with what might be predicted from studies of the effect of central medians, which is generally to increase speeds. Site 6 had a relatively wide (3.5 m) central median landscaped with mature trees and a white stripe on the left separating the 3.0 m lane from angled parking in front of shops. The trees and parked cars immediately adjacent to the relatively narrow driving lane may have served to nullify any speed-increasing effect ordinarily associated with a central median. In fact these roadside characteristics have been reported to reduce vehicle speeds by 12-14% (Martens et al. 1997) and thus Site 6 may not have been an appropriate example with which to contrast the effects of a central median.

The higher speed variability associated with Sites 4 and 6 ($SD=8.25$ and 9.97 respectively) also reflect that the drivers at these locations have had a mixture of purposes and destinations: some driving through the area, others looking for addresses, shops, or parking. Vehicles at Site 5 had a greater conformity of speeds ($SD=5.93$) perhaps indicating a greater proportion of through traffic, but it should be noted, also had a C85 speed (60.0 km/h) 10 km/h higher than the posted speed (C85 speeds for Sites 4 and 6 were 55.75 and 52.0 km/h respectively).

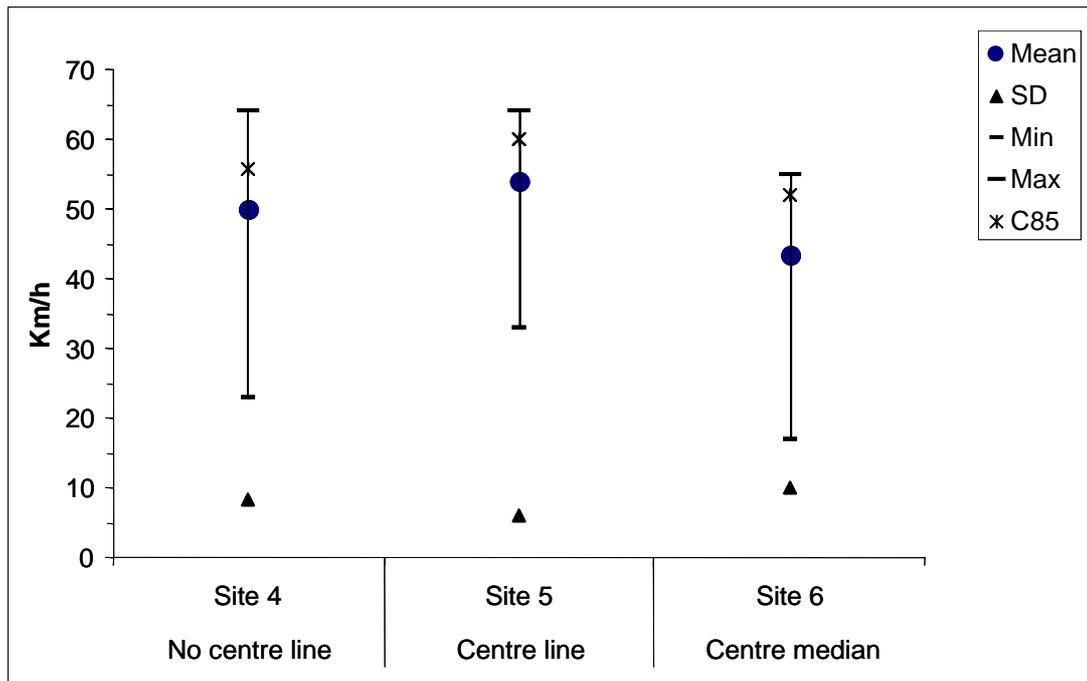


Figure 3.2 Speed profiles at three urban sites.

3.3 Summary

The sample site survey results generally supported predictions made from the speed management literature. They also indicated some potential issues associated with mixed-use roads in the urban environment. As lane width and number of lanes increased in an open road environment, so did the average and C85 vehicle speeds.

In the urban environment the results were less clear-cut. The absence of lane delineation was associated with lower speeds when compared to lanes separated with a dashed white centre line. When lane delineation was achieved with a wide central median, however, the lowest vehicle speeds were observed. These results may have been caused by the proximity of landscaping and angled parking (which have a perceptual narrowing effect), or by a mixture of driver destinations (reflected in the high speed variability obtained at the site).

The pattern of urban speeds observed thus may be seen as a drawback of the specific sites selected for comparison, but might also serve as an indication that clear functional differences in categorising roadway use may not always be possible.

4. Expert survey

Based on the findings published in the research literature it was possible to identify a broad range of design features with varying degrees of effectiveness for speed management and speed change management treatments. In order to make recommendations for testing and/or implementing self-explaining road designs in New Zealand, it was desirable to reduce the range of design features by identifying those with the greatest promise across different road and traffic environments. Although some generalisations regarding the effectiveness of these treatments can be made on the basis of the published literature (as described in the earlier sections) it was hoped to further refine these generalisations and supplement the information on their effectiveness (degree of speed compliance) with some indication of how long-lasting the effects were (their sustainability) and road users' subjective reactions to them (their acceptability).

To achieve this goal the decision was made to use road safety researchers and practitioners as data integrators, using their experience and expertise to provide estimates of how well each type of design feature functioned in terms of its effectiveness, sustainability, and acceptability. Accordingly, a questionnaire was designed to collect ratings of road designs for speed change and speed maintenance and distributed to a sample of researchers and practitioners who had published in the area of speed management. Because the only criterion for being included in the sample was to have published research on the subject of speed management, the assumption was that the respondents comprising the sample would represent a diverse set of formal qualifications, outlooks and experiences that would provide us with a perspective on speed management treatments that was not available from the published literature alone.

4.1 Method

The questionnaire was composed of two parts:

- Questions asking about treatments for speed maintenance (i.e. treatments that encourage drivers to maintain an appropriate speed).
- Questions about treatments for speed change (i.e. threshold treatments that clearly indicate a change in speed zone).

For each section of the survey the respondents were instructed to first identify the design features they felt were appropriate for specific road categories and then to rate those design features according to their:

- effectiveness (speed compliance),
- sustainability (resistance to habituation),
- suitability (road user acceptance).

Based on the literature review, five road categories were identified in the survey:

- urban through roads,
- rural through roads,

- urban distributor roads,
- rural distributor roads,
- access roads (primarily residential).

Similarly, two types of speed change threshold were identified:

- change from through road to distributor road,
- change from distributor road to access road.

Although the respondents were asked to identify individual design characteristics for each category of road or threshold (e.g. individual road widths), they were then asked to rate the effectiveness, sustainability, and suitability of each design feature (e.g. road width generally) across all five road categories or both threshold types. Thus, the respondents were being used as data integrators to provide an estimate of how well each type of design feature functioned as a speed management treatment. Before distribution, the questionnaire was pre-tested on three representative respondents and their comments were used to improve the questionnaire format and item wording. Based on the pre-test feedback we estimated that the questionnaire would require approximately 10-20 minutes to complete. The full questionnaire, as revised and sent to the respondents, is shown in Appendix B.

The questionnaire was sent to 40 road safety researchers as an electronic form attached to an email message describing the goals of the study and instructions for returning the completed forms. A total of 17 completed questionnaires were received, including 4 from the Netherlands, 4 from the United States, 2 from England, 1 from Sweden, 1 from Poland, and 5 from New Zealand. Five replies were received from researchers indicating that they were unable to complete the questionnaire within the time required because of time or travel commitments. Of the remaining 18 questionnaires sent (45%) it is unknown how many actually reached their intended recipients as only 7 of those generated an automated read receipt from the respondents' email systems. No attempt was made to follow-up non-replies with additional messages.

4.2 Results

Feedback from the respondents who completed the questionnaires indicated that they thought it was a very interesting exercise, prompting them to consider some speed management issues in a way they had not considered previously. Overall, the answers provided by the respondents showed good consistency, indicating that the various road categories and threshold types were understood and recognised by the respondents. Two of the respondents commented that they felt the questionnaire format was "somewhat restrictive" with regard to the types of road categories covered and/or the requirement to generalise across road categories for some ratings. One respondent explicitly commented that they were including motorways and freeways in the rural through-road category as they generally were not considered to be urban. This idea was shared by most of the respondents, as judged by their design speeds, and a concept implicit in the definition of this road category. Note that the experts were not asked to judge the treatments from any particular perspective (i.e. what was practical from a cost-benefit perspective as

opposed to what was ultimately desirable) and thus the responses may represent a combination of both outlooks.

No calculation of statistical reliability or confidence levels was attempted on the survey responses, in part because of the relatively small sample size, but also because it was hoped to characterise the range of opinions in some detail, rather than compare ratings across different groups of respondents or treatment contexts. In this regard, many of the respondents provided a wealth of additional information in the form of written comments accompanying their completed questionnaires and, where possible, these narratives have been included in the results below.

4.2.1 Treatments for speed maintenance

The first part of the questionnaire asked the respondents to consider the five different categories of road, and for each category to indicate which road design features were appropriate. These five road categories were based on the principal road functions described in the speed management research literature, and the first question asked the respondents to identify the appropriate design speed for each category. The resulting speed ratings are shown in Figure 4.1. The average design speed obtained for urban through roads was 69.09 km/h (median=60 km/h) and ranged from 60-100 km/h. The New Zealand respondents tended to indicate lower design speeds (mean=62.5 km/h) than the overseas respondents (mean=72.86 km/h). It should also be noted that a few respondents indicated that they had no roads in this category in their own country or that they were relatively rare. The average design speeds for rural through roads were higher than 100 km/h and ranged from 80 to 130 km/h. Once again, the New Zealand respondents tended to indicate somewhat lower design speeds (mean and median=100 km/h) than the overseas respondents (mean=106.67 km/h and median=110 km/h).

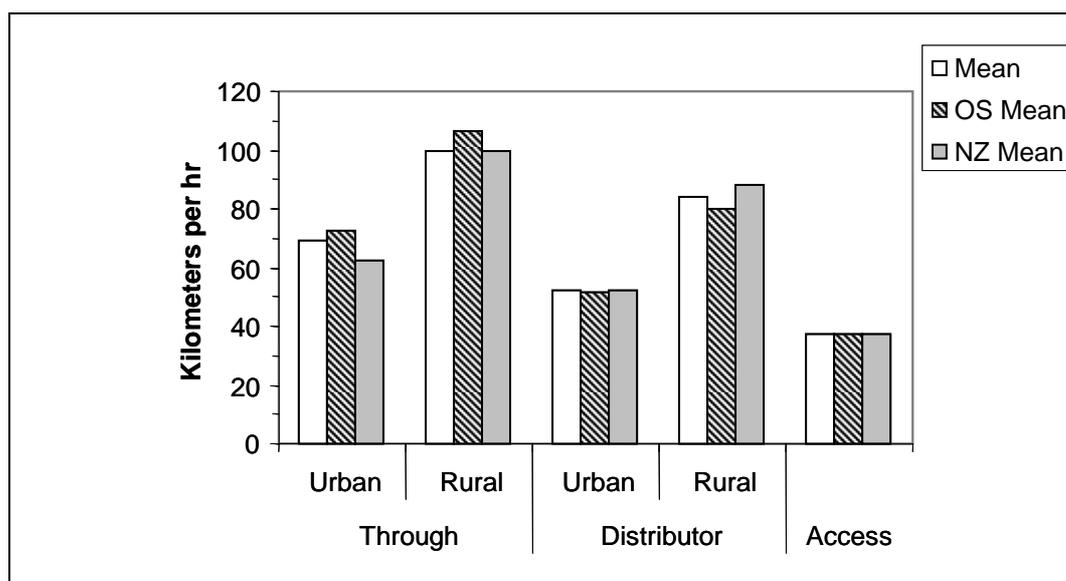


Figure 4.1 Respondents' average ratings of design speeds for five road categories.

Urban distributor roads were assigned a mean design speed of 52.0 km/h (median=50 km/h) and ranged from 40-80 km/h. For this road category New Zealand

respondents' means were slightly higher than the overseas respondents at 52.5 km/h as compared to 51.67 km/h but both groups' median speeds were at 50 km/h. For the rural distributor roads the difference between the two groups of researchers was larger (New Zealand mean=88 km/h; overseas mean=80 km/h). Overall, the design speed ratings ranged from 80–100km/h with a mean of 84 and median of 80 km/h. The access road speeds ranged from 30–60 with a mean of 37.5 km/h and median of 30 km/h. The New Zealand and overseas means for access roads were the same at 37.5 km/h although the New Zealand median rating of 35 was higher than the overseas median of 30.0 km/h.

Following the assignment of design speeds, the respondents indicated which road design features they thought were appropriate for each road category and rated the effectiveness, sustainability, and suitability of each type of feature. Shown in Figure 4.2 are the overall effectiveness, sustainability, and suitability ratings for each design feature. Lane width, number of lanes, and median characteristics appear to have received the best overall ratings of effectiveness, sustainability, and suitability, followed by the presence of cycle lanes, footpaths, and road surface treatments. Edge lines and centre lines were rated lower in terms of their effectiveness, and clear zones were rated the lowest as a speed management treatment.

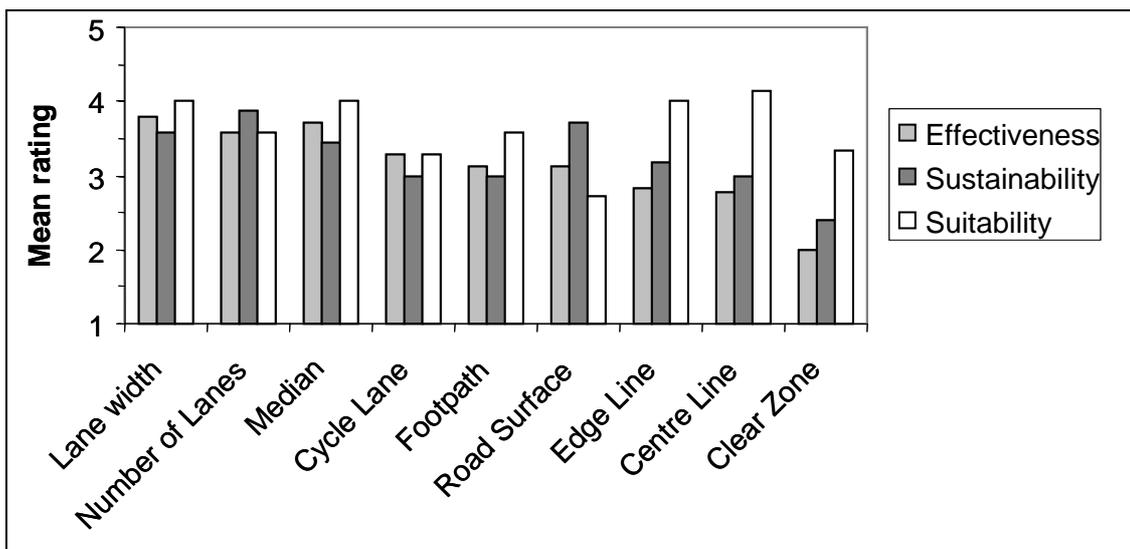


Figure 4.2 Respondents' ratings of design features (where: 5=high, 4=good, 3=medium, 2=slight, and 1=none).

The respondents' answers to the questions regarding lane width are shown in greater detail in Figure 4.3. The widest lanes were assigned to the urban through roads (mean=3.68 m), the narrowest to the access roads (2.67 m), with rural distributor roads in the middle (3.26 m). Through roads were generally assigned wider lane sizes (ranging from 3.1 m to 5.0 m, overall mean of 3.63 m) than distributor roads (ranging from 2.75 m to 5.0 m, overall mean of 3.34 m). Similarly, urban roads were assigned wider lanes (ranging from 2.75 m to 5.0 m, overall mean of 3.55 m) than rural roads (ranging from 2.75 m to 4.0 m, overall mean of 3.42 m). New Zealand respondents tended to assign wider lanes in the urban environment than the overseas researchers, with the exception of access roads where the New Zealand mean of 2.56 m was narrower than the overseas average of 2.75 m. Overseas respondents also assigned smaller lane widths to

rural distributors than New Zealand respondents, averaging 3.17 m as opposed to 3.39 m. The effectiveness, sustainability, and suitability ratings of lane width as a speed maintenance treatment were generally in the "good" range (averaging 3.78, 3.57, and 4.0 respectively) for all the researchers surveyed. The use of lane width as a speed maintenance treatment received the highest overall effectiveness ratings, ahead of all other design features.

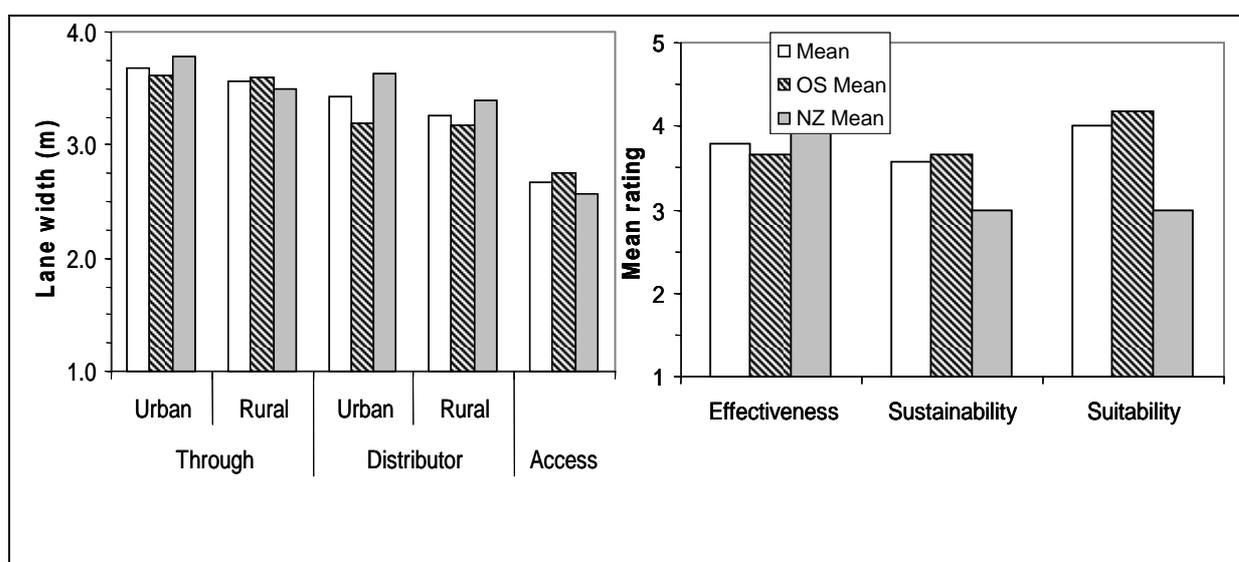


Figure 4.3 Mean ratings of lane width and its effectiveness, sustainability, and suitability as a speed maintenance treatment (where: 5=high, 4=good, 3=medium, 2=slight, and 1=none. OS=overseas).

Using the number of lanes as a speed maintenance treatment was also rated favourably by the respondents. Figure 4.4 shows the effectiveness, sustainability, and suitability ratings for the number of lanes. Number of lanes received the third-highest effectiveness ratings (behind lane width and central medians) but was rated best overall in terms of its sustainability (resistance to habituation). As can be seen in the figure, however, the New Zealand researchers' ratings of this design feature were uniformly lower than the overseas respondents. As regards the specifics of the number of lanes appropriate for each road category, the respondents indicated that through roads, both urban and rural, should have a lane configuration of 2+2 (four lanes total) or greater. For urban distributor roads, respondents' answers ranged from 1+1 (two lanes total) to 2+2, with a substantial majority (71%) choosing the 1+1 configuration. For rural distributor roads, respondents' again preferred the 1+1 configuration, with a minority of respondents (29%) indicating a 2+1 configuration (periodic overtaking lanes).

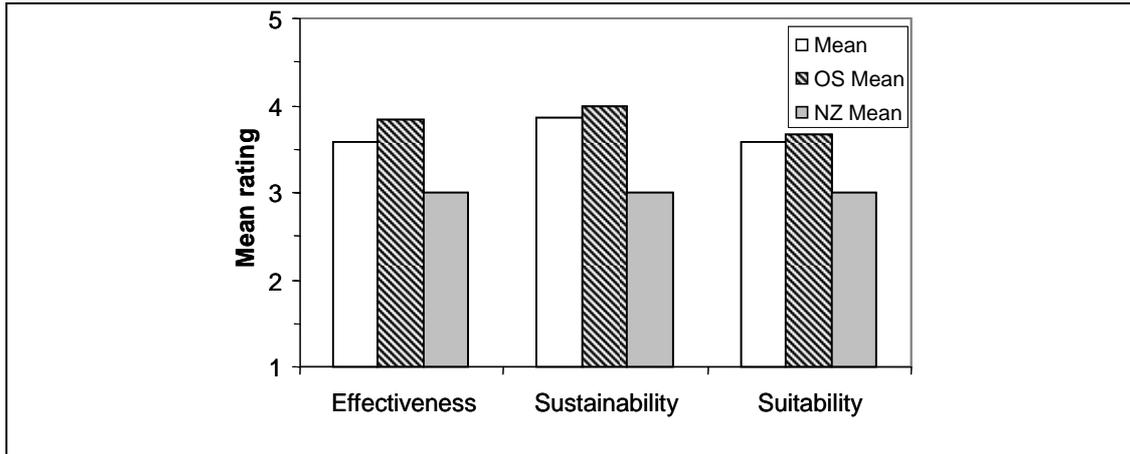


Figure 4.4 Mean ratings of number of lanes as a speed maintenance treatment (where: 5=high, 4=good, 3=medium, 2=slight, and 1=none).

As shown in Figure 4.5, use of central medians to affect speed maintenance received similarly high ratings by the respondents. The effectiveness ratings overall were second to lane width, but central medians were judged as the most effective design feature by the New Zealand respondents. In the case of rural through roads there was unanimous agreement that a central barrier between traffic should be included. Respondents were also unanimous in stating that no median was appropriate for access roads. Landscaped central reserves were most often identified for urban through roads, followed by flush medians and barriers, raised medians, and no medians. For urban distributors, most respondents identified raised medians and landscaped central reserves, followed by flush medians, and no medians. For the rural distributor category, respondents mentioned barriers, raised medians, central reserves, flush medians, and no medians. In general, barriers were seen as most often appropriate for rural roads, landscaped central reserves for urban through roads, raised medians for urban distributors, and no medians for access roads.

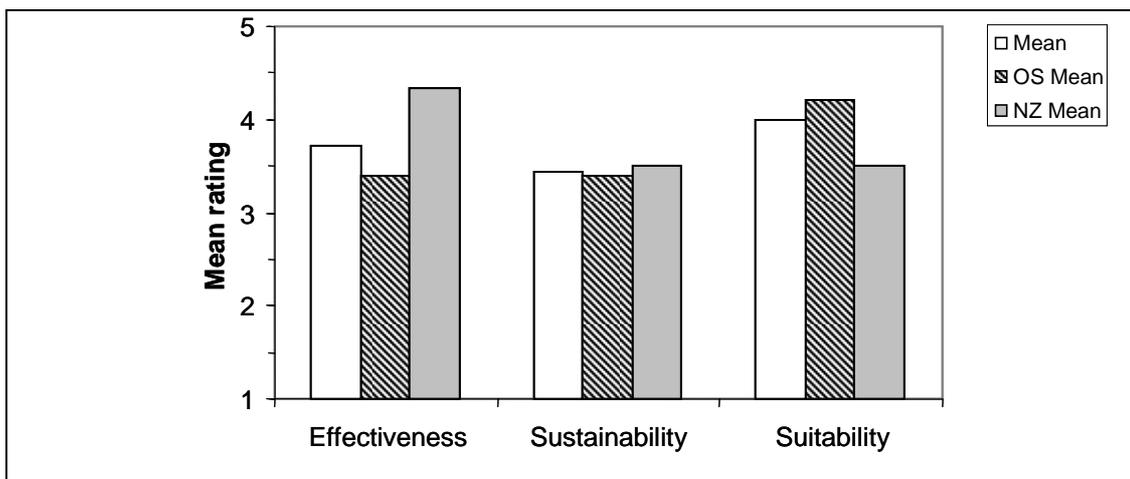


Figure 4.5 Mean ratings of central median as a speed maintenance treatment (where: 5=high, 4=good, 3=medium, 2=slight, and 1=none).

The next group of design features, cycle lanes, footpaths, and road surfaces, were rated in the "medium" range (see Figure 4.6). Although good agreement existed on the effectiveness, sustainability, and suitability of cycle lanes, some divergence of opinion occurred on footpaths and road surfaces. The New Zealand respondents rated the use of footpaths as the most sustainable and suitable of the three design features. Although the overseas respondents were in agreement with the relative suitability (user acceptance) of footpaths (presumably caused by amenity value), they judged the sustainability of footpaths to be the lowest of the three design features. Although road surface was rated as the most effective and most sustainable of the three design features by overseas respondents, the New Zealand respondents rated it the lowest of the three design features. This difference may have been caused in part by the greater range of road surfaces in the overseas respondents' design vernacular; they included a wider use of cobbled, brick pavers, open-graded asphalt, and textured asphalt surfaces (as well as use of colour) in their responses, in contrast to the simple smooth/rough distinction typical of the New Zealand respondents.

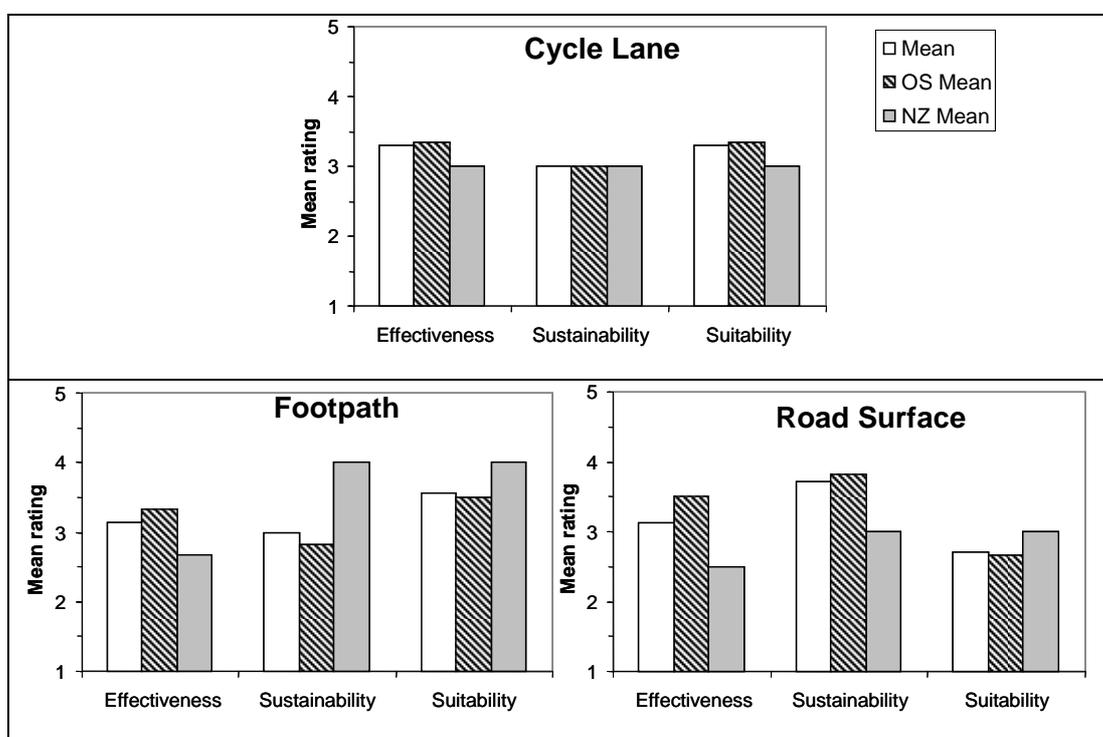


Figure 4.6 Mean ratings of cycle lanes, footpaths, and road surface as speed maintenance treatments (where: 5=high, 4=good, 3=medium, 2=slight, and 1=none).

The respondents were unanimous in saying that cycle lanes should not be associated with rural through roads. All respondents were also in agreement that cycle lanes should be a part of urban distributor roads, some of them (35.3%) saying that cycle lanes and paths could and should be physically separated from the traffic flow. There was, however, only a slight majority view (58.9%) that cycle lanes should be included in urban through roads, again with many of these respondents saying the cycle lane should be physically separate. Respondents were divided on whether access roads should have a cycle lane: 76.5% answered no, with many explicitly stating that cars and cycles should share the road space in these areas. None of the respondents felt that footpaths were appropriate

for through roads, and all but one (94.1%) felt they were inappropriate for rural distributor roads. All the respondents indicated that urban distributors should have footpaths, with a few commenting that they should be combined with cycle lanes and separated from the roadway. Most respondents felt that access roads should have footpaths, although some (17.7%) thought pedestrians could also share the roadway with cars (and cycles). Nearly all of the respondents (88.2%) felt that the road surface on access roads should be coloured and/or textured (including the use of bricks or cobblestones). Opinion on the appropriate surfaces for the other roads was more divided; 76.5% felt that urban through roads should be smooth, 70.6% felt rural through roads should be smooth, 70.6% felt that urban distributors should be smooth, and 58.8% felt rural distributors should be smooth.

The final group of design features, edge lines, centre lines, and clear zones had average effectiveness ratings in the "medium" to "slight" range, although the suitability ratings tended to be in the "good" to "high" range (one New Zealand respondent commented that suitability would be high for centre lines "as they had no real effect" on speed). The majority view was that edge lines should be solid (as opposed to dashed edge lines, 17.7%) and all respondents stated that access roads should not have edge lines. Some respondents stated that urban roads should not have edge lines either: 29.4% for urban distributors and 11.8% for urban through roads. A range of views was expressed on the appropriate centre lines with the only unanimity being that access roads should not have centre lines. A majority of overseas respondents commented that centre lines were not needed with appropriate median designs, and that if they were present they should be double lines for rural through roads and dashed lines for other roads (again with minority opinions in favour of solid or double lines for the other road categories). One respondent felt that the centre lines should also be combined with raised reflective pavement markers (RRPMs) for rural distributor roads. Other treatments mentioned by respondents as being highly effective and sustainable treatments included: median and shoulder landscaping for urban through roads; side barriers, roundabouts and RRPMs for rural through roads; raised zebra crossings and small roundabouts for urban distributors; side barriers, roundabouts, and RRPMs for rural distributors; and speed humps for access roads.

4.2.2 Treatments for speed change

The second part of the questionnaire asked the respondents to rate effectiveness, sustainability, and suitability of design features for speed change thresholds. Unlike the speed maintenance designs, however, the respondents were free to select as many or as few of the design features as they wished for each threshold type.

Shown in the top panel of Figure 4.7 is the frequency with which each type of design feature was selected for each type of speed change threshold. Signage, perceptual narrowing, and physical narrowing were most often selected as features for thresholds between through and distributor roads (selected by 12, 11, and 8 of the respondents respectively). A wider range of features was selected by the respondents for the thresholds between distributor and access roads: physical narrowing (14 respondents); road surfaces (12); speed tables and humps (12), signage (11); judder bars and rumble

mats (9) were all selected by over half of the respondents, and perceptual narrowing was selected by 8 (47.1%) of the respondents.

As can be seen in the lower panel of the figure, however, the frequency with which a design feature was selected was not a particularly good indicator of its effectiveness rating. Speed tables and speed humps were rated as the most effective design feature for both types of speed change threshold, followed by physical narrowing, road surface, and judder bars/rumble mats.

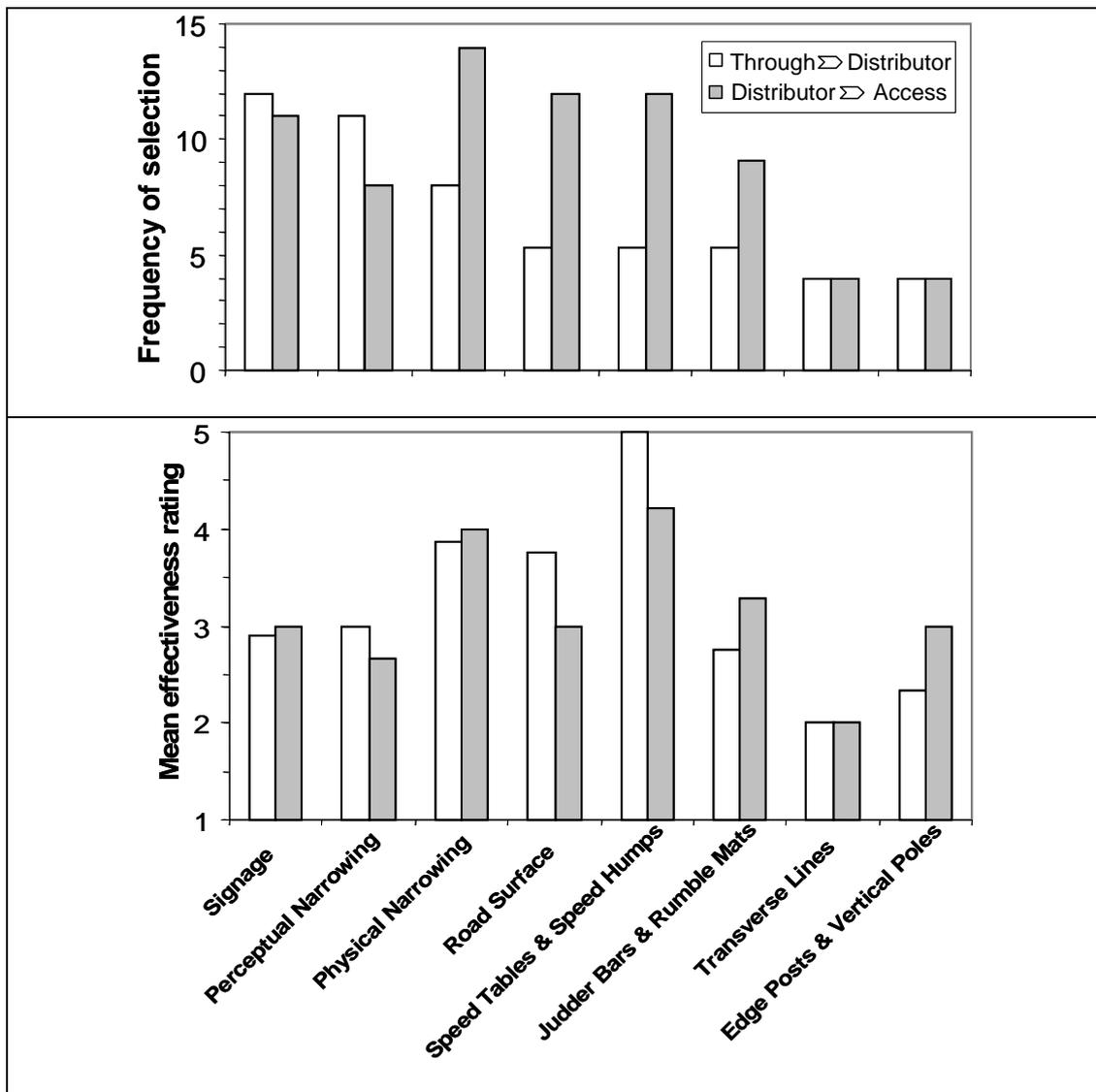


Figure 4.7 Frequency of selection and mean effectiveness ratings of design features for speed change thresholds (where: 5=high, 4=good, 3=medium, 2=slight, and 1=none).

Figure 4.8 shows that speed tables and speed humps received effectiveness and sustainability ratings in the high range, but very low ratings of their suitability (user acceptance), particularly by the New Zealand respondents. The overseas respondents' average ratings of speed humps and speed tables (as well as the frequency with which they were selected) indicated that they were judged as being somewhat more suitable for

thresholds between distributor and access roads than for through road/distributor road thresholds.

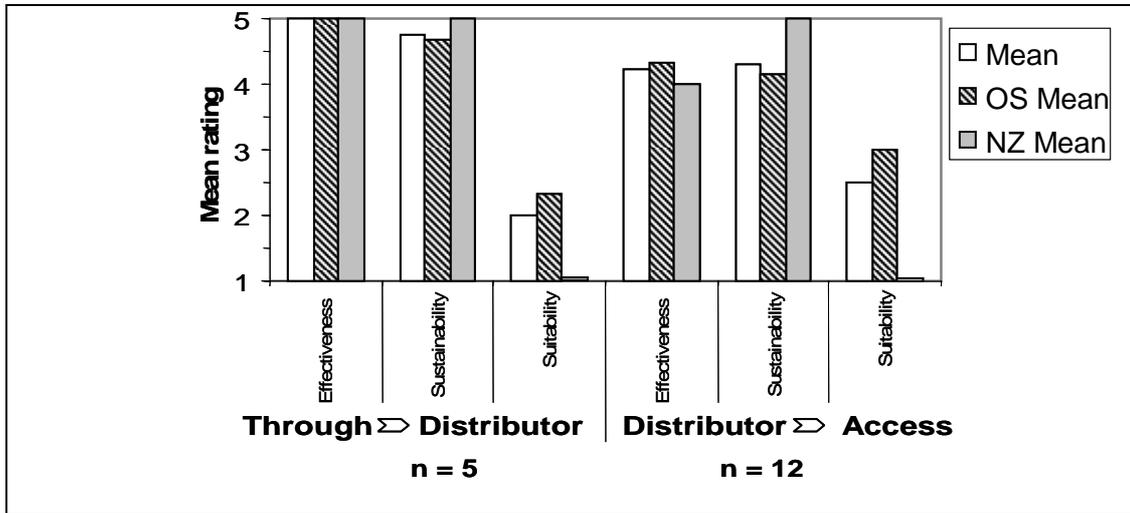


Figure 4.8 Ratings of speed tables and humps as a speed change treatment (where: 5=high, 4=good, 3=medium, 2=slight, and 1=none).

The next most highly rated speed change design feature was physical narrowing. For speed change thresholds separating through and distributor roads, the respondents most frequently identified raised central islands as the physical narrowing method of choice, followed by build-outs and chicanes. As can be seen in Figure 4.9, both groups of respondents agreed that these measures would be quite effective and sustainable, albeit with only slight levels of suitability (user acceptance). Build-outs and chicanes were the most frequently cited physical narrowing designs for distributor/access road thresholds, with two respondents noting that chicanes should be combined with speed humps at the thresholds.

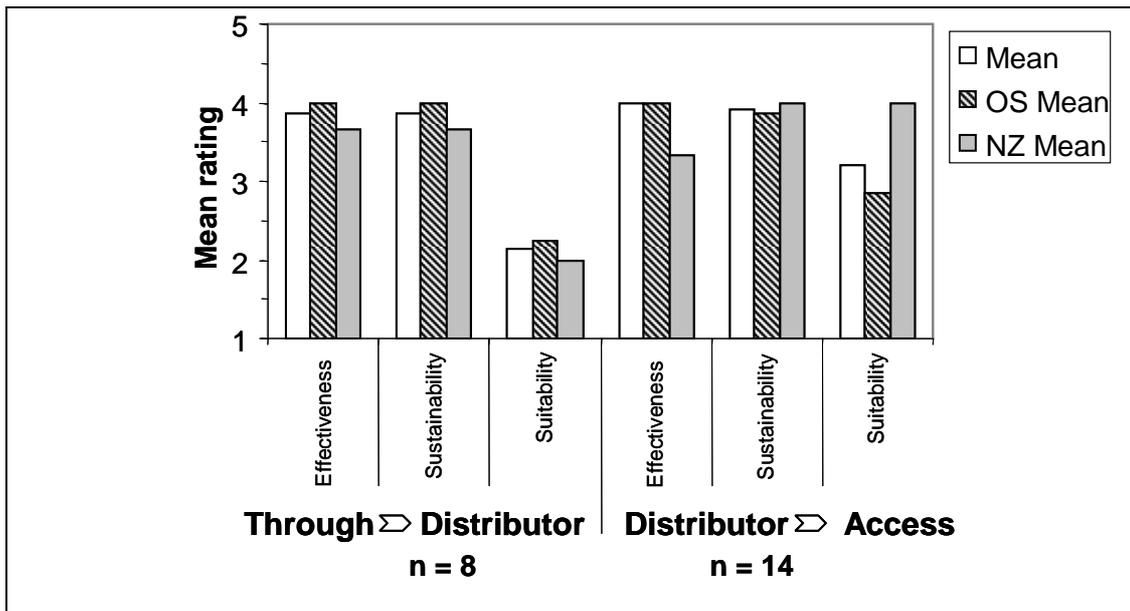


Figure 4.9 Ratings of physical narrowing as a speed change treatment (where: 5=high, 4=good, 3=medium, 2=slight, and 1=none).

Here the respondents indicated a much higher level of suitability when applied to these lower speed change thresholds, as well as having good effectiveness and sustainability. One respondent noted that the use of chicanes to narrow the roadway to a single lane can be very effective for entry into access roads but, unless priority is given to the entering vehicles, they could be stuck in the distributor road while giving way to traffic leaving the access road. Another respondent noted that when chicanes are used as a 'one-off' slow point (i.e. at through/distributor thresholds) they could be hazardous.

Road surface treatments (Figure 4.10) were rated nearly as effective as physical narrowing, although fewer respondents selected them, particularly for the through/distributor thresholds. As with the physical narrowing treatments, change in road surface was one of the most frequently chosen treatments for distributor/access thresholds and the higher levels of rated suitability reflect this clear preference. Slightly more respondents mentioned changes in surface texture as compared to changes in colour at distributor/access thresholds: 58.3% compared to 41.7%. The change in texture was always from smooth to rough and included a range of textures including brick and cobbles. Interestingly, although the New Zealand respondents had rated road surface treatments lower than the overseas researchers in the context of speed maintenance, no such difference was observed for threshold treatments. The predominant surface treatment for through/distributor thresholds was texture. Only one respondent identified changing pavement colour at these points.

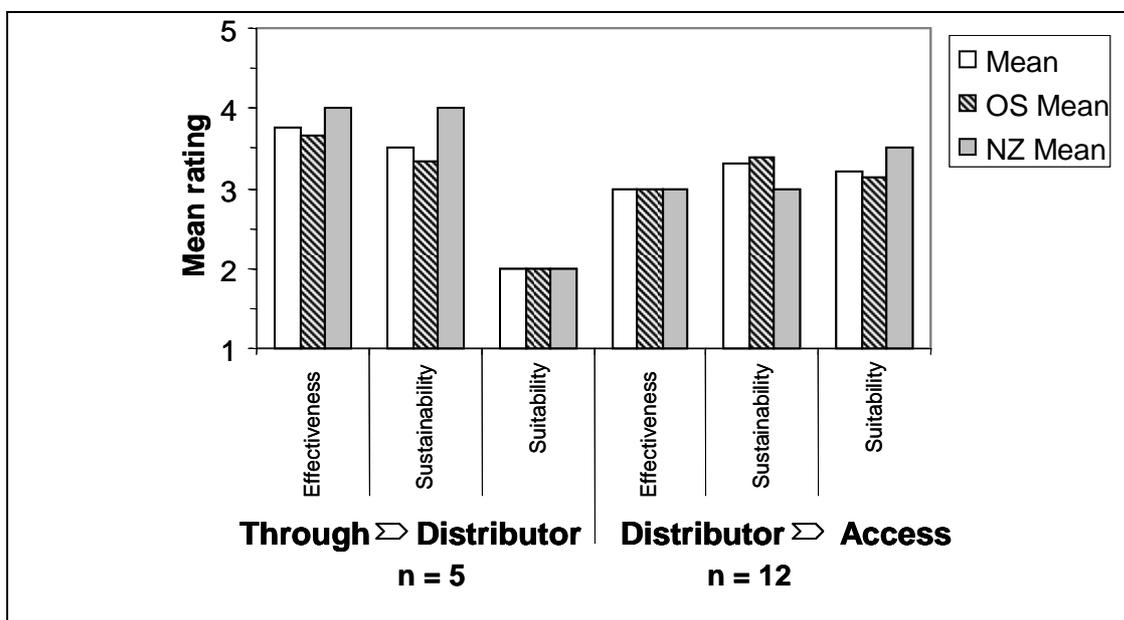


Figure 4.10 Ratings of road surface as a speed change treatment (where: 5=high, 4=good, 3=medium, 2=slight, and 1=none).

Overall, judder bars and rumble mats had the fourth-highest effectiveness ratings, but they were only sixth in terms of their frequency of selection. Figure 4.11 shows that the New Zealand respondents in particular felt that their sustainability and suitability was very low, particularly for through/distributor thresholds. Twice as many respondents identified rumble mats as judder bars (44% as compared to 22%) but 33% did not

distinguish between them. One respondent commented that these audible treatments should not be used within 250 m of homes because of the noise nuisance.

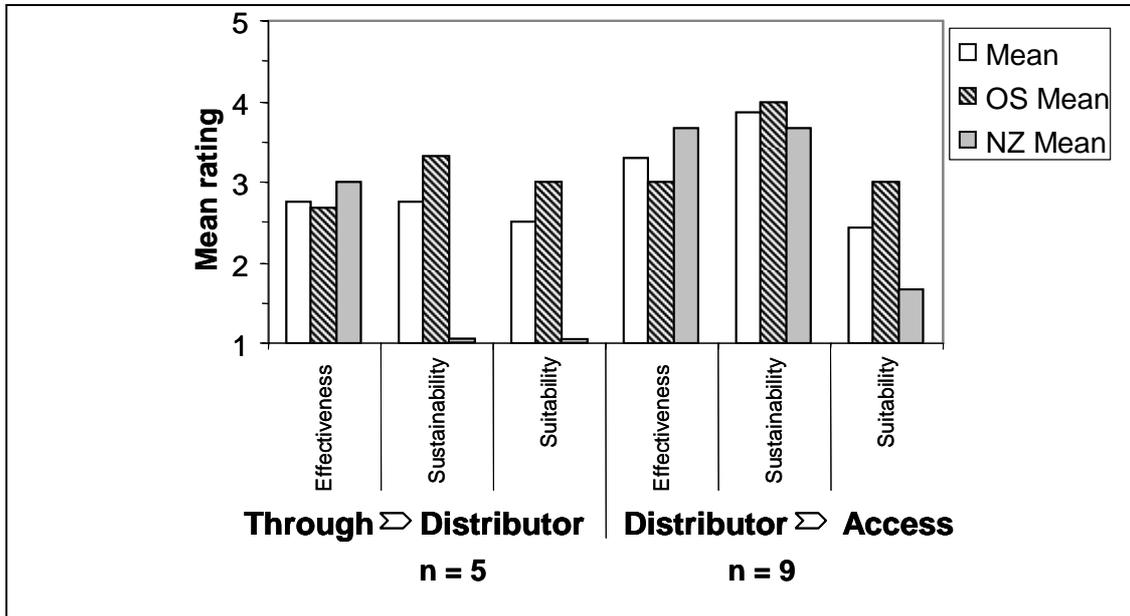


Figure 4.11 Ratings of judder bars & rumble mats as speed change treatments (where: 5=high, 4=good, 3=medium, 2=slight, and 1=none).

Signage and perceptual narrowing were among the most frequently mentioned speed change design features, particularly for distributor/access thresholds, albeit somewhat lower rated in terms of their overall effectiveness. Figure 4.12 shows the respondents' ratings of signage were nearly equal in every respect, even in terms of their frequency of selection.

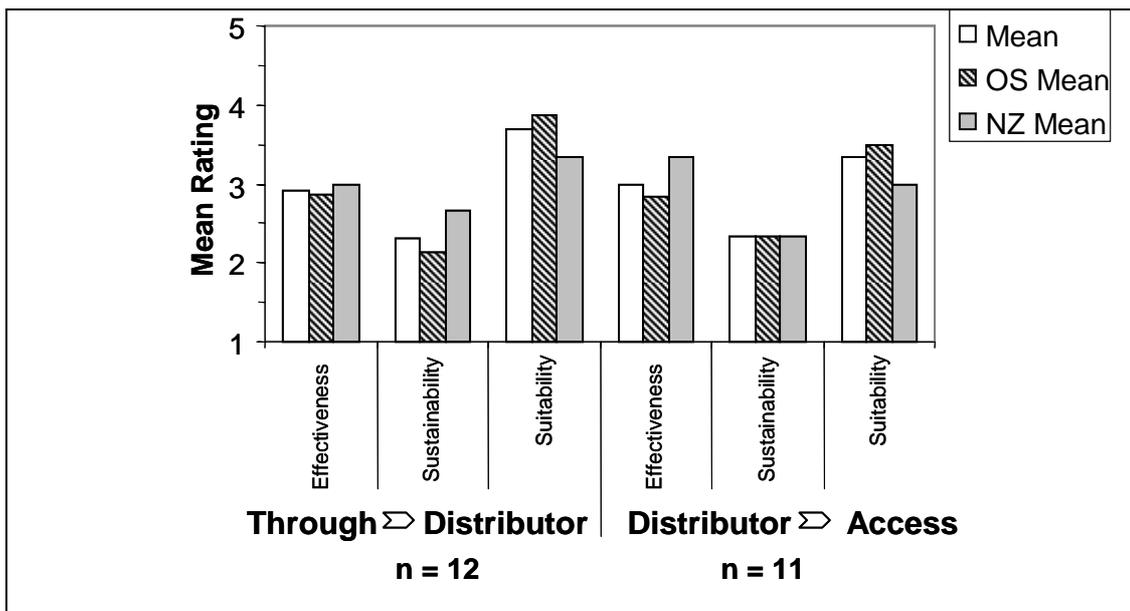


Figure 4.12 Ratings of signage as a speed change treatment (where: 5=high, 4=good, 3=medium, 2=slight, and 1=none).

In particular, signage received some of the higher suitability ratings, again particularly for distributor/access thresholds. The most frequently identified signage for through/distributor thresholds were normal-sized static signs, with three respondents (25%) suggesting dynamic or variable message signs in some circumstances. For distributor/access thresholds all respondents cited using static signs, with two mentioning using oversized signs on both sides of the road signaling entry into an urban access area of 30 km/h or lower speeds. Although most respondents felt that signs were a necessary component of speed change thresholds, their effectiveness was rated as only moderate.

Perceptual narrowing treatments were the second most frequently identified treatment for through/distributor thresholds, and like signage, were rated as highly suitable although only moderately effective (see Figure 4.13). The most commonly identified perceptual narrowing design for through/distributor thresholds was relocating the edge lines to narrow the lane (45.5%), followed by the addition of hatching to the road edge (36.4%). Other perceptual narrowing treatments identified included the use of landscaping, angle-parked vehicles, and intermittent edge markings. For the distributor/access thresholds the respondents were equally divided between the use of hatching, landscaping, parked vehicles, and intermittent edge markings. Other possible speed change treatments mentioned by the respondents included the use of "well designed" roundabouts and landscaped central islands, architectural elements (undefined), vehicle-activated signs showing the drivers' speed, and intelligent speed adaptation systems.

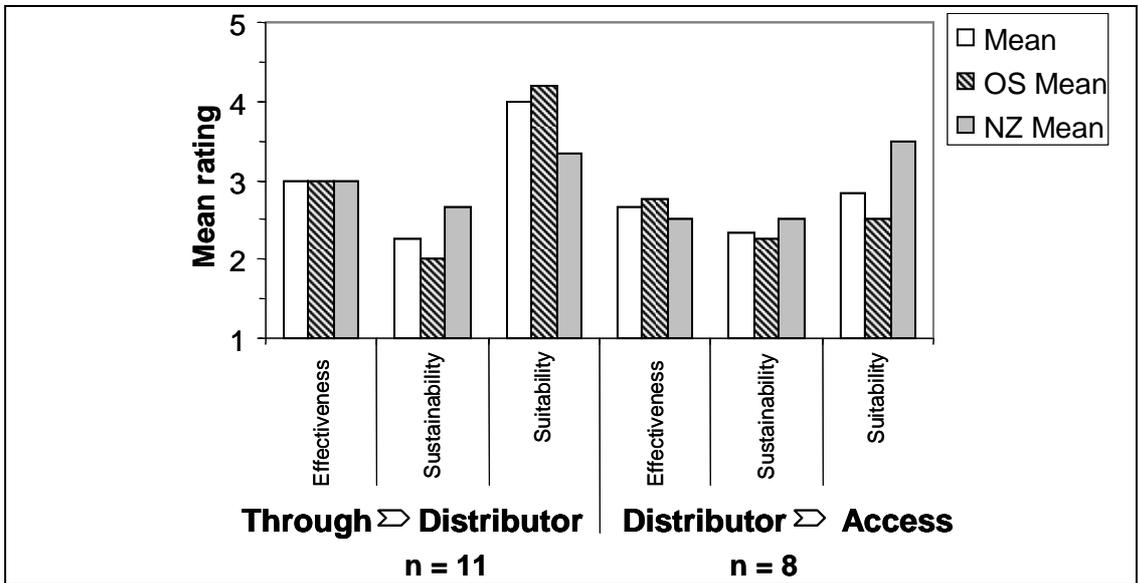


Figure 4.13 Ratings of perceptual narrowing as a speed change treatment (where: 5=high, 4=good, 3=medium, 2=slight, and 1=none).

4.3 Summary

The effectiveness ratings obtained from the survey showed generally good agreement between the New Zealand and overseas respondents. Given that agreement, some generalisations can be drawn from the respondents' answers about the most successful speed management designs.

- Across the five road categories (urban through roads, rural through roads, urban distributor roads, rural distributor roads, and access roads) the respondents identified number of lanes, lane width, and use of centre medians as having the greatest combination of effectiveness, sustainability, and suitability.
- Additional benefits were seen for the use of cycle lanes, footpaths, and road surface treatments, albeit at lower levels of effectiveness, sustainability, and suitability. Manipulating centre lines, edge lines, and clear zones were rated highly in terms of suitability (user acceptance) but as having the lowest effects on drivers' speeds.
- The survey respondents' ratings of speed change or threshold designs differed markedly depending on the speed profile of the threshold. For speed change thresholds at higher speed profiles, signage, perceptual and physical narrowing using edge lines, hatching, angle parking, and landscaped central islands were most often identified as the treatments of choice.
- For lower speed transitions, signage and physical measures employing build-outs, speed tables, and changes in road surface texture and colour were most often identified as having the highest levels of effectiveness, sustainability, and suitability.

5. Findings and conclusions

The review of the published literature on speed management focused on two distinct types of speed management treatments based on different functions:

- speed change treatments used to indicate specific locations where speed change is required,
- speed maintenance treatments that reinforce a specific design speed and aid drivers in maintaining it.

Speed change designs at village gateways or urban thresholds have commonly employed a combination of features, some physical and some visual. The location of gateways has important implications for their effectiveness; if they are not accompanied by downstream changes in road conditions such as decreases in road width or increases in urban density, the speed reductions produced by the gateway may dissipate within 250 m. At other speed change locations (typically within urban or village areas) the treatments are often less complex and involve either predominantly visual treatments (e.g. signage and perceptual narrowing) or physical treatments producing deflection (chicanes and build-outs) or discomfort (speed humps, judder bars, and transverse rumble strips) at the speed change threshold. The design features used at gateways and thresholds also differ depending on the speed change profiles at the threshold site. For example, physical measures have robust effects but may be unsuitable for reduction of speeds greater than 50–30 km/h. For higher-speed changes, threshold designs that place a greater reliance on perceptual features such as signage, visual narrowing, flush medians and hatching, and traffic medians may be more appropriate.

An even wider range of treatments for speed management (i.e. speed maintenance) were identified in the research literature, in part because these designs are intended to reinforce appropriate speeds (across a greater range of operating speeds) rather than initiate a change in speed at a specific site. Some of the most effective treatments have manipulated lane width, the number of traffic lanes, and central medians to moderate vehicle speeds. Lane widths have been manipulated physically by adding landscaped or raised medians as well as perceptually by moving the painted edge line. Roadside features such as the proximity of angle parking and landscaping also have a perceptual narrowing effect and reduce drivers' speeds. Other treatments such as changes in road surface, centre lines, signage, cycle lanes, and footpaths have also been employed, but with lower levels of effectiveness. The use of physically restrictive measures such as periodic placement of speed humps and chicanes has been reported to be effective but much less desirable because of their low acceptability to road users and residents.

One method of drawing valid generalisations from the published literature is to statistically compare individual studies' methodologies and effect sizes. This technique is known as meta-analysis: a systematic analysis of trends across different studies. Meta-analyses of the published research on speed management show that many of the treatments reviewed are indeed generally effective in reducing speeds and crashes, even in the absence of the clear differentiation of road categories that is implicit in the self-

explaining roads and sustainable safety design philosophies. The results of these meta-analyses are conclusive as speed change thresholds and speed maintenance treatments produce significant and stable reductions in:

- vehicle speeds (by up to 27%),
- the number of injury crashes (average of 15%),
- the number and severity of injuries (average of 11%).

New Zealand data on the effectiveness of the various types of speed management treatments were not readily available because of both the novelty of some of the treatments, and the admixture of treatments and data collection protocols employed when speed management treatments have been attempted here. In order to provide some indication of what effect speed management designs have on New Zealand roads, a limited observational sample examining various road widths, centre lines, and central medians was undertaken. It must be emphasised that this activity was not intended as a comprehensive speed survey. The aim was to provide a simple ordinal comparison of vehicle speeds for a few of the more robust speed management variables identified in the literature.

The results of the comparison were consistent with predictions made from the speed management literature. In the open road environment, as lane width and number of lanes increased so did the average and C85 vehicle speeds observed. In the urban (50 km/h) environment, the absence of centre line markings was associated with lower speeds when compared to lanes separated with a dashed white centre line. When lane delineation was achieved with a wide landscaped central median and accompanied by angled parking the lowest vehicle speeds were observed, presumably caused by a perceptual narrowing effect.

In the next stage of the research the decision was to use road safety researchers and practitioners as data integrators, using their experience and expertise to provide estimates of how well each type of design feature functioned in terms of its effectiveness, sustainability, and acceptability. The goal of this exercise was to refine the list of speed management designs identified from the literature and supplement the information on their effectiveness (degree of speed compliance) with some indication of how long-lasting the effects were (their sustainability) and road users' subjective reactions to them (their acceptability). The results of questionnaire ratings from a sample of 17 researchers and practitioners (4 from the Netherlands, 4 from the United States, 2 from England, 1 from Sweden, 1 from Poland, and 5 from New Zealand) showed generally good internal agreement, and good agreement with the results of the literature review. For example, comparing the survey ratings shown in Figure 4.2 to the effectiveness data in Tables 2.2 and 2.3 shows that manipulations of lane width, number of lanes, and the use of a central median are consistently identified as having the some of the greatest effects on speed compliance.

Similarly, the survey ratings of speed change or threshold designs agreed with the literature review in showing different recommendations depending on the speed profile:

- For lower speed transitions physical measures employing build-outs, speed tables, and changes in road surface texture and colour were identified as most effective, sustainable, and suitable.
- For speed change thresholds at higher speed profiles, perceptual measures using edge lines, hatching, angle parking, and landscaped central islands received the highest ratings.

Inasmuch as the survey respondents were undoubtedly familiar with the published literature (and personally responsible for a portion of it), it is perhaps no great surprise that their ratings were consistent with the literature review. The value added from their responses, however, lay in their supplementary comments and that they were able to identify specific configurations of the various speed management design features for distinct road categories. For example, one of the points emphasised in many of the survey responses was that consistency in application of speed management treatments has been shown to be very important, i.e. roads should have a consistent 'look and feel' in order to be self-explaining). Further, the respondents noted that roads with different functions (from different categories or speed profiles) should be readily distinguishable based on their appearance. Based on the survey responses, and the literature review, we were able to make some generalisations and recommendations about road design characteristics for speed management which:

- manipulate a constrained set of road features,
- are designed to elicit the correct speeds from drivers,
- allow drivers to readily recognise the road category and distinguish it from others,
- will increase homogeneity of speeds (minimise individual differences),
- will resist habituation (behavioural adaptation) and possess good road user acceptability.

Table 5.1 shows the speed management (speed maintenance) design recommendations derived from the literature and survey phases of the present research. The five road categories shown in the table:

- urban through roads,
- rural through roads,
- urban distributor roads,
- rural distributor roads,
- access roads),

were distilled from a range of self-explaining roads schemes employed overseas (principally the Netherlands and United Kingdom) and, while they may require additional refinement for the New Zealand context, they provide a useful point of departure for describing some initial speed management design recommendations.

1. In addition to making the design speed and appearance compatible within each road category, it is also desirable to have the speeds clearly distinguishable for each road category. With that goal in mind, the table shows the design speed ranges for each road category based on the recommendations received from the

researchers and practitioners. To make these design speeds even more discernable, they could be further adjusted upwards or downwards to make the differences between categories more obvious. For example, the speed for urban through roads could be anchored at the lower end of their range (60 km/h) to make them clearly different from the higher-speed rural through and rural distributor roads. Access roads could be similarly anchored at the lower end of the speed range (30 km/h) to make them distinct from the urban distributors. The principal design features to be manipulated across the five road categories are the number of lanes, lane width, and use of centre medians.

2. A second group of design features, cycle lanes, footpaths, and road surfaces, were generally acknowledged as having lower effects on drivers' speeds but, as pointed out by the survey respondents, they will afford some additional distinctiveness to the appearance of the different road categories as long as they are consistently applied (as indicated in Table 5.1).
3. The third group of features are less important as regards their influence on drivers' speeds, and although some notional design recommendations do appear in the table, they would be expected to be at a much lower priority. The 'other' category lists additional design features recommended by the survey respondents, such as landscaping and raised reflective profiled markings (RRPMs), which should be considered in developing a consistent look and feel for each road category.

With regard to implementing the design characteristics shown in the table it is recommended that a road controlling authority (RCA) first categorise or classify the roads within an area of interest and then select a minimum of three to four of the design features from the table to be applied to the roads in each category. Roads that are designated as urban distributors should all share some characteristics that make them distinct from access and through roads in the same area. For example, lane widths might be different for all three categories, but it may prove impractical to make the number of lanes consistent for all the distributor roads within an area. In that case, features further down the table, such as cycle lanes and footpaths, could be used to produce a consistent appearance for distributors and make them distinct from roads in other categories.

Generally speaking, the features further down in the table listings would be expected to have lesser effects on drivers' speeds by themselves, but they will offer considerable benefits when used to accompany and reinforce the other design features selected for the roads within a category. Additional testing of the design features, both in simulation and in field tests, would be prudent before RCAs contemplate adopting the design recommendations in any comprehensive fashion.

As with the speed maintenance treatments, some design generalisations can be made for speed change thresholds. Once again, it is desirable to manipulate a relatively constrained set of design features and ensure that those features have little or no overlap between threshold categories. However, because thresholds are placed in an underlying road context (one of the five categories or road types) their speed-change-essential features are somewhat constrained by that context as well as by the physical requirements for

safety at the speeds of interest (i.e. speed humps would not be safe for a transition from 100 km/h to 60 km/h).

Table 5.1 Generalised design characteristics for speed maintenance.

Characteristics	Road category				
	Through		Distributor		Access
	Urban	Rural	Urban	Rural	Residential
Design speed	60 - 70	100 - 110	50	80	30 - 40
Number of lanes	2+2	2+1 or 2+2	1+1 or 2+2	1+1 or 2+1	1 or 1+1
Lane width (m)	3.75	3.5	3.5	3.25	2.5
Centre median	Planted median	Barrier	Raised or planted	Barrier	None
Cycle lane	Yes (sep)	No	Yes	No	Shared
Footpath	No	No	Yes	No	Shared
Road surface	Smooth	Smooth	Smooth	Smooth or rough	Coloured and/or textured
Centre line	None (mdn)	None (mdn) or double	Dashed	Double or dashed w/RRPMs	None
Edge line	Solid	Solid	Solid	Solid	None
Clear zone (m)	1 - 10	1 - 10	0 - 6	1.58 - 8	0 - 1.5
Other	Landscaping	Side barriers & RRPMs	Raised zebra crossings	Side barriers & RRPMs	Speed humps

To promote consistency in their appearance we have identified designs for only two threshold types, based on the speed profile of the threshold, rather than all ten possible transitions between the five road categories. Table 5.2 shows the most suitable and sustainable design features for each threshold type ranked in terms of the recommendations received from the survey respondents. Although specific locations may require the use of one design feature at the expense of another, in order to maintain the distinctiveness of the threshold type they should be consistent with the categories indicated (i.e. changes in edge lines should only be used to indicate through/distributor thresholds, and changes in road surface used to indicate distributor/access thresholds). Gateway treatments (i.e. rural-urban thresholds) may employ some additional design features, but it is recommended that, where possible, their essential features be consistent with thresholds at other locations.

Table 5.2 Generalised design characteristics for speed change thresholds.

Characteristics	Threshold type	
	Through road ⇒ distributor road	Distributor road ⇒ Access road
Signage	Static signs	Oversized, both sides of road
Perceptual narrowing	Edge lines, hatching, angle parking, etc.	
Physical narrowing		Build-out (curb extension) or chicane
Road surface		Change in road texture and/or colour
Speed table		Speed table
Other	Roundabouts or landscaped central islands	

In summary, the present research provides strong evidence that speed management approaches based on psychological principles, such as those advocated by the National Road Safety Committee and the Ministry of Transport's National Speed Management Initiative, are indeed practicable and have potential for achieving considerable savings of lives and dollars in New Zealand.

The available research shows conclusively that speed management treatments (including speed change thresholds) are effective in terms of speed reduction, crashes, and injury rates. Experience overseas has shown that implementation of speed management designs requires careful attention to the key principles of functionality, homogeneity, and predictability. The present report seeks to support those principles by identifying the most promising speed management design features for the New Zealand context.

6. Recommendations

The goal of the present research was to identify and develop research findings that would enable the development of New Zealand speed management approaches akin to self-explaining and sustainably safe initiatives in other countries. The speed management approach adopted by this research programme was intended to produce road designs that:

- manipulate a constrained set of road features,
- are designed to elicit the correct speeds from drivers,
- allow drivers to readily recognise the road category and distinguish it from others,
- will increase homogeneity of speeds (minimise individual differences),
- will resist habituation and behavioural adaptation.

Further to this goal, the present report identified some of the most promising speed management treatments as shown in the design recommendations in Chapter 5.

In the light of the evidence that speed management and self-explaining roads approaches overseas have produced significant reductions in vehicle speeds, crashes, and injury rates it is recommended that additional progress towards implementation of such an approach in New Zealand should progress through the following steps:

- **Road categorisation activities.**

These begin with the establishment of one or more working groups to identify the appropriate road categories for the New Zealand roading system. Initial actions undertaken should focus on how well the road hierarchies developed in the Netherlands and United Kingdom suit the New Zealand context, and what if any changes to them need to be made.

This should be followed by application of the hierarchy to roads in one or more target districts to identify an optimal categorisation protocol and the proportion of roads that can be successfully categorised with the protocol. Consultation and information exchange with national and local RCAs should then be used to refine the hierarchy before finalizing recommendations for the Ministry of Transport, the National Road Safety Committee, and other stakeholders.

- **Laboratory studies of driver reactions to candidate treatment designs.**

These would involve the collection of objective and subjective reactions to the candidate speed management designs. For example, representative drivers' subjective reactions (estimates of appropriate speed, appearance of safety, and aesthetic ratings) would be collected for a range of still photos and video sequences depicting the speed management treatments.

Additional research on drivers' objective reactions (speed change and speed maintenance) would be collected using high-fidelity driving simulations depicting the speed management treatments. These studies would allow some greater refinement and adaptation of speed management designs based on driver reactions and feedback.

- **Field trials of area-wide implementation of treatment designs.**

These would involve application of the road classification hierarchy and implementation of treatment designs on the roads of a selected area or region. The implementation may consist of voluntary acceptance of a design guide for a region so that some initial installation of thresholds and remediation work is undertaken with the aid of a Land Transport New Zealand traffic management allocation, and future maintenance and remediation work on roads progressively brings area roads into greater conformity with the design guide. This would be accompanied by systematic data collection on the effects of the various treatments on an area-wide (rather than blackspot) basis.

- **Implementation of a speed management design guide for New Zealand roads.**

Following a successful area-wide trial, and identifications of any refinements or process modifications resulting from the trial, a speed management design guide should be prepared for New Zealand roads. Progress towards implementing the design guide might be achieved incrementally (rather than rapidly) through a series of Traffic Notes and guidelines, but may eventually take the form of an annex or supplement to the Manual of Traffic Signs and Markings (Transit 1998, 2004)..

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Appendix A Annotated bibliography

Author:	Alicandri, Elizabeth; Warren, David L.
Date:	2003
Title:	Managing speed
Journal:	<i>Public Roads</i> 66(4): 48-52

Description

This report describes current speed management initiatives in the United States ranging from road engineering and demonstration projects to enforcement. Although roads in the US are designed to carry people safely at speed, in 2000 12,000 people were killed and more than 700,000 were injured in speed-related crashes. The National Highway Traffic Safety Administration (NHTSA) estimates the cost of these crashes at \$US 28 billion. The NHTSA's Earl Hardy recommends a holistic approach including the gathering and analysing of data, setting appropriate speed limits, improving engineering and enforcement, developing innovative strategies for speed improvement and educating practitioners, policy makers and the public about effective solutions.

Ensuring that using speed cameras and enforcement officers are perceived to deter speeding rather than gather revenue and educating the public about what changing speed limits can and cannot do are also highlighted in this report.

Setting appropriate speed limits, i.e. using speeds at the 85th percentile for setting speed limits and allowing a tolerance of no more than 8 km/h, would focus enforcement on higher risk drivers.

Local roads also have higher incidence of fatalities than interstate highways and arterial routes because of differences in engineering. Highways are designed for long, fast travel providing drivers with few interruptions and a clear view of the road ahead. Local roads can have sharp curves and hills that can restrict the driver's view and also accommodate a variety of users, including pedestrians and cyclists.

When implementing traffic-calming measures, such as speed bumps and curb extensions, other safety issues caused by these measures should be taken into account.

Author:	Brewer, J.; German, J.; Krammes, R.; Movassaghi, K.; Okamoto, J.; Otto, S.; Ruff, W.; Sillan, S.; Stamatiadis, N.; Walters, R.
Date:	2001
Title:	Geometric design practices for European roads
Publisher:	Report No. FHWA-PL-01-026. Alexandria, VA, USA: Federal Highway Administration, US Department of Transportation

Description

This report summarises findings of a US delegation whose purpose was to review and document European procedures and practices in roadway geometric design and context-sensitive design. They found potentially transferable practices regarding: public involvement in planning; self-explaining, self-enforcing rural roads; design flexibility; area-wide traffic-calming measures; intersection control through roundabouts; and integration of bicyclists and pedestrians. Countries were Sweden, Denmark, the Netherlands, England and Germany.

Speeds. All these countries use a guiding speed for designing roadways and speed selection is based on road type. In Sweden 'environmental reference speed' (applied (only) to urban areas so far) is used to design roadways in such a way that it is difficult to drive above the speed limit. A roadway design philosophy common to all countries was the reliance on the physical roadway design to 'enforce' operation speeds. This concept of self-explaining or self-enforcing roads allows the Europeans to establish speed limits close to the expected operating speeds. An interesting observation was the lack of speed enforcement by the police and greater emphasis placed on other enforcement means such as road geometry and speed cameras. Reliance on geometry to enforce speed was, however, more prominent in urban settings. Another observation was a greater acceptance of lower speed limits compared with the United States.

Rural roads. High speeds on rural roads are also a safety factor for these countries. In Sweden, for example, run-off crashes on two-lane roads make up one third of all crashes on these roads (115 out of a total of 339). Percentages in other countries were similar. Head-on crashes were the second most common. Rural roads range in width from 13 m (5.5 m travel lanes and 1 m shoulders) in Sweden and Denmark to 10.5 m (3.75 m travel lanes and 1.5 m shoulders) in Germany, and 9.3 m (3.65 m travel lanes and 1 m shoulders) in England. The major cause of run-off crashes is high speed so those countries are focusing on attempts to control and reduce speeds and efforts to implement self-explaining, self-enforcing roads.

With the exception of the Netherlands, all countries visited use a common treatment on high volume rural roads, the conversion of a two-lane road to a 2+1 facility. The middle lane serves as a passing lane in which the right of way alternates periodically. Another approach for improving safety on these roads is the use of narrower lanes, which require drivers to slow down. This approach is implemented by either narrowing the roads or by visually decreasing the road width. The more widely used techniques are painting wider edge lines or eliminating the centre line.

Traffic calming. The goal is mainly to reduce speeds by forcing drivers to drive at lower speeds. Desired speed reductions ranged from a few km/h to 20 km/h. Denmark and England realised more than 60% reductions in crashes. The most effective traffic-calming means are humps, but they require precision in design and construction to achieve a comfortable ride when crossed at the desired speed. For successful implementation, an area-wide strategy is required with a systemic rather than a localised solution.

Roundabouts. Roundabouts are used extensively in all countries visited and are seen as an effective traffic control device at intersections. A Danish study of 201 roundabouts found a 71% reduction in injury crashes, a Swedish study found a 34% reduction in injury crashes at 21 urban intersections and a similar study of 200 sites in the Netherlands found a 51% reduction in all crashes and a 72% reduction in casualty crashes. Despite a significant reduction in the severity of crashes, the reduction in the overall number of crashes is sometimes not as large.

Bicyclists and pedestrians. All countries visited consider and address the needs of cyclists and pedestrians. Sweden, Denmark and the Netherlands place high levels of importance on the needs of these groups and provide separate facilities as a part of the network. Germany and England consider them in their planning. All countries have difficulties integrating cyclists into roundabouts.

Recommendations and implementation strategies

European countries generally want to design roadways that are integrated with communities and enhance the environment. This philosophy permeates their project development process, safety improvements, roadway design concepts, geometric design guidelines, public involvement and environmental commitments.

Aspects this report is looking at implementing in the United States are:

- encouraging states to consider public involvement in the earliest possible stage of the planning process,
- investigating the use of 2+1 roads,
- encouraging the use of and increasing education about roundabouts,
- identifying and documenting available literature on traffic calming,
- promoting the development of context-sensitive design through courses and presentations.

Author:	Carsten, O.M.J.; Tight, M.R.; Pyne, H.C.; Dougherty, M.S.
Date:	1995
Title:	Speed on rural arterial roads
Publisher:	<i>Report number: GR/J48870.</i> Leeds, UK: Institute for Transport Studies, The University of Leeds

Description

The aim of this research was to investigate the effectiveness of a variety of measures for reducing driver speeds on rural single-carriageway arterial roads. Treatments investigated included the use of road markings to reduce lane width or produce horizontal deflection, the use of signs both on posts and on the road surface, and the use of optical illusions to affect driver perception of speed or road width. The treatments were designed to:

- reduce speed, speed variance and/or overtaking on straight roads,
- reduce entry speeds at curves,
- reduce speed at village approaches and through villages.

Method

Three simulated roads were created: villages, bends, and a general section. Different treatments within each road type were presented in counterbalanced orders. A validation study found that speeds in the simulator were faster than those on a real road at points where speeds were not constrained by the horizontal alignment of the road.

Results

Village treatments. Only the transverse lines produced speeds significantly different from the control at the beginning of villages, producing reductions of up to 4 mph in mean speeds and 7 mph in C85 speeds. Central hatching without a 'road narrows' sign was the only effective treatment for the middle of the village, producing reductions of 3 mph and 4 mph. Central hatching *with* a 'road narrows' sign was the only effective treatment at the end of the village; reductions were 3 mph and 9 mph. In a second phase of testing, the combination of countdown speed signs and the speed limit painted on the road was effective at the start of the village, but speed reductions were not maintained through the village. Chicanes (with and without hatching) and transverse lines also worked at mid and end points, but there was no added benefit from using both treatments. The Wundt Illusion worked at the beginning of a village but not at later points. Hazard marker posts and paint colours had no effect.

Bend treatments. Transverse lines (including central transverse lines), central hatching, the Wundt Illusion, and hatching at the edges of the road, produced speeds significantly lower than the control. Speed reductions of up to 4 mph (mean) and 7 mph (C85) were obtained. Further speed reductions may be obtained by painting 'SLOW' or the triangular advisory speed sign on the road in combination with the above treatments.

General treatments. All treatments that involved lane narrowing produced speeds significantly different from the control. Speed reductions of up to 7 mph (mean), 6 mph (C85), and a reduction of 33 mph in speed variance were achieved. Combining the treatments was not useful, and results indicated that:

- continuous shoulder delineation was more effective than broken lines,
- shoulder width was not important for widths between 1.35 m and 2 m,
- type of delineation and width of hatched area was not important for lane widths between 3 m and 3.65 m,
- carriageway width was an important factor.

Overtaking. Double continuous centre lines, a central hatched area, and a narrow carriageway all significantly reduced the number of overtaking manoeuvres compared to the control. Wider shoulder and narrower lanes also produced a significant reduction, but only if overtaking manoeuvres started after the heavy goods vehicle (HGV) started to signal.

Author:	Charlton, Samuel G.
Date:	2004
Title:	Perceptual and attentional effects on drivers' speed selection at curves
Publisher:	<i>Accident analysis and prevention</i> 36(5): 877-884

Description

This paper describes a simulator experiment assessing the effectiveness of various types of warnings on drivers' speed selection on curves. The experiment compared three types of warning device across three levels of curve severity to determine which was most effective in reducing speed. To find out the relative influence of attentional and perceptual components of the warnings, drivers were exposed to different levels of a hands-free cell phone task to see if the warnings' effectiveness would be influenced by this task. The relative conspicuity of warnings presented at different locations in the drivers' visual field was tested by drivers reporting whenever they detected specific signals on roadside signs, painted on the road surface, or on the dashboard.

Method

Thirty participants with an average age of 28 took part in the experiment. The primary apparatus was a driving simulator consisting a 21 inch CRT monitor displaying coloured road scenes, a steering wheel, and foot pedal controls. The driving scenario was based on a 28.5 km re-creation of an actual road and contained road markings, signs and roadside objects. The road width was 11.4 m (4 m lanes, 1.6 m sealed verges). The simulated road was mainly rural and had a speed limit of 100 km/h with an initial speed limit of 50 km/h, then up to 70 km/h, and then up to open road speed. Oncoming traffic was present

throughout the simulation. The road contained twelve 45° curves (between 518 m and 2812 m apart). Three types of curves were included: four 45 km/h curves (45°, 184 m), four 65 km/h curves (45°, 216 m), and four 85 km/h curves (45°, 288 m). Curves were based on actual curve geometries with known recommended speeds. Each curve either had one of 3 types of warning (PW17 curve warning, chevron sight board, pavement marking), or no warning. The experiment used a 'within subjects' design, with participants exposed to three different experimental conditions:

- normal driving on the simulated road,
- cell phone repetition scenario,
- cell phone rhyming scenario.

Results

All three curve warnings slowed participants relative to the non-warning curves for severe curves regardless of the demands of a secondary task (cell phone), but for less demanding curves only those warnings with a strong perceptual component were effective in reducing speed in the presence of the cell phone task. It would appear that curve warnings that contain perceptual components or emphasise the physical features of the curve work best. The secondary task added to driver workload and drivers became less responsive to primary task demands. There was no significant difference between men and women for average speed. Younger drivers drove at significantly higher speeds throughout. There was a tendency for the cell phone conversations to have a bigger effect on young drivers and on female drivers (increased curve entry speeds), especially for more severe curves.

The researcher concluded that attentional and perceptual demands are not independent, as cell phone tasks delayed or eliminated participants' speed reduction at the 45 km/h curves compared to the baseline scenario. Curve warnings that contain perceptual components or emphasise perceptual features of the curve have the greatest slowing effect.

Author:	Charlton, Samuel G.; Alley, Brett D.; Baas, Peter H.; Newman, Jean E.
Date:	2002
Title:	Human factors testing issues in road safety
Publisher:	In Charlton, S.G., O'Brien, T.G. (Eds). <i>Handbook of human factors testing and evaluation</i> . 2 nd ed. (pp. 97-126). Hillsdale, New Jersey: Lawrence Erlbaum

Description

This paper describes a range of experiments on rural-urban threshold design, driver fatigue, and mental workload effects on driving. For the purposes of this review the focus is on the series of laboratory tests and field measurements undertaken to evaluate eleven

different rural threshold designs in terms of their effectiveness in slowing drivers to the prescribed speed.

Method

In the laboratory, simulated roads were presented to participants on a medium-fidelity driving simulator. In a complementary test, a proposed rural-urban threshold was constructed and tested in the simulator from design blueprints before its placement on the road. Field data were collected at the site before and after its placement and compared with the effects obtained for the same threshold in the simulator. One test employed an additive factors method (where a progression in design entails adding more features to the previous design) to investigate the effectiveness of alternate typical rural threshold designs. Another test was designed to isolate the effects of attention and speed adaptation by removing the speed restriction information from the various simulated rural threshold designs so that any effects of sign design and lateral proximity of the traffic islands could be attributed to perceptual factors alone.

Results

When the effectiveness of different rural threshold designs were tested in the simulator it was found that as the complexity of the rural threshold designs increased there was a concomitant increase in the effectiveness of the treatment. It was further observed that the single most effective aspect of rural threshold design was the inclusion of oversized signs. While this observation suggested that capturing a driver's attention was the key to threshold effectiveness, when the speed restriction information was removed from the oversized signs the rural threshold designs were still effective. That is, even when there was no statutory reason for drivers to slow down at the signs (i.e. no lowering of the speed limit), they still decreased their speed, presumably because of perceptual factors associated with increased edge rate information.

One of the interesting results of the test programme experiment was that, although there were significant differences in speed through the threshold, by 250 m downstream all of these significant differences had disappeared. Further, in the case of signs without speed restrictions, the tendency was for drivers to return to a speed of a greater magnitude than that at which they were originally travelling. Ultimately, these threshold designs were making participants speed up, and this is problematic. It is notable that some on-road implementations of rural thresholds have been seen to have similar effects on motorists. This suggests that the effects of a rural-urban threshold are transitory, and that to achieve full effectiveness complementary countermeasures may need to be introduced further downstream. Another finding of note was a habituation effect so that the earlier a particular rural threshold design was presented in the test sequence, the more effective it was. With repeated exposure, the thresholds' effectiveness diminished. This trend too has been noted in on-road implementations, some thresholds producing an average speed reduction of 10.4 km/h at 6 months, but only 5.2 km/h at 12 months after implementation. Finally, the simulator test of the proposed threshold conducted before its implementation on a local road predicted only slight or marginal effectiveness. Early indications from actual traffic speeds obtained after the threshold was completed suggest that the prediction was accurate.

The test programme demonstrated that the introduction of oversized signs and a restricted lateral proximity were effective in slowing drivers down. The data suggest that the introduction of oversized signs worked to both intimidate the motorist and to produce a critical increase in edge rate in peripheral vision, causing the observer to perceive an increase in speed. Further, the study noted the presence of habituation effects such that the effects of rural-urban thresholds did not persist 'downstream' from the treatments and that even their immediate effects will diminish with repeated exposure.

Author:	Coleman, Janet A.; Morford, Garrett
Date:	1998
Title:	Speed management program in FHWA and NHTSA
Journal:	<i>ITE Journal</i> 68(7): 22-26

Description

Most highways and motor vehicles are designed to be safe at the speed travelled by most motorists. Speeding, exceeding the speed limit or driving too fast for conditions, involves many factors including personal behaviour, public attitudes, vehicle performance, roadway characteristics, enforcement strategies, and speed zoning (setting a reasonable speed limit for a given section of road).

In 1995 about 43% of speed-related fatal crashes occurred on roads with a speed limit of less than 55 mph. Studies show that increased speed leads to increased injury and other associated factors, such as loss of control, reduced effectiveness of passenger safety technology and so forth. However, speed limits are often viewed as guides with few, if any, consequences when ignored. Many things that are done often reinforce the idea that speed limits are only guides, such as setting speed limits too low for the design speed of the road, the inability of enforcement agencies to enforce speeding violations, and courts not punishing offenders enough.

The FHWA, NHTSA and the Center for Disease Control contracted with the Transportation Research Board have released a report on how to set speed limits. The study included the following items:

- Speed-roadway relationships,
- Study to determine Crash Risk of Speeding,
- Characteristics of Fast/Slow Drivers to Determine Motivations for Speeding,
- Synthesis on Speed management,
- Synthesis of States Laws on Speed Limits,
- Acceptable Speed limits from Non-motorists' Perspective,
- Technology Development Area,

- Traffic Calming State-of-the-Art Report.

Enforcement methods and public education campaigns on speeding and aggressive driving also make up part of the effort to reduce speeding. The United States Department of Transport (USDOT) policy on speeding is

...to provide guidance to state and local governments to set speed limits that maximize the efficient and rapid transportation of people and goods while eliminating the unnecessary risk of crashes due to unsafe speeds.

The strategies used to achieve this should be balanced and cost effective. They are:

- ensuring that speed limits are reasonable and appropriate for conditions,
- providing information and education on the risks associated with speeding,
- understanding who speeds, when, where and why,
- using a variety of technology beyond enforcement for speed management,
- targeting enforcement where speeding presents a serious hazard and accompany this with public information, education, research and demonstration.

Author:	Comte, Samantha
Date:	1998
Title:	Simulator study on the effects of ATT and non-ATT systems and treatments on driver speed behaviour
Publisher:	<i>Working Paper R. 3.1.2. Managing Speed on European Roads (MASTER) project.</i> Finland: VTT

Description

This paper evaluates the use of variable message signs, in-car advice, automatic speed controls, and transverse bars on curve approach and negotiation speeds. ATT systems rely on *Advanced Transport Telematics* to provide relevant and timely information to drivers. The effectiveness of this information is enhanced if enforcement is initiated. If the intervention required is more than an advisory system, automatic speed control systems offer a solution. However, the solutions offered must be both reliable and acceptable and limit the effects of behavioural adaptation. This experiment, using a simulator, tested four systems designed to reduce speed on curves. The four systems ranged from advisory (transverse bars or an in-car advice system), to one which conveyed the threat of punishment (VMS), to a fully automated speed control system. A control condition was also included to act as a baseline.

It was hypothesised that by providing information and speed advice to drivers that speeds would reduce on treated curves, that the systems would vary in their effectiveness, and that negative effects such as increased distraction and mental workload would be encountered.

Method

The Leeds driving simulator, a fixed base simulator presenting 120° forward view and 50° rear view, was used. The two types of curve were one with a 100 m radius (75 m length) and the other with a 200 m radius (150 m length). Delineation was 2 m with 7 m gap for the centre line and 1 m with 3.5 m gap for the straight sections. A bend warning sign was placed 150 m before the curve. At 95 m before the curve delineation changed to a double line with one continuous line and one broken line (1 m mark, 5 m gap, 150 mm wide). At 35 m before the curve it changed to a double continuous line. Curved sections had no features apart from a crash barrier. Advisory speeds were 30 mph for the smaller radius curve and 40 mph for the larger radius curve. Driving behaviour was measured in terms of curve approach and negotiation, using speed, heading, and their derivatives. The NASA-RTLX² was administered to the 30 participants after each drive and the route was rated in terms of mental demand, physical demand, time pressure, performance, effort, and frustration level. Acceptability levels of each system were also obtained.

Results

On the curve approach only the automatic speed control achieved significantly lower (than control) maximum brake pressures, i.e. with automatic speed control, drivers were also able to better decelerate on the approach to the curve. Average speed measurements from the 30 m segments before the curve showed that, for both curve radii, similar speed profile patterns emerged. In the control condition, speed reduction does not occur until about 100 m before curve entry; at this point heavy deceleration occurs. The advisory conditions exhibit similar shapes. The automatic system exhibits a sharper curve but smooth and minimum speed is attained before curve entry. Regression analysis indicated that VMS encouraged drivers to reduce their speed earlier than other systems. This may be caused by drivers seeing the signs earlier or adjusting their speeds in order to read the signs.

For the 100 m radius curves (advisory speed of 48 km/h), each of the systems significantly reduced speeds of drivers as they negotiated the treated curve. Post hoc tests revealed that speeds in the control condition were significantly higher than in all other conditions and that the SL system had the greatest effect. The 200 m radius curves (advisory speed 67 km/h) yielded different results from the 100 m radius curves. Only the In-Car display, SL and transverse bars significantly reduced speeds. The impact of the VMS on driver speed was minimal. The automatic speed control also positively affected the lane-keeping ability of the driver. All systems were able to produce significantly lower speeds 100 m past the end of the curve.

The speed limiter received significantly lower acceptability ratings than the other systems. Apart from being seen as more restrictive, the system may also have caused participants to change gears more often. Subjective workload scores yielded no significant differences between conditions.

² National Aeronautics and Space Administration – Task Load Index- Raw Score, a commonly used workload inventory.

Conclusions

All the advisory systems reduced speeds on the order of approximately 6 km/h. In the short term, at least, traditional measures are just as effective as ATT solutions. The provision of information was particularly effective in smaller radius curves. The VMS was more successful at reducing approach speeds to the curves but was similar in performance after that. This experiment did not take into account short-term 'novelty effects'.

Author:	Department for Transport
Date:	2004
Title:	Tomorrow's roads – Safer for everyone. The first three-year review
Publisher:	London, England: Department for Transport

Description

This report documents what has been achieved in the area of speed management in England over a three-year period. The commitments of the programme included:

- publicising the risks of speed and reasons for speed limits,
- developing a framework for determining appropriate vehicle speeds,
- developing a hierarchy of rural roads based on their function and quality and creating consistency,
- encouraging local authorities to introduce 20 mph speed limit areas,
- researching a number of speed management problems,
- speed camera funding pilot schemes.

Progress to date

- Although a decrease in speeds of motorists exceeding the 30 mph speed limit has occurred since 2002, driving in excess of the speed limit remains high on all roads. This is despite a reduction in the acceptability of speeding.
- A guidance plan focusing on giving advice for setting local speed limits, 20 mph zones, traffic calming, enforcement and signing is in development.
- Research has led to a greater understanding of speed in rural areas and local authorities have begun to use vehicle-activated signs, which are proving effective on rural roads, particularly at junction and bend approaches.
- Ongoing research is being conducted into rural road hierarchies.
- Many local authorities are implementing 20 mph areas in their local transport plans.
- The re-design of mixed priority routes (routes that have a lot of vehicle, pedestrian and cyclist traffic) has been looked into and the first demonstration projects were implemented in summer 2004.

Author:	Dijkstra, Atze
Date:	2000
Title:	Transforming 'traditional' urban main roads into sustainably-safe roads
Journal:	<i>Second international symposium on highway geometric design</i> . Leidschendam, The Netherlands: SWOV Institute for Road Safety Research

Description

This paper examines the redesign of urban streets to create a sustainably safe traffic and transport system with regard to creating the 'ideal' inherently safe distributor. The main aim of the 'sustainably safe' traffic concept is to reduce road accidents. Categorising roads based on sustainable safety has been the goal of the Centre for Research and Contract Standardization in Civil and Traffic Engineering (CROW) working party, which has drawn up preliminary guidelines for categorising roads based on sustainable safety. The next step is to alter existing guidelines to fit with these recommendations.

The three main principles of a sustainably safe road system are:

- functionality (the functionality of the road must match its intended use – three road categories: through-roads, distributor roads, and access roads),
- homogeneity (the system should avoid significant differences in speed, driving directions, and mass),
- recognisability (roads should be easily recognised so that it will elicit the correct behaviour from road users).

The proposed sustainably safe road network for urban areas should not include through-roads. This leaves distributor and access roads. The functional requirements for distributor roads are the same as those for all categories in the entire road network and should be seen as an inextricable whole:

- Enlarge areas with traffic calming.
- Maximise the use of safe roads and routes.
- Journeys must be as short as possible.
- Quickest and shortest routes must coincide.
- Road categories must be easily recognisable.
- The number of possible types of design should be limited and made uniform.
- Avoid encountering oncoming traffic.
- Avoid encountering traffic crossing the road being used.
- Separate types of traffic.
- Reduce speed at potential points of conflict.
- Avoid obstacles near the carriageway.

The author describes several additional requirements for the design of sustainably safe urban distributor roads:

- the length of a road section/junction: traffic must flow smoothly,

- the structure of the road network in residential areas,
- discontinuities in the cross-section should be minimised and warnings must be given,
- redundant sight distance can lead to speeding,
- specific sign or marking for a road category helps to ensure that users know what category of road they are on.

Author:	Elliott, M.A.; McColl, V.A.; Kennedy, J.V.
Date:	2003
Title:	Road design measures to reduce drivers' speed via 'psychological' processes: A literature review
Publisher:	Report number TRL564. Crowthorne, Berkshire, UK: TRL Limited

Description

The aims of this review were to:

- identify relevant psychological theories to provide an insight into how specific road design measures might reduce driving speeds,
- aid the development of new road design innovations to reduce speed,
- review the effectiveness of differing road design measures in reducing driving speed.

Psychological principles

The theoretical principles associated with drivers' reasons for speeding included:

- *Cognitive load*: Increasing the complexity of the driving task (hence cognitive load) led to reduced speeds in several studies.
- *Utility*: Decreasing the perceived profit of an individual to speed. By increasing the negative consequences of speeding with design measures to increase, for example, physical discomfort, stress, perceived accident risk, or risk of enforcement, speeds should be reduced.
- *Perceived danger/risk*: Increasing perceived risk can reduce speed because drivers may compensate for the increase in perceived risk by slowing down to maintain their accepted level of risk tolerance.
- *Retinal streaming*: As drivers use the information in the visual periphery to estimate their travelling speed, influencing this perception could create the illusion of travelling faster than is actually the case.
- *Driver stress*: Increasing driver stress may lead to reduced speeds, but as stress is complex and multidimensional, it may only be effective for certain types of people

and have negative consequences such as reduced ability to make 'safe' driving decisions and an increase in the frequency of driving errors.

- *Fear of enforcement:* Enforcement of speeding laws is seen as very effective way of reducing speed. If there were a way to design roads that would make drivers think that they would be caught speeding, this would reduce speeds. However, measures such as speed camera signs lose their effectiveness if mobile cameras are not used.
- *Better knowledge of posted speed limits:* Concepts such as self-explaining roads would ensure that drivers know what speed they should be driving simply by the design of the roads.
- *Better knowledge of own travelling speed:* In-vehicle technologies and vehicle-activated warning signs that warn drivers when they are exceeding the speed limit might be effective for those who are motivated to keep within the speed limit.

Reducing speeds by increasing cognitive load or perceived risk can have negative consequences. Increased cognitive load may also increase accident risk. Frequent junctions, parked cars and interventions that encourage increased levels of pedestrian and cyclist activity might reduce vehicle speeds, but this type of intervention should not be used purely as a traffic-calming measure. For example, if driving speeds are not sufficiently reduced, these interventions might actually decrease safety because of the additional hazards that accompany them and because of the extra demands they place on the driver.

Road design features

A large volume of literature exists on road design interventions and their effects on vehicle speeds. The paper describes two recent studies in detail:

- The Scottish Executive Study selected 10 Scottish towns on through routes that appeared to be naturally traffic calmed as case studies.
- TRL's Research for the Highways Agency investigated perceived safe travel speeds and suggested design elements to be considered when developing traffic-calming schemes.

Other road design features described in the paper include:

- *Trees and overgrowth.* Theoretically, roadside trees may lead to increased cognitive workload or increased flow in the periphery, causing speed reductions. The effect of roadside trees on speed is debatable with evidence for 12-14% reductions in mean speed and other studies showing little or no effect on drivers' speed estimation. The approach should be used with caution as it can reduce safety.
- *Buildings.* Buildings closer to the road produce greater speed reductions. Buildings also affect estimates of travel speed by 1–3 mph. Architectural detail has also been found to be strongly correlated with assessed speeds. The effect of buildings may be caused by increased cognitive workload, the influence on the amount of flow, or buildings being associated with urban environments, that generally have lower speed limits and more pedestrian activity.
- *Statues, monuments, etc.* Interesting landmarks or architecture on the side of the road have not been found to reduce speeds, but the placement of a structure in the

centre of the road was found to reduce speeds by 5 mph. This was likely caused by drivers having to reduce speeds to negotiate the structure, and reducing forward visibility.

- *Pedestrians*. The presence of pedestrians is linked with reduced speeds because of increased cognitive workload and an increase in risk associated with speed. Some designers use this concept and create areas where pedestrians and vehicles share the pavement.
- *Carriageway width*. Carriageway narrowing has been found to reduce estimated driving speeds by as much as 7 mph. Lane width can influence driving speed by increasing the effort needed to negotiate a vehicle down a narrow carriageway. Wider roads also provide more time and space to deal with hazards. Depending on the roadside, the narrowing of a carriageway could also result in increased flow in the visual periphery.
- *Number of traffic lanes*. Fewer traffic lanes have been associated with lower driving speeds, estimates of safe travelling speed, and estimates of speed limits.
- *Build-outs*. Build-outs reduce the width of the carriageway and can range from pinch-points, where the narrowing is only slight, to full chicanes, where the effect is physical.
- *Width of pavement (footway)*. Widening pavements may increase driving speeds, but if it is done in such a way that the carriageway becomes narrower, it can reduce speeds.
- *Dual carriageways*. Medians have been found to increase speeds, possibly because of an increase in perceived safety, but when medians reduce carriageway width they are associated with lower driving speeds.
- *Central island*. Wide short landscaped medians that diverted traffic with no loss of lane width have been found to reduce speeds by 4.7 km/h. A structure in the centre of the carriageway reduced speeds by 5 mph. In both cases traffic was diverted and forward visibility reduced.
- *Parked cars*. Parked cars have been shown to reduce speeds. Parallel parking reduced estimated speeds by 5 mph, right-angled parking reduced estimated speeds by 7 mph.
- *Rough road surface*. Several research papers have found that rough road surfaces are effective in reducing speeds up to 14 – 23%. Imprinted surfacing reduced mean speeds by 4 mph.
- *Speed camera signs*. Speed camera housings and/or signs have been shown to reduce speeds even in the absence of speed cameras.
- *Vehicle-activated signs*. Signs activated when a vehicle exceeds a threshold have been found to reduce speeds up to 7 mph and have a lasting effect (3 years).
- *Warning signs*. These are generally used to serve as warning to slow drivers down when approaching a curve or hazard. Evidence exists to show that they are more effective when the message they give is reinforced by other measures and when they are visually intrusive.

- *Countdown signs.* Do not affect speeds by themselves but may be effective in conjunction with other measures, such as gateways.
- *Road roundels.* When used by themselves, mixed results, may reduce speeds by 3 mph in a 40 mph zone.
- *Centre white lines and channelisation.* Double white lines used to indicate hazards and hatching used to segregate traffic (channelisation) do not affect speeds but can also be used to narrow roads. Removal of the centre line on moderately narrow rural roads has been shown to reduce speeds by 7 mph.
- *Edge treatments.* Longitudinal red strips with hatching on edge and centre of rural road found to reduce speeds by 5.6 mph in simulator. The Drenthe treatment which replaced edge lines with 4 m-long rectangles of rough road surface chippings, reduced mean speeds by 3 km/h in an instrumented car.
- *Transverse markings.* When used on approaches to dual carriageways, roundabouts reduced crashes by 50%. Have produced reductions in speed ranging from 13 km/h to 4 km/h.
- *Rumble devices.* When used in transverse groupings can reduce speeds by 6 mph. Their effect may lessen over time since less discomfort occurs when traversed at higher speeds.
- *Coloured surfacing.* Coloured road surfacing is generally used in two ways: to emphasise a traffic-calming feature or to delineate road space. A series of buff-coloured bands incorporating a SLOW marking at an isolated development on a rural road was found to reduce mean speeds by 6 mph on a driving simulator.
- *Cycle lanes.* Cycle lanes have been found to reduce speeds by 1 mph and up to 4 mph when a cyclist was present. Cycle lanes produce even greater reductions when they narrow carriageway width.
- *Bus lanes.* Bus lanes by themselves can reduce speeds 1–2 mph, but when a bus was present speeds were found to reduce by 4 mph. As with cycle lanes, they are even more effective when they reduce the available road width.
- *Frequency of road junctions.* Increasing frequency of roadside junctions is associated with lower travelling speeds. This may be caused by an increase in perceived danger and an increase in cognitive load or driving stress.
- *Village gateways.* A gateway comprised of simple signing and marking measures may reduce mean speeds by 1–2 mph, whereas more comprehensive measures, with high visual (e.g. coloured road surfacing) impact may reduce mean speeds by 5–7 mph. Gateways with physical measures (e.g. narrowing) have been found to reduce mean speeds by up to 10 mph.
- *Home zones.* Although no one type of road user has priority in a home zone, the road may be configured to make it more favourable to pedestrians and cyclists and less favourable to motorists. Pilot data suggest substantial speed reductions may be achieved.
- *Quiet lanes.* Quiet lanes also use the concept of shared space and are narrow single track country lanes. Traffic-calming measures are kept to a minimum. Small decreases in traffic flows but little changes in mean speeds, perhaps because of a floor effect.

Conclusions

Psychological measures have generally produced smaller speed reductions than physical measures. The more successful non-physical measures tend to be visually intrusive and may be considered out of place in rural areas. Generally, more complex environments tend to be associated with slower driving speeds. Roadside activity (pedestrian or street parking) is associated with lower speeds. Combinations of features tend to be more effective than individual measures. Natural traffic calming (e.g. humpback bridges) can be very effective and very acceptable to residents. Reductions in speed can generally be linked to increased safety. However care is needed to ensure that measures that reduce speeds by increasing perceived risk do not increase the actual risk.

Author:	Fitzpatrick, Kay; Carlson, Paul J.; Wooldridge, Mark D.; Brewer, Marcus A.
Date:	2000
Title:	Design factors that affect driver speed on suburban arterials
Publisher:	<i>Project Report 1769-3</i> . Texas Transportation Institute: Austin, Texas

Description

This project investigated which geometric, roadside, and traffic control device variables affect driver behaviour on major suburban arterials. The goal was to establish direct relationships that could be used to improve the selection of design elements. Safety should be improved when the designer's intended speed matches the operating speed on a facility.

Method

In Phase 1 of the project pilot studies were conducted to identify the best data collection method. After reviewing several techniques, two were selected for pilot testing:

1. Laser Pilot Study - Laser guns were used to collect around 100 speed profiles of free-flowing vehicles as they approached, traversed, and departed six study sites.
2. Individual Driver Pilot Study- An instrumented test vehicle and six drivers were used to acquire speed profiles of a predetermined route.

Analysis indicated that the Laser Pilot Study provided more data at more sites with a greater variety of test conditions for less cost than the Individual Driver Study.

In Phase 2 speed profile data were collected from free-flowing vehicles on 24 horizontal curves and 36 straight sections at various locations (an expansion of the Laser Pilot Study). Data were analysed from 19 of the horizontal curve sites and all of the 36 straight section sites.

Results

Multiple regression analyses were used to determine which design factors had the greatest influence on drivers' C85 speeds. Speed limits were found to explain approximately 53% of the variance in both the curved and straight sections. However, as the C85 speed is frequently used to set the posted speed limit, another set of analyses were done that did not include the influence of the posted speed limit.

On straight sections of road, lane width was the only significant predictor of vehicle speeds, accounting for 25% of the variance in the regression equation. For curved sites the presence of a central median (i.e. no median, two-way left turn median, or raised median) and the level of roadside development (i.e. commercial, park, residential, or school) together accounted for 52% of variance in C85 speeds, while curve radius and deflection angle together accounted for 21% of the variance.

Recommendations

- On suburban arterial horizontal curves higher speeds should be expected when the access density is less than 12 pts/km and when a median is used.
- High deflection angles are associated with lower speeds.
- Higher speeds are associated with higher posted speed limits.
- On suburban arterial straight sections away from a traffic signal, higher speeds should be expected with greater lane widths.

Author:	Forbes, Gerry; Gill, Ted
Date:	2000
Title:	Arterial speed calming: Mohawk Road case study
Publisher:	TRB Circular E-C019, Washington, DC: Transportation Research Board

Description

This article examines the region of Hamilton-Wentworth's public involvement process and road design to address speed and mobility concerns on Mohawk Road in the town of Ancaster. Mohawk Road is a two-lane arterial roadway connecting the town of Ancaster to Highway 403 and to the city of Hamilton. The road goes through primarily residential area with some open space. The speed limit on the road was 50 km/h. Before reconstruction, speed studies found that the mean and C85 speeds in the test section were 54 km/h and 63 km/h respectively, and 67% of the vehicles in the test section were exceeding the speed limit. Traffic was busiest during the afternoon (~1,500 vehicles per hour). The road's alignment had several vertical and horizontal curves, and lane widths were as narrow as 3 m. Shoulder widths were generally deficient along the entire study section. Crash frequency in the test section was 6.2 crashes per year, well below the average frequency for this type of road.

Method

Three meetings provided a forum for the public to present their views and ideas about proposed changes to the road. Staff provided information and collected opinions from the public. The first meeting was held to identify the residents' problems with the road, their ideas for solving the problem, and features of the community that they would like to preserve. Proposed solutions were evaluated by staff and presented at the second meeting. Identified solutions were: do nothing; erect traffic signals; erect Stop signs; speed humps; reduce the speed limit; police enforcement; and speed control medians (SCMs). The effectiveness and impacts of each alternative were reviewed and the public chose SCMs and police enforcement. The public was informed about issues surrounding SCMs. The third meeting was to establish where the SCMs would be placed.

In general treatments that make roads safer also tend to increase the operating speed, so a balance had to be struck to accommodate both safety and speed control. The main changes to the conventional design features of the road were the provision of a lane width of 3.3 m, 1.0 m paved shoulders and a left-turn lane at Academy Street. Wider lanes were used to accommodate the relatively large volume of traffic. The left turn lane was constructed to deal with a 'rear end crash' safety concern. The primary purpose of SCMs is to reduce speed, but they can adversely affect safety because of the fact they are classified as a hazard and therefore they increase crash potential. The SCMs were initially designed to be 4.0 m wide (creating a 2.0 m deflection) but were changed at some locations because of property constraints (4.0 m, 3.5 m, 3.5 m, and 3.0 m). Short approach tapers (10:1) were used to create a smooth transition at 50 km/h, but make it uncomfortable if traversed at higher speeds. The SCMs break the pavement width from 8.6 m (two 3.3 m lanes and two 1.0 m shoulders) into two 4.3 m pieces. This reduction in width is intended to have a psychological effect causing the driver to reduce speed. Trees were planted in the median and on the side of the road to heighten the effect.

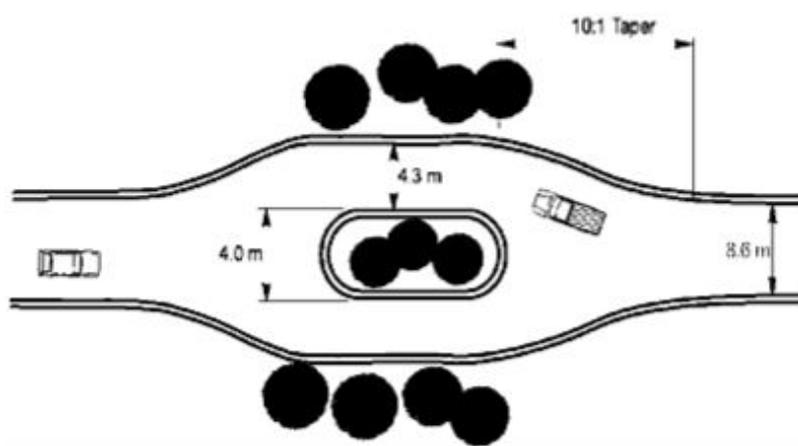


Figure A 1.1 Speed control median in Ancaster, Ontario, Canada.

Results

In order for the speed calming effort to be considered a success, it needed to achieve an actual and perceived reduction in speed without significantly compromising safety.

Evaluation was comprised of before-and-after speed and crash studies and a survey of residents. Speed data were collected using automatic counters at several locations in the test section and in a control section along Mohawk Road. Speed data were collected for 48 hours at all locations. The mean speeds for the test section dropped from 54.0 km/h to 49.3 km/h (a 9% drop) and was statistically significant at a 99% confidence limit. Speeds on the control section dropped by 3%. The percentage of vehicles exceeding the speed limit was reduced 20%, from 67% to 47% (statistically significant at 99% confidence limit) compared to the control section, which experienced a drop from 88% to 85%. Reliable crash data were not available at the time of writing. The authors concluded that SCMs are effective speed control devices for two-lane arterial roads, but long-term speed measurement and the effects of the SCMs on crash rates are seen by the authors as necessary to fully quantify measures of effectiveness.

Author:	Gårder, Per; Ivan, John N.; Du, Jianhe
Date:	2002
Title:	Traffic calming of State Highways: Application New England
Publisher:	Project UCNR13-5, Cambridge, MA: Massachusetts Institute of Technology

Description

This report describes the safety and public acceptability of implementing traffic-calming devices on major arterial routes. Only a few examples of truly traffic-calmed arterials were found world-wide. Overall effectiveness has been moderate but with a clear reduction in pedestrian injuries. Humps and vertical devices are less accepted than narrow roadways and horizontal realignments. Public is in favour of having 'other people' comply with speed limits, but do not themselves act according to speed limits. Reduced speed zones without aggressive enforcement appear to be ineffective in reducing speeds. Authors suggest that in-vehicle electronic speed governors would result in fewer negative side effects than reconstruction of roadways.

Pedestrian safety

The Swedish Vision Zero programme has the following road hierarchy to help with the reduction of pedestrian fatalities.

- Through traffic routes with a speed limit of 70 km/h or more should have only grade-separated pedestrian crossings.
- 50 km/h urban arterials should have actual speeds reduced to less than 30 km/h at every pedestrian and bicycle crossing, and to 40 – 50 km/h elsewhere.
- Residential local streets should never allow (actual) speeds greater than 30 km/h.
- Traffic-calmed streets planned for walking speed should be promoted.
- Car-free areas are to be encouraged.

Traffic calming

Woonerf developments in Delft, the Netherlands, during the early 1970s were the beginning of traffic calming. On these 'living streets' speeds are drastically reduced through reconstruction using chicanes, speed humps, neckdowns, and planters. Subsequently extended to area-wide focus, including main traffic arteries, villages, shopping streets and town centres. In Germany traffic calming is less formalised than in the Netherlands: street closures, diagonal diverters at intersections, chicanes, humps and neckdowns. Some towns wish to reduce maximum speeds to 50 km/h while others are attempting to reduce speeds to 30 km/h. Some towns have taken out curbs so that travel lanes and sidewalks are integrated in a truly traffic-calmed environment. These areas have maximum speeds of 4–7 km/h or walking speed.

Denmark also has streets similar to Woonerf with speed limits of 15 km/h and 30 km/h. The 30 km/h streets yielded a reduction in injuries of 45% compared to before periods. Similar concepts exist in Sweden, Finland, Austria and Switzerland.

Traffic calming of arterials in Europe and in the US includes the use of gateways as well as roundabouts at entry points and the construction of chicanes, road narrowing, refuge islands, tree planting, and in some cases, road humps, cushions, or speed tables. Area-wide traffic calming (involving hierarchical road system, removal of through traffic from residential streets, and speed reducing measures) reduced injury accidents by an average of 15%; 25% for residential and 10% for arterials, but many of these roads were most likely not traffic calmed (Elvik 2001). Evaluation of two traffic-calmed towns in Denmark (with traffic volumes of between 4,000 and 5,000) found crash reductions of 40% and 33% in a five year period (however authors suggest that regression to the mean may account for some of this reduction). The Berlin Moabit scheme has had an overall reduction in personal injury accidents of 41%, a 57% reduction in fatalities, 45% reduction in serious injuries, 65% reduction in pedestrian fatalities. A review of 600 traffic-calming schemes in Denmark indicated a reduction of 43% in casualties compared to untreated areas.

In Victoria, BC, a four-lane road was narrowed to two lanes, had all-day parking installed as well as pedestrian refuge islands; traffic volumes did not change, but C85 speeds were reduced from 51.4 km/h to 46.5 km/h and crashes were reduced from an average of 35.75 per year to 19 per year.

In the US, introduction of roundabouts has resulted in 80% reduction in fatal and incapacitating injury crashes (estimated as 40% reduction in fatalities & 80% reduction in serious injuries after controlling for regression to mean) and reduced vehicle speeds 15%. Traffic calming of arterial (12,000 vehicles per day (vpd)) in Maine by including bike lanes, two speed tables, and electronic signs slowed speeds by 15 mph, significantly reduced crashes, reduced traffic volumes 10–17%, 2:1 public approval, but increased emissions of volatile organic compounds (Note: chicanes & neckdowns were installed but removed immediately because of public concerns).

A study in Connecticut, US, assessed the general impact of traffic-calming devices. The study investigated the acceptance, effect, and impact on route choice behaviour of traffic-

calming devices. 183 people were interviewed in two towns in Connecticut. Overall, traffic calming was seen as an effective way to slow down traffic and make a friendlier community. Speed humps were the most commonly used traffic-calming device, but they were also the most controversial, with many residents even more unsatisfied with humps than traffic passing through. They may object to them for reasons such as noise, aesthetics, or pollution caused by extra acceleration and deceleration.

Author:	Godley, S.T.; Fildes, B.N.; Triggs, T.J.; Brown, L.J.
Date:	1999
Title:	Perceptual countermeasures: Experimental research
Publisher:	<i>Report No.CR 182.</i> Clay, Victoria: Monash University Accident Research Centre

Description

This report describes results from a series of simulator studies that tested a number of perceptual countermeasures (PCMs) in three categories:

- decelerating vehicles (PCM = transverse lines, Wundt Illusion, herringbone illusion),
- continuous roads (PCM = lane width reduction, medians, wide edge lines, rumble edge lines),
- curve enhancements (PCM = lane edge hatching, guide posts).

Method

Each experiment involved between 24 and 36 participants, male and female, of various ages, with full driver's licence and a minimum of 3 years driving experience. The simulator was a mid-range fixed-base simulator with full car body and normal car controls. The screens provided 180 degrees of forward lateral vision and 60 degrees of rear lateral vision. Road environments were rural except for Experiment 6 when both industrial and rural environments were used.

Experiment 1: Transverse lines

Transverse lines are high contrast, painted or thermo-plastic strips usually 60 cm wide and placed across the driving lane over lengths of 50-400 m and usually on the approach to a hazard. Transverse lines, herringbone patterns, peripheral transverse lines and edge of road trees were tested in this experiment. Speed at the transverse line patterns and the peripheral transverse lines sites decreased 8 km/h (normal driving) and 11 km/h (speed adapted). The only speed difference found between the full lane width and

peripheral transverse line patterns was in the first 100 m of treatment (and up to the first 200 m). Drivers initially slowed down with the tree treatment, but then appeared to compensate for the lost speed and the final 300 m was driven at a faster speed than the control road. Speeds converged during the last 100 m of treatment. Decreasing the spacing between lines did not appear to have any effect on drivers' speeds.

Experiments 2 and 3: Illusory lane width narrowing

Three herringbone patterns (backwards/constant spacing, backwards/decreasing spacing, forwards/decreasing spacing) and a Wundt pattern were used in the experiment. Participants used a scale to rate the treatment roads as being either wider or narrower seen from a plan view, as well as when seen from a driver's point of view. In the plan view the backward herringbone pattern had narrower lane width ratings than the control road. The forward pointing herringbone was rated as statistically different from the backward herringbone pattern, but not the control road (plan view). From the driver's view the patterns were not rated statistically different from each other or the control road. The Wundt Illusion was rated as narrower than the control road in the plan view, but it was not different from the control in the driver's view. The herringbone patterns did reduce speeds compared to the control road by 2.03 km/h, but the speed reductions did not differ among the three versions of pattern used. The Wundt Illusion pattern led to a 3.75 km/h speed reduction. It appears that the Wundt Illusion has no advantage over traditional transverse lines.

Experiment 4: Drenthe province edge line and centre line perceptual countermeasure

The Drenthe PCM had four speed reduction and/or safety enhancements:

- a narrow perceptual lane width of 2.25 m,
- 45 cm wide unpainted and intermittent edge lines made of gravel chippings designed to reduce visual guidance (to reduce driving speeds and increase monitoring of lane position),
- a widened intermittent centre line at 30 cm and verge post-mounted reflectors containing 80 (km/h) placed at 500 m intervals,
- '80' painted on the road after every intersection.

The Drenthe PCM reduced travel speeds by 1.88 km/h (compared to wide control road) and mean lateral positions closer to the centre line (compared to the narrow control road). There was no significant difference in lateral deviation between the Drenthe PCM and the wider control road. Participants appeared to increase the level of attention they gave to narrower lane widths and treatment lane delineation in general. Despite the steering effort results, performance on the secondary task indicated that gravel edge lines demanded a higher level of mental workload than roads with the painted edge line.

The other variations (Experiments 5 & 6) failed to produce significant speed reductions.

Authors:	Greibe, Poul; Nilsson, Puk Kristine; Herrstedt, Lene
Date:	1999
Title:	Speed management in urban areas: A framework for the planning and evaluation process
Publisher:	<i>Report Number 168.</i> Copenhagen, Denmark: Danish Road Directorate

Description

This report describes a general framework for planning, implementing and evaluating speed management programmes in urban areas. Speed management is about regulating car speed by using various methods. Planning and designing the road network in such a way that the appropriate speed is obtained is an important part of speed management.

Speed has a significant effect on road safety and even small changes in speed can lead to large reductions in accidents and injuries. A 5 km/h reduction in speed has been estimated to reduce the annual number of fatalities in the EU by 11,000 and injury accidents by 180,000.

Figure A1.2 shows a general framework for a speed management programme.



Figure A1.2 Framework for a speed management approach.

By assessing the state of the transport system, using road, accident, traffic, surrounding, and opinion data, it is possible to determine the extent of problems and identify the most important issues in a specific area.

Setting targets will provide information on goals, provide measurability and determine the amount of work to be done.

The formulation of a strategy should outline decisions or settings on economy, time plans, and traffic policies. The strategy should facilitate managing the process and make clear how future work will be handled.

Road classification (classification of a road hierarchy) forms the basis of a speed management planning process. Designing and adapting various roads and paths in the urban network helps to reduce conflicts between different functions of the road network. Roads are classified into a specific number of classes depending on the identified/desired function of each road. When evaluating which class a road should belong to, a number of criteria have to be considered. For example:

- the present function of the road, including traffic flows,
- whether buildings on the road have frontage,
- whether shops or similar facilities are facing the road,
- the number of vulnerable road users,
- the number of residential properties along the road,
- the capacity and width of the road,
- whether the road is wide enough to add bicycle facilities.

For each class road class one or more specified speed intervals are set. Speed is determined in consideration of safety, accessibility, perceived risks, etc. Speed classification examples are shown in Table A1.1

Table A1.1 Simplified example of the Danish road and speed classification system.

Road class	Speed class	Examples of road characteristic
<u>Traffic Road</u> Major roads serving through-going traffic and traffic between urban areas	90–110 km/h	Motorway, highway, vulnerable road user (VRU) not allowed, no parking.
	60–70 km/h	VRU separated from motor traffic, VRU crossings only at grade separated or signalised junctions, parking not allowed on carriageway, limited access, no speed reducers, 2–6 lanes, lane width 3.5 m.
	50 km/h	VRU separated from motor traffic, crossing facilities needed for VRU, medium access, no angle or perpendicular parking, 2–4 lanes, lane width 2.75–3.00 m.
	30–40 km/h	Cyclists mixed with motor traffic, pedestrians separated, high degree of access, no angle or perpendicular parking, 1-2 lanes, lane width 2.75–3.00 m.
<u>Local Road</u> Minor road serving only local traffic in e.g. residential areas	30–40 km/h	Cyclists mixed with motor traffic, pedestrians separated, high degree of access, 1 – 2 lanes, lane width 2.75–3.00 m.
	10–20 km/h	VRU mixed with motor traffic, 'shared' areas, motor traffic must give way, 1–2 lanes, lane width 2.75 m.

Speed management techniques

If roads in the speed management system have been classified to a desired speed level lower than the previous limit, various speed management techniques can be used. Conversely, if the speed limit increases, it must be ensured that the road layout and design is capable of handling traffic safely and efficiently. As signs stating the allowed or recommended maximum speed have proven to be inefficient in most cases, redesigning is called for. It is considered psychologically more meaningful and generally beneficial to ensure that road design and stipulated speed are clear to drivers.

Author:	Janssen, Theo
Date:	2000
Title:	Sustainable safety in The Netherlands: From launching a vision to implementation in practice
Journal:	<i>Proceedings of the Royal Society for the Prevention of Accidents 65th Road Safety Congress: 2-32</i>

Description

This paper describes the history and implementation of The Netherlands' Sustainable Safety policy, otherwise known as the self-explaining roads initiative. The Dutch government has set targets of a 50% reduction in road deaths and a 40% reduction in injuries by the year 2010. As part of achieving these targets a scientifically supported long-term concept of a considerably safer road traffic system was developed. The system is termed a 'sustainable safe road traffic system' where:

the road infrastructure has been adapted to the limitations of human capacity through proper road design, in which vehicles are technically equipped to simplify driving and to give all possible protection to vulnerable human beings, and in which road users have been properly educated, informed, and, where necessary, deterred from undesirable or dangerous behaviour. Man should be the reference standard and road safety problems should be tackled at its roots.

Adhering to three safety principles is at the core of a sustainable safe road system:

- functional use of the road network by preventing unintended use of roads,
- homogeneous use by preventing large differences in vehicle speed, mass and direction,
- predictable use by enhancing the predictability of the road's course and the behaviour of other road users.

Education should be implemented as a part of the strategy to ensure that road users are willing to have their freedoms restricted in return for a higher level of safety. Sustainable safe road transport comes down to creating three categories of mono-functional roads:

- pure through roads,

- pure distributor roads,
- pure access roads.

Multi-functionality leads to contradictory design requirements and higher risks. The implementation of sustainable safety policy followed three lines:

- to develop the concept into more practical terms,
- to implement a start-up programme,
- to carry out different demonstration projects.

Demonstration projects

The Dutch Ministry of Transport has implemented a number of demonstration projects on sustainable safety. Lessons learnt from these projects included:

- Ensure that broad support is achieved, especially from road users.
- A sustainable safe traffic system cannot depend on a single initiative.
- Monitoring is important to ensure that goals are reached.
- Ensure that industry is committed to the plan.

Functional requirements for categorising roads

The creation of a sustainable road traffic safety system must begin with a categorisation plan. Functional demands are necessary for this and a step-by-step plan must be followed to realise the required mapping of roads. Every road in an area is designated one category only, and the functional requirements for that road category are already specified. This plan must ensure a blueprint for all roads to be built in the future. Roads and streets must be designed so that they optimally meet the corresponding functional requirements. Functional requirements are meant for road authorities. They result in differentiation and the assignment of a road's function.

- Flow function. This requires a design that allows high speeds. No oncoming, crossing or intersecting traffic is permitted. Speed and mass differences should be minimal. Stationary objects alongside the carriageway should be kept at a safe distance or protected.
- Distributor function. A relatively high density of junctions which hinders flyover solutions. Applying separate frontage access where possible should separate slow- and fast-moving traffic. Crossing the verges between the main carriageway and the parallel road should not be possible. Oncoming traffic should be avoided as much as possible. Where slow and fast moving traffic intersect, driving speed should be slow, or traffic flows should be separated in time. Roads with a distributor function should prohibit traffic flows as much as possible. There should also be a minimum of hazardous obstacles. Design will vary depending on whether the setting is rural or urban.
- Access function. This is meant for roads where origins and destinations are adjacent to the road and entering and leaving these is allowed.
- Residential function. Pedestrians, cyclists and parked cars, among others, will use these areas. Therefore the roads should be designed so that the residential function

is immediately recognisable. Speeds should be limited to no more than 30 km/h in urban areas and 40 km/h in rural areas.

Based on the Dutch situation, it can be concluded that:

simply by 'upgrading' the roads that currently tend towards a flow function, even without introducing the envisaged design, and by downgrading the roads that currently have a mixed flow and access function, it is possible to realise a redistribution of traffic and hence safer roads, so that the road accident risk will be reduced by at least one third (p.16).

Operational criteria

Operational criteria result in recommendations for design and regulations that guarantee the distinction between the different road categories. It is essential that road users are able to recognise the roads, leading to predictable behaviour. The twelve principal requirements are:

- realisation of residential areas that are as large as possible,
- minimal parts of trips over unsafe roads,
- trips as short as possible,
- shortest and safest route are the same,
- prevent searching for destinations,
- make road categories recognisable,
- reduce the number of traffic solutions and make them uniform,
- prevent conflicts of oncoming traffic,
- prevent traffic and pedestrian conflict,
- separate different means of transport,
- reduce speeds where conflicts occur,
- avoid obstacles along roads.

Categorisation process

In almost every country there will be road networks that will be an autonomous result of past developments. In order to create a sustainable safe road network from these roads the following step-by-step process can be followed:

Step 1: Establish conditions and starting points from a sustainable safe point of view, taking into account conditions and starting points from other policy areas.

Step 2: Formulate goals for the residential areas and main transport modes.

Step 3: Unite and attune goals.

Step 4: Apply operational criteria.

Step 5: Adjust goals if necessary.

Step 6: Compare sustainable safe goals with goals in other policy areas.

Step 7: Deliberate and choose.

Pre-requisites for a programme

Based on Dutch experiences, the prerequisites for a successful programme are:

- Road safety experts, politicians, policy makers, and professionals must all co-operate and be part of the process.
- The direction of the programme should be seen as appealing for parliament and the press.
- Road safety organisations and lobby groups have to consider the concept as giving them new chances.
- The concept has to be appealing with no obvious drawbacks. This will reduce resistance.
- The concept has to have both short- and long-term appeal.
- The concept should be integrated into existing budget streams.
- Define the concept as a 'winner'. Look for structural possibilities to connect the concept to other activities.
- Find intelligent ways to commit stakeholders.

Authors:	Kirk, Stephanie; Hills, Brian; Baguley, Chris
Date:	2003
Title:	Roadside, village and ribbon development
Publisher:	<i>CaSE Highway design note 4/01</i> . Berkshire, UK: Transport Research Laboratory

Description

This paper deals with issues associated with roadside development in third world countries, including the placement of village markets, rest areas, and 'linear villages'. The paper describes a range of speed management and traffic-calming measures and evaluates their cost-effectiveness. Linear villages, similar to rural towns in New Zealand, have issues with traffic volumes and speed. Accident rates for these villages can be 60% higher than similar undeveloped rural roads.

Traffic-calming schemes can reduce both accidents and speed where they are implemented. These schemes include: gateway features, chicanes, road narrowing, mini-roundabouts and speed humps inside a village or at the gateway.

Approach zones, where the driver is warned that the section of road they are about to enter has higher development than the previous section of road, can employ gateways, road markings, rumble strips, and jiggle bars. Of these solutions, jiggle bars, followed by gateways, are rated as producing the best safety outcome for the cost. The least cost-effective solutions were rumble strips and rumble areas. Pavement markings were among the lowest cost solutions, but were not particularly effective by themselves.

Transition zones lie between the approach zone and the core zone. Changes in road geometry, enforcement and visual appearance help to encourage a change in driver behaviour in transition zones. The most effective solution (and most costly) were carriage way deviations in which a reduction in carriageway width forces drivers to deviate their path. Barrier curb footpaths were rated second in effectiveness (and were less costly) and are used to segregate pedestrians from vehicular traffic and produce a visual narrowing of the carriageway.

Core zones have higher pedestrian and non-motorised transport densities and more turning vehicles. Physical and visual countermeasures are used to slow drivers and warn them of hazardous locations such as schools. Round-topped humps 100-75 mm high and 3.7 m long, appropriate for 30 km/h speed areas, were rated most cost effective. Slightly more costly are flat-topped humps located where a need for pedestrians to cross exists. Warning signs were rated least effective (and least costly).

Case study: Fiji

This was a traffic-calming scheme developed in Fiji by the Traffic Accident Road Safety Unit. Photographs and brief descriptions of the treatments are shown in Figure A1.3

Approach zone



Drivers are made aware that speeds must be reduced from 100 km/h to 50 km/h. This is done by adding a gateway and a road marked bar pattern (17 bars) can also be added in front of the gateway.

Transition



The carriageway width is reduced from 7.3 m to 6.5 m. Shoulder width increases from 1.5 m to 1.9 m. Signing is normally placed before the physical restriction and rumble strips can also be added.

Core



Here is where most conflict occurs between vehicles and pedestrians. Speed humps and advisory signs have been added.

Figure A1.3 Fiji village traffic-calming scheme zones and brief descriptions.

Author:	Macbeth, Andrew G.
Date:	1998
Title:	Calming arterials in Toronto
Journal:	Compendium of the 68 th Annual Meeting, Institute of Transportation Engineers, Toronto, Canada

Description

Traffic calming is usually considered in the context of local streets. Traffic calming on arterial roads (traffic volumes ranging from 15,000 to 30,000 vehicles per day) needs to be more subtle with things such as speed humps considered in appropriate for several reasons, such as the impact on emergency services and noise levels. Toronto's arterial traffic calming has relied on three main techniques (medians, road narrowing and bicycle lanes). All of these measures have a reduction in the number of lanes in common. Speed reductions have been achieved, partially as a result of the reduced opportunities for passing (vehicle speeds are limited by the speed of the leading vehicle), and partially because the road seems narrower. Traffic calming is feasible on some arterial roads, but not all methods should be used. Traffic calming in Toronto has resulted in decreased speeds and increased pedestrian and cyclist safety.

Results

- **Medians.** The existence of a median on a street generally leads to an increase in speed, but when a median reduces the number of lanes available, it is likely to reduce speeds. Several arterial roads have been converted from 4 to 2 lane roads by using both flush and raised medians.
- **Narrowing.** Localised narrowing is a cost-effective way of reducing a four-lane road to two lanes. A section of Davisville Avenue was narrowed from 8.5 m to 6.5 m with the addition of a chicane constructed using modular traffic-calming islands. The length of the treatment was 80 m; the middle 30 m consisting of short-term parking flanked by a shorter transitional zone at each end. Parking outside the chicane was on the opposite side of the road from the short-term parking for the school. The limits of parking were defined by four traffic-calming islands, which meant that the chicane existed even if no cars were parked there. The C85 speed of vehicles at this location dropped from 50 km/h to 45 km/h, a 10% decrease. Another cost-effective way to narrow lanes is to allow parking on both sides. Lane width on Davenport Road (30,000 vehicles per day) was reduced from 3.15 m to 3 m using bicycle lanes and parking. Although bus operators were not happy, no increase in collisions was recorded.
- **Bicycle lanes.** More than 20 km of Toronto's arterial roads have been equipped with bicycle lanes in the last 5 years. Typically these have been four-lane roads carrying between 15,000 and 20,000 vehicles per day. With bicycle paths on each side, they become two-lane roads with parking available throughout the day. One such example was St George Street in the University district (15,000 vpd) where flush medians, parking, plantings, varying road surface textures, and wider

footpaths were used to narrow the road from 14 m to 11 m. The treatment was extremely popular.

Author:	Martens, Marieke; Comte, Samantha; Kaptein, Nico
Date:	1997
Title:	The effects of road design on speed behaviour: A literature review
Publisher:	Working Paper R 2.3.1, Managing Speed on European Roads (MASTER) project. Finland: VTT

Description

Proper road layout can indicate to motorists that high speeds are not appropriate and even suggest that they are impossible. On a properly designed road, drivers would reduce their speed voluntarily. In this way roads may become 'self-explaining' in that their layout explains what type of driving behaviour is expected. Current road designs (apart from motorways) do not give drivers any clues as to what type of category (urban, rural etc.) the road is in and this may lead to driving behaviour that is inappropriate for the traffic situation. This literature review identifies the advantages and disadvantages of various speed reducing measures.

- **Speed humps.** Speed humps are up to 3.5 m long and normally about 0.15 m high. The amount of speed reduction created by speed humps can be influenced by adjusting the height and length of the speed hump. For example, a speed hump of 0.075 m was found to reduce speeds to below 32 km/h. Although speed humps are useful in reducing speed in urban areas they are not popular with road users and lead to abrupt changes in speed. Emergency services and heavy vehicles may also have difficulty with them. Additional problems include increased noise level, drivers avoiding them by driving on the grass or curb, drivers driving down other roads without speed humps and speeding down these, and drivers driving at low speed still receiving a punishment. If speed humps are to be used they should have clear warning signs and an appropriate driving speed should be posted.
- **Horizontal deflection.** The amount of road over which the driver can see is important in speed judgments. Road narrowing that has little height above the road surface does not really obstruct vision. The effectiveness of road narrowing can be enhanced by the addition of vertical elements such as trees and lampposts in a gateway treatment. Road narrowing usually means vehicles are closer to the centre line potentially causing problems with sideswipe collisions.
- **Roundabouts.** Roundabouts are effective in breaking up large stretches of road that might otherwise encourage speeding. Roundabout effectiveness is mediated by the extent to which drivers are forced into a roundabout manoeuvre. Mini-roundabouts at intersections have been found to reduce accidents significantly.
- **Village gateways.** Village gateways were found to be effective if stringent measures were used in their design. These measures should be aimed at physically

reducing speed and should be applied at regular intervals to maintain speed reductions. Design and siting of measures need careful consideration. Wider roads appear to be more suitable for gateways where more opportunity exists to provide horizontal deflection such as narrowing and central islands. Advance warning signs may make the measures more effective by influencing drivers who do not know what they will encounter. Yellow poles to give a road narrowing impression, a 50 km/h sign, different coloured pavement and a central island 140 m before the gateway have resulted in a mean decrease in speed from 77 km/h to 66 km/h (still over the 50 km/h speed limit).

- **Lane width.** Lane width leads to increased influence of other traffic and roadside obstacles and more effort must be placed into steering and as a consequence driving speed usually decreases. Consistent results of narrowing: speed reductions of 5.7 km/h for every metre of lane width reduction beyond 4 metres; higher speed for 3.4 m wide lanes than for 3 m wide lanes on two comparable bridges. However, the method used to achieve reductions in lane width is important; when a vehicle-free central area between lanes was installed to reduce lane widths from 4.6 m to 3.6 m, speeds increased 7.5 km/h (which the author suggests was caused by improved visual guidance).
- **Pavement width.** Driving lanes and extra pavement strips on both sides of the road contribute to the total amount of pavement width. This extra space decreases drivers' uncertainty and usually increases speed. Increased pavement width has been found to increase speed: mean speed with a pavement width of 6 m was found to be about 80 km/h and with a width of 8 m speed increased to 90 to 100 km/h.
- **Lateral clearance.** Lateral clearance is the space between obstacles to the left and right sides of the road or the space that is visually available between obstacles (front gardens, overgrowth, lampposts, ditches beside the road, etc.). A reduction of lateral clearance from 30 m to 15 m decreases speed by only 3%, but decreasing lateral clearance to 7.5 m reduced speed by 16%. The effect depends on the kind of shoulder (soft or hard) and the amount of danger associated with leaving the road (e.g. hitting a tree). By reducing the spacious image of an urban street the proportion of drivers driving over the speed limit reduced from 81% to 58%.
- **Road markings.** Road markings can cause increases in speed since they reduce uncertainty by providing visual guidance. Transverse marking patterns and decreased spacing between the centre-line markings can decrease speed as this gives the illusion of increased speed. Herringbone markings have also been found to reduce speed. Transverse markings can reduce speed variance. Some uncertainty exists about the durability of speed reductions, which may last only weeks or months. Longitudinal road markings have not been found to reduce speed by themselves, but if used to reduce lane width speed decreases have been found. A white edge line separating parked cars from driving lane reducing lane width from 5 m to 3.7 m and reduced speeds by 5%.
- **Buildings and overgrowth.** Buildings, trees, and parked cars next to the road have been found to reduce speed (12-14%) and the distance of housing from the road has been found to be positively correlated with urban car speeds. The number

of visible entries and exits on the right side of the road and the amount of overgrowth has also been found to influence speed. More entries and exits equal lower driving speed. The amount of overgrowth can serve as a guide, increasing speed, or, if there are groups of bushes or trees (not a continuous wall of overgrowth) they may increase the amount of flow in the peripheral vision and speed may decrease. Rural roads with no prominent features result in an underestimation of one's driving speed whereas tree-lined roads do not. Distraction and limited visibility have been cited as problems with a large number of buildings or trees on the side of the road.

- **Road surface.** Types of roughness include longitudinal roughness (e.g. bumps), transverse roughness (e.g. tracks in the road), road surface irregularities (e.g. potholes) and roughness caused by road material (e.g. a brick road). Road roughness can explain 91% of variation in driving speed and produces a 14-23% reduction. Increases in speed of 2.6 km/h occur after resurfacing. When a smooth surface was followed by rough, a mean speed reduction of 5% occurred.
- **Peripheral vision.** Restricting the amount of peripheral information available may lead to an underestimation of driving speed. Twenty-five degrees of peripheral visual stimulation led to more accurate speed estimation than 25 degrees of frontal visual stimulation. Speeds exceeding 2 radians/second (rad/s) in peripheral vision (at about 30 degrees left and right of the fovea) are considered very disturbing. Road users usually choose their speed and position on the road so that the angular speed of objects in peripheral view does not exceed this value. These results seem to indicate that the layout of the periphery (density of information) should be designed in such a way that exceeding the speed limit exceeds this value of 2 rad/s.
- **Rumble strips.** Transverse rumble strips are an effective measure in reducing speed and accidents before entering areas such as intersections and other areas where care is required. They produce uniform, moderate, and durable (up to one year) deceleration. When used in front of pedestrian crossings no decrease in speed occurs, but they may have an alerting function. The downside is that they cannot be avoided and have negative consequences even at lower speeds. The Drenthe treatment using continuous rumble strips on edge lines found the best results were for a narrow lane width of 2.25 m, with extra space available aside the lane of 0.70 m.

Conclusions

Most road design adaptations lead to the best speed reducing results if they are combined with other adaptations in road design. By providing drivers with the idea of increased risk for increased speed, driving speed can also be reduced. Optimally, perceived and actual risk should correspond. Reducing lane width and placing obstacles on the side of the road lead to increased accident risks so care should be taken to minimise the negative consequences of these measures. An optimal design would be a road that leads to appropriate driving behaviour without compromising safety. This may be achieved with self-explaining roads. These roads should be designed in accordance with subjective road categories and use knowledge on the effect of design characteristics on subjective road

categorisation. If the road layout explains what type of road the driver is driving on unintentional speeding may disappear. In that case anyone who speeds is doing so intentionally and enforcement may be appropriate.

Author:	Nije, Kees; Talens, Hillie
Date:	2001
Title:	Traffic calming: Implementation of a philosophy
Journal:	<i>ITE Journal 71(3): 34-38</i>

Description

This paper describes implementation of the sustainable safety approach into the Netherlands' design and layout of roads by the Centre for Research and Contract Standardisation in Civil and Traffic Engineering (CROW). The harmonisation of the function, design, and use of roads is essential when considering their layout and arrangement. When design and function match, road users will use the road as intended. A sustainable safe infrastructure is based on three essential safety principles:

- functional use: preventing incorrect road use,
- homogenous use: prevention of large differences in speed, direction and volume at moderate (50 km/h~70 km/h) and high speeds (>80 km/h),
- predictable use: prevention of uncertain behaviour by road users.

CROW's method for categorizing existing and future road systems consists of three steps:

- functional criteria for the system,
- operational criteria for road categories,
- design criteria for every category.

Functional criteria

To classify a road system safely, the number of permitted road categories must be restricted. Based on previous experiments, safety principles and experience, there are two safe road categories: roads designed for high-speed travel (through roads), and roads that have access to housing etc. (access roads). Roads between these two extremes are called distributor roads. Along with the three categories are 12 functional requirements derived from safety principles. The first four are requirements that can be set for a road system (network). The following three are applicable to routes. Numbers 6, 7, 8 and 12 are important for road sections.

1. Create connected residential areas that are as large as possible.
2. Reduce driving on relatively unsafe roads as much as possible.
3. Keep trips short.
4. Have the safest and shortest routes converge.

5. Avoid search behaviour.
6. Make road categories recognisable.
7. Limit the number of traffic solutions and make them uniform.
8. Avoid conflicts with oncoming traffic.
9. Avoid conflicts with cross traffic.
10. Separate types of vehicles.
11. Reduce speed at potential points of conflict.
12. Avoid obstacles along the carriageway.

Operational criteria

These are intended to clarify the differences between categories for road users. In a sustainable safe traffic system all users are always aware of the type of road they are on and what is expected of them. The article provides several examples of operational criteria for various road types. The design elements listed below are specified in the operational criteria for each road type. The items in italics are 'essential characteristics' as identified in a comprehensive study conducted by the Netherlands Organisation for Applied Scientific Research and the Institute for Road Safety Research (SWOV).

Design elements (essential elements in italics)

Colour and texture of pavement	Road access
Crossing on road sections	Parking
Public transport stops	Lighting
Slow-moving motorised traffic	Bicycles
Speed control measures	Mopeds
Statutory maximum speed limit	Signs
Transition of road category	Obstacle distances
<i>Carriageway separation</i>	<i>Provision for breakdowns</i>
<i>Longitudinal road markings</i>	<i>Carriageway design</i>
<i>Intersection principles</i>	

Design criteria

Design requirements are based on functional and operational requirements for sustainably safe roads. Design recommendations for roads outside built-up areas, area boundaries, and roads in built-up areas are listed below.

Through roads outside built-up areas:

- full longitudinal markings and non-traversable carriageways,
- maximum speed 100–120 km/h; connections are only exit and entrance roads,
- advance directional signs and junction signs,
- high quality asphalt or pavement,
- no access to properties,
- no stopping or parking,

- bus stops are separated from the carriageway and combined with rest areas where possible,
- emergency lanes,
- obstacle distance of 10 m at 100 km/h and 13 m at 120 km/h,
- no cyclists or slow-moving motorised traffic,
- no speed-inhibiting measures.

Distributor roads outside built-up areas:

- characterised by broken edge lines,
- maximum speed 80 km/h on road sections and 40 km/h through intersections,
- depending on the number of lanes, traffic volume and spatial possibilities, a median with continuous edge markings or two continuous lines with vertical traversable elements in between can be chosen,
- number of lanes depends on traffic volume and desired level of service,
- on long two-lane road sections, short passing lanes directly after intersections are an option,
- directional signs, advance directional signs,
- asphalt or concrete surface,
- crossing via signalled intersection or roundabouts,
- access to property via parallel access roads,
- pedestrian or cyclist at-grade crossing with physical speed inhibitors,
- obstacle distance of 7 m,
- driveable shoulder in case of breakdowns,
- no cyclists,
- slow moving traffic should use the access road.

Access roads outside built-up areas:

- single carriageway without lane markings and possibly visually narrowed,
- carriageways should be less than 5.5 m wide,
- wider lanes can be marked by broken lines,
- speed limit 60 km/h or below,
- 30 km/h maximum at intersections and connections,
- physical speed inhibitors are desirable, but not at intersections; they should be placed just before intersections,
- distance for obstacles at 4 m,
- pedestrian access provided in connection with speed-inhibiting measures.

Area boundaries:

- An area boundary is designed with the purpose of informing road users that a different speed is required because they are entering or leaving an urban area.

- At the location of an area boundary, road users should be able to see buildings. The location of the boundary is related to the expectations of road users.
- The area boundary is easily recognisable.
- The ambient characteristics support the location and the technical design of the boundary. The number of solutions is limited and uniform.
- The design brings about the desired (speed) behaviour of road users.
- The difference in maximum speed between the situation in and outside built-up areas is no more than 30 km/h.
- Transition occurs in phases when the difference is greater.
- Drivers must be able to negotiate traffic measures at area boundaries without difficulty. The traffic function determines the design of the area boundary (function precedes design).

Distributor roads inside built-up areas:

- speed limit 50–70 km/h,
- road markings in combination with carriageway separations are important distinctive characteristics for road users,
- two lanes with a traversable carriageway (with difficulty),
- asphalt or concrete,
- connections to property and premises not permitted,
- crossing should be combined with intersections,
- parking in lanes on a parallel road,
- separate bus bays,
- speed inhibitors can be used at intersections.

Access roads inside built-up areas:

- maximum speed limit 30 km/h,
- no road markings,
- preferably brick pavement,
- all types of traffic use the road,
- parking spaces on the road,
- buses and trams stop on the carriageway,
- lampposts preferably no higher than 4 m,
- speed inhibiting measures at various logical points (e.g. intersections).

Conclusion

Sustainable traffic safety is a preventative approach in which traffic safety is part of spatial planning, road user behaviour and infrastructure design. It involves integrating infrastructural provisions, traffic education, and communication with residents.

Author:	Retting, Richard A.; McGee, Hugh W.; Farmer, Charles M.
Date:	2000
Title:	Influence of experimental pavement markings on urban freeway exit-ramp traffic speeds
Publisher:	<i>Transportation Research Record 1705 (00-3272): 116-121</i>

Description

This paper examined the impact of an experimental pavement markings intended to reduce speeds on freeway off-ramps with horizontal curves. The experimental marking pattern narrowed the lane width of both the curve and a portion of the tangent section leading into the curve.

Method

The study was conducted at four urban freeway exit ramps. All had advisory signs and the pavement markings were intended to reinforce these signs. A before-and-after design with a control comparison was used. Traffic speeds were measured 6 weeks before installation and 2 weeks after installation at both the control and experimental sites. The experimental pavement markings narrowed the lane width of the curve and a portion of the tangent section leading to the curve by use of a gradual taper of existing edge-line or exit gore pavement markings or both.

Results

- Speed data were analysed for 84,188 passenger vehicles (average of 5,262 per site) and 3,557 large trucks (average of 222 per site). Summary measures included mean speed, C90 speed, and percentage of vehicles exceeding speed thresholds. Logistic regression models were used to measure the effect of the pavement marking on the likelihood that a passenger vehicle exceeded the advisory speed by 10 mph (16 km/h) or that a large truck exceeded the advisory speed by 5 mph (8 km/h). Speed thresholds were set higher than advisory speed limits because vehicle speeds were measured before the point of curvature. At the Virginia B ramp, large truck speeds were not recorded due to an unexplained decrease in the number of large trucks.
- Passenger vehicle speeds were significantly reduced at three out of the four sites (the New York ramp and two Virginia ramps). Passenger vehicles exceeding the posted speed by more than 16.1 km/h (10 mph) decreased from 83% to 66% at the New York ramp, from 40% to 27% at Virginia ramp A, and from 27% to 21% at Virginia ramp C.
- Large truck speeds were significantly reduced at three out of the four sites. At the New York ramp the proportion of large trucks exceeding posted speeds by more than 8 km/h (5 mph) decreased from 77% to 55%. Virginia ramps A and C had reductions from 35% to 18% and 49% to 30% respectively. At the control and upstream sites, speeds either remained the same or increased.
- Finally, the researchers noted that the research was limited by a small number of ramps and the inability to distinguish short-term effects. They also noted, however, that even short-term effects are useful for warning drivers unfamiliar with the road.

Author:	Silcock, D.; Turner, B.; Walker, R.
Date:	2001
Title:	Development of a rural road hierarchy for speed management
Publisher:	Interim Report No 2. London: Department for Transport

Description

This report describes the activities to be undertaken in the development of a rural road hierarchy for the UK. The primary objective is to reduce casualties by creating a framework for reducing inappropriately high speeds in areas where this is a concern. Currently most non-motorway rural roads are set at 60 or 70 mph. However this speed limit caters for different roads with different purposes, even when actual speeds attainable on the road are much lower. The current speed limit system causes confusion for motorists as speed limits other than 30 mph or 70 mph are not well understood. Speed limits are also inconsistently applied, which is one factor leading to their abuse. The road environment also has a major influence on speed and, as a result, lowering speed limits does not always lower vehicle speeds. In rural areas, traffic calming and signage is said to detract from the rural environment. The current classification system is unsuited to categorising roads in terms of usage and in rural areas; this can lead to inappropriate speeds and anxiety for pedestrians and other road users. A new hierarchy for rural speed management could assist drivers by consistent application of speed limits. It could also lead to a reduction in casualties and reduced anxiety for pedestrians and other road users.

Examples of road hierarchies

The concept and use of a road hierarchy is not new, with countries like the Netherlands implementing the sustainable safety approach and other guidelines available on creating hierarchies. In terms of implementing the Dutch sustainable safety concept, it must be stressed that there are large differences between the rural environment in the UK and in the Netherlands. Many distributor roads in the UK are also used as access roads and the Netherlands have a greater coverage of motorways. Many important lessons from the Dutch experience, such as the problems encountered and how they were overcome, time scales, costs and the need for consultation, can be learnt. In the development of a road hierarchy for speed management, other forms of road hierarchies need to be taken into consideration. This does not mean that existing hierarchies will govern the new hierarchy, but that it must co-exist with them.

Road users' expectations

Different road users will have different expectations depending on how they are using the road. Locals in a village on a main route will expect to be able to walk safely in the village, but when taking a journey outside the local area, be able to drive at a reasonable speed. As a result, the working group felt that drivers' expectations of the operating speed and speed limits that would prevail on a road are closely correlated with its current classification, especially for A roads and motorways. In situations when desired speeds are below drivers' expectations, then re-classification would need to be considered. Conflicting expectations and the practicalities for key players must also be taken into

account, particularly for those who will need to implement and enforce the new hierarchy. The following key points have been established for defining a template for the rural road hierarchy:

- The hierarchy must be functional, relating to what roads are used for and by whom. 'Where this conflicts with current classification it is implied that the classification should be changed.
- Balance is required to meet the needs of all road users.
- The application of the hierarchy must be consistent.
- The hierarchy should be largely self-enforcing.
- The timescale and costs involved in the implementation of the hierarchy need to be considered.
- The speed management hierarchy is mainly concerned with existing roads, but must also include new roads.
- A small number of tiers within the hierarchy is desirable, in order to make the system simple and easily understood. Three is the preferred number.
- Although it is not essential for the speed management hierarchy to be based on speed limits, few would understand it if it was not.
- Roads should be subject to periodic review to cater for changing conditions.

Proposed template for a speed management hierarchy

The proposed rural road hierarchy has three tiers:

- **Tier 1:** Through roads of national or regional importance that give priority to the safe and efficient movement of vehicles. Acceptable speed limits of 60 mph for single and 70 mph for dual carriageway roads. In exceptional cases lower speed limits may be appropriate (e.g. because of poor road geometry).
- **Tier 2:** Mixed roads that cater primarily for motorised traffic, with limited numbers of vulnerable road users and occasional access to properties such as farms rather than frequent access to residences. A suggested maximum speed is 50 mph with a 30 mph speed limit in the villages. Junction treatments may also be required as junctions are a source of accidents. Where there are vulnerable road users, physical separation should prevail, with special facilities at isolated locations.
- **Tier 3:** Local roads that are primary for access, particularly roads through villages, and where vulnerable road users are to be expected, and without physical separation. Maximum speeds could be 40 mph, and 30 mph or less in villages. In some cases, such as in quiet lanes or restricted carriageway widths, a speed limit of 20 mph is appropriate.

Protocol for assigning roads within the hierarchy

Several mechanisms could be used to formalise this allocation of roads to differing tiers within the hierarchy:

- a flow chart approach,
- a points scoring system,

- a 'look-up' table, based on a priority order of criteria.

A flow chart approach has clarity, but may be inflexible. It can also be used to identify physical or enforcement measures that may be needed to ensure that the speed limits for that level in the hierarchy are not exceeded.

A points scoring system would require an agreed list of criteria, against which points would be scored. The total number of points scored would determine the tier to which a road is allocated.

A 'look up table' approach would use a similar set of criteria to the points system. Certain criteria would have the effect of automatically allocating a section of road to a particular level, irrespective of other criteria.

An unambiguous protocol, still allowing for local flexibility for unusual situations, is necessary to ensure that the road network is consistent. The protocol for assigning roads within the template should have weightings to allow roads of certain descriptions to override other considerations, and automatically be designated to certain levels within the hierarchy. The mechanism for co-ordination across local authority boundaries in the application of the protocol needs to be considered. Some roads will not fit naturally within the criteria. In these locations intervention will be needed to upgrade the road or control speed.

Implementation

The implementation of the three-tier system could present practical problems. The top and bottom tiers of the hierarchy will be easier to achieve than the middle ground. The group of roads involving mixed use may be large, and will take more time and resources. Some concern exists about how the designated speeds would be communicated to motorists, particularly on tiers with a number of different speed categories. Speed limits are seen as the best way to do this. Two broad avenues can be pursued to implement the hierarchy. One is the re-engineering of roads to upgrade them to the allocated speed limit and calm those that have been allocated to the low speed categories. Additional enforcement would also be needed to reinforce the lower speeds. The other involves ISA (Intelligent Speed Adaptation), which may be feasible in 10 to 15 years.

Summary and recommendations

A new hierarchy for speed management on rural roads can provide benefits by providing consistent use of speed limits, enabling drivers to recognise what speed they should drive on which roads and assist vulnerable road users by providing a framework for traffic speed reduction. Any rural road hierarchy should be simple if it is to gain road users' understanding and acceptance. It should be based on three tiers:

- Tier 1 – through routes and traffic distribution,
- Tier 2 – for mixed use,
- Tier 3 – local use roads.

The template should relate to the existing road classification system. A protocol is needed to allocate roads to the template.

If the desired speed is not achievable using self-enforcing roads, action such as traffic calming will be needed. The rural road hierarchy should be implemented on a trial basis.

The implications for classes of vehicles other than cars, and the current speed limits that apply to these vehicles must also be considered. If extensive use of repeater signs is to be avoided, the implementation of the hierarchy would require changes to the current laws governing speed limits. Further research into the hierarchy is also necessary:

- careful examination of lessons learnt in the Netherlands,
- incorporation of the wider transport policy for the hierarchy, included economic and social issues, such as sustainable transport,
- development of the assessment framework to determine the appropriate speed for sections of road within the tiers of the hierarchy,
- research on appropriate speed limits for HGVs and buses,
- consideration of the legal issues surrounding the replacement of repeater signs with alternative methods to indicate the prevailing speed limit,
- consideration of the signs and markings needed to specify the limit in a way fitting the rural environment,
- an evaluation of costs and time scale to implement the rural speed hierarchy,
- further research into drivers choice of speed in different road environment, including speed monitoring to establish the nature and extent of the problem and to inform decisions on appropriate vehicle speeds and limits,
- development of effective and acceptable traffic-calming measures in rural areas.

Author:	Theeuwes, Jan; Godthelp, Hans
Date:	1995
Title:	Self-explaining roads
Journal:	<i>Safety Science</i> 19: 217-225

Description

This paper is the original description of the self-explaining roads concept. It focuses on how potential errors can be reduced by changing road environment. It considers the inherent safety of a road and 'self-explaining' properties that can elicit safe behaviour by design. As better education, information and enforcement have only a marginal effect on accident reduction, it is crucial that the road and vehicle environment is conducive to safe driving practice. How to design roads to reduce the probability of errors is a crucial question. Self-explaining roads (SERs) and how drivers categorise different types of road, as well as driver expectancy, have been studied and used to create a list of design criteria for the development of SERs.

Categorisation of road environments

The concept of categorizing the traffic environment comes from the idea that people attempt to structure their world. These structures are called prototypes and are basically abstract ideas about an object. For example a chair is expected to fulfil a certain set of characteristics. As these prototypes are based on experience, it is reasonable to assume that categorizing roads into certain types for certain situations will make it easier for people to behave accordingly. Conversely, having inconsistent road types will make it more difficult to create the correct behaviour. A motorway is a good example of a clear category of road.

The effects of traffic behaviour

The prototypical representation of traffic environments, which is the basis for the categorisation process, contains information regarding typical spatial relationships between road elements and road users, otherwise known as *schemata*; and information regarding typical sequences of events in time, called *scripts* or *frames*. The classification of a road environment activates particular scripts and schemata that tell the driver where (in place and time) particular road users and elements can be expected. If the environment induces incorrect expectations, errors in visual selection are likely to occur. The processing of traffic schemes is thought to include elements from incoming information and higher-level memory representations (schemata and scripts). If the expectations of a certain road environment are not met (e.g. a sign post on the left when they are normally on the right), drivers may simply miss warning signs or other important elements, and accidents can occur. Even conspicuous objects are not perceived when they are irrelevant to the task at hand. Therefore roads that connect different places should be of a single type, e.g. a road connecting cities or a road connecting residential and shopping centre, should be designed as one type of road.

Self-explaining roads

Roads are self-explaining when they are in line with road users' expectations. Motorways are somewhat self-explaining, but Dutch rural 80 km/h roads are not. These roads do not have any prototypical recognisable properties, nor do they compel the traffic behaviour required for these roads. Consistent and easily understandable codes can reduce these problems to some extent. Adding things like global positioning systems (GPS) and other intelligent measures can enhance these concepts by adding variable speed advice dependent on local circumstances, finding optimal routes etc.

When creating new roads one should start with a few easily recognisable and distinguishable road categories. Four categories can be distinguished: motorways, highways connecting larger regions, rural roads connecting residential and shopping areas, and roads that go from door to door.

For these four categories SERs should fulfil the following tentative criteria:

- unique elements (i.e. easily distinguishable from other categories),
- unique behaviour for a specific category,

- road elements should induce the correct behaviour (e.g. smooth roads for motorways for fast driving),
- crossings, road sections and curves should be uniquely linked to each category,
- choice of road categories should be behaviourally relevant,
- no fast transitions from one road to the next,
- changes in category should be clearly marked e.g. rumble strips,
- when teaching the different categories both name and expected behaviour should be taught,
- category-defining properties should be visible at night,
- road design should exclude speed differences and differences in direction of movement,
- road elements, markings and signing should fulfil standard visibility criteria,
- traffic control systems should be uniquely linked to specific categories.

Author:	Traffic Advisory Unit
Date:	1994
Title:	VISP (Village Speed Control Work Group) – a summary
Publisher:	<i>Traffic Advisory Leaflet 01/94</i> . London: Department of Transport

Description

In July 1991 the UK Secretary of State for Transport announced a joint study between the County Surveyors' society and the Department of Transport to investigate measures for reducing vehicle speeds through villages. Twenty-four village schemes were monitored, 19 from England, 4 from Scotland and 1 from Wales. Eight were trunk roads (4 England, 4 Scotland).

Method

Eleven of the schemes had measures only on approaches; four schemes had measures only in the villages; and nine had measures both on the approaches and in the villages. Where gateways were used on the approaches they consisted of enhanced signing, with carriageway narrowing involving either physical changes or the use of edge lines and hatched markings. Some had central islands and many used surface treatments. In five schemes 30 mph roundel markings were used at the gateways and in two of these, they were continued in the village. For three villages, transverse bar markings were laid on the approaches. Speed limits were mainly 30 mph and 40 mph.

Results

Those with only minor gateway treatments (no measures inside the village) achieved C85 speed reductions below 3 mph at the gateway and 2 mph in the village. More significant

gateway treatments yielded C85 reductions of 6–7 mph at the gateway and 2–3 mph in the village. Major gateways, with physically restrictive measures achieved speed reductions of 10 mph but inner village reductions were no different from the other gateway schemes.

For schemes that used measures in the villages alone, C85 speed reductions were less than 3 mph.

For schemes that used both village and significant gateway measures, C85 speeds were reduced by up to 9 mph at the gateway and up to 10 mph in the village. In one scheme with a major gateway and measures inside the village, both with significant physical restrictions, C85 speed reductions of 12 mph at the gateway and the village were achieved. Even with the more significant schemes, C85 speeds remained over the speed limit.

Public opinion showed that most people were aware of the changes, but consultation varied. Half the respondents mentioned traffic speed as a problem before the scheme implementation. Heavy traffic was also viewed with concern. Between 1/3 and 1/2 of respondents felt the schemes had slowed traffic, but that the speed reductions were not enough.

Achieving major reductions in speed requires a mixture of gateways and complementary measures. Distinctively designed gateways can produce significant reductions in speed at approaches. However, by themselves, they will seldom be sufficient to reduce C85 speeds below the speed limit and reductions achieved will not be carried through the village. Placing them near to the first buildings may be better than placing them at the village boundary. Where physical islands or build-outs are too expensive or unsuitable, hatched markings or coloured surfaces are a substitute. Coloured surfaces can act as a reminder of the speed limit, but do not result in any significant speed reductions by themselves.

Author:	Traffic Advisory Unit
Date:	1997a
Title:	Traffic Calming on Major Roads: A49, Craven Arms, Shropshire
Publisher:	<i>Traffic Advisory Leaflet 10/97</i> , London: Department of Transport
Available online:	http://www.dft.gov.uk

Description

An integrated set of traffic-calming measures supporting a speed limit change from 40 mph to 30 mph was installed on the A49 trunk road in the village of Craven Arms in Shropshire. Before implementation, the C85 speeds at the entrance were 48 mph during the day and >50 mph at night. Within the village speeds ranged from 33–44 mph for normal traffic and from 32–40mph for heavy vehicles. Two-way traffic flows were ~9000

vehicles per day, with heavy vehicles making up about 16% of the total. After installation was completed (in May 1995), mean and C85 speeds fell by 9 mph at gateways (to 33 and 39 mph respectively), 9 mph post-gateways (to 33 and 37 mph), and by 10 mph (to 18 and 22 mph) in the centre of the village.

Method

The traffic-calming measures included:

- speed countdown signs – located at both sides of the carriageway at 150 m, 100 m and 50 m before the gateway.
- gateway treatments – dragon's teeth markings, followed by a '30 mph' roundel marking on a red background extending across the full width of the carriageway (roundel only on approach lane). The vertical element of the gateway was a 30 mph speed limit sign about the Craven Arms village sign.
- pavement markings – repeated speed roundel markings on a red background extending across the full width of the carriageway. Centre hatching with red surface in-fill in between roundels.
- narrow speed cushions – contrasting colour, height 60 mm; length 3.5 m; width 1.5 m; side ramp gradients 1:4; on-ramp gradient 1:8; off-ramp gradients 1:10.
- mini-roundabouts – placed before the speed humps, laid flush with the road to limit any excessive vehicle body rattle or ground vibration.



Speed limit countdown signs



Dragon's teeth



Speed limit roundels



Speed cushions

Figure A1.5 Examples of traffic-calming measures, A49, Craven Arms, Shropshire.

Results

For inbound traffic at both gateways, speed reductions of 9 mph (21%) were achieved. However, mean and C85 speeds were still above the revised speed limit, at 33 mph and 39 mph respectively. It is not possible to say which part of the gateway treatment was more effective than any other. As dragon's teeth were inconspicuous from a distance, they did not give any advance warnings to drivers. Outbound speeds reduced by 7 mph (mean) and 8 to 9 mph (C85).

Between the gateways and the central part of the village, overall speed reductions of around 9 mph were found. Light vehicles' mean and C85 speeds were ~33 mph and 37 mph respectively. Heavy goods vehicles' speeds were 29 mph and 33 mph respectively. Placing roundels in pairs on a distinctively coloured background, made them more conspicuous and undoubtedly contributed to their effectiveness.

The mini-roundabout and speed cushion system, in the centre part of the village straddling the A49, was particularly successful in reducing speeds to at or below the speed limit. At the northern end of the village speed reductions of around 7 mph were obtained, mean and C85 speeds were 26 mph and 30 mph. In the southern part of the village 10 mph speed reductions (36%) were obtained. Mean and C85 speeds were 18 mph and 22 mph. Equivalent heavy goods vehicle speeds were 17 mph and 20 mph respectively.

Mean journey time increased by 31 seconds northbound and 24 seconds southbound.

Noise reductions of 9.5 dB(A) for light vehicles and 5 – 8 dB(A)³ for heavy vehicles were achieved at cushion locations, 4 dB(A) for light vehicles and 3 dB(A) for heavy vehicles at gateways. Overall daytime noise levels fell 3 dB(A) adjacent to calming measures and 2 dB(A) away from physically traffic-calmed areas. Lower noise reductions than were expected may have resulted from mini-roundabouts generating some noise. Night-time (midnight to 0600) noise levels were generally unaffected. Ground-borne vibration levels in building structures increased, although still below the mean threshold for human perception. Vibration levels were 50% higher where heavy vehicles clipped speed cushions.

Public opinion surveys showed that residents did not perceive any decrease in noise levels and felt that vibrations had increased (possibly caused by low frequency noise from vehicle exhausts and engines). Only about 39% of those interviewed were happy with the scheme. About 67% felt that countdown signs, gateway markings, and repeated red patches were useful. Mini-roundabouts were criticised with regard to priority and people not giving way. Approximately 40% of those interviewed thought the speed cushions and centre hatch markings were of little value.

No accident statistics were available at time of publication.

³ dB(A) is an abbreviation for the A frequency weighted decibel as per IC651, a scale of sound measurement which emulates the human auditory response.

Author:	Traffic Advisory Unit
Date:	1997b
Title:	Chicane schemes
Publisher:	Traffic Advisory Leaflet 12/97. London: Department of Transport
Available online:	http://www.dft.gov.uk

Description

This report documents the findings of research conducted by the Transport Research Laboratory on the effects of chicane schemes installed by local highway authorities. Attitude surveys conducted on various traffic-calming treatments indicate that the public view chicanes more favourable than they do road humps. Two general types of chicanes exist: 'single-lane working' chicanes in which build-outs are staggered on alternate sides of the road effectively narrowing the road such that traffic from one direction has to give way to opposing traffic; and 'two-way working' in which build-outs produce deflection but lanes are separated by road markings or a central median.

Method

Forty-nine chicane schemes were studied, with data from 142 individual chicanes.

Results

The data indicated that an increased path angle (the angle through which the traffic lane is displaced) leads to a reduction in speed. In general path angles of 15° – 20° reduced mean speeds to less than 20 mph (C85 speeds of 20–25 mph) and path angles of less than 10° allowed mean speeds of 25 mph or more (C85 speeds over 30 mph). Path angles at single-lane working chicanes are typically greater than two-way working chicanes.

Across all single-lane working chicanes studied, the mean speed was 21 mph and the C85 speed was 26 mph (the mean reduction in C85 speeds was 14 mph). For the two-way working chicanes the mean speed was 27 mph and the C85 speed was 31 mph (mean C85 reduction was 11 mph). Mean speeds between chicanes of all types averaged 29 mph and C85 speeds were 31 mph. Greater reductions in speeds between chicanes were obtained for the single-lane working schemes with mean (23 mph) and C85 (27 mph) speeds both reduced by 12 mph. Two-way working chicanes produced mean speeds of 31 mph and C85 speeds of 34 mph for an overall speed reduction of 6 mph.

The effect of chicanes on traffic flows is mixed. Danish advice for single-lane working chicanes is no more than 3,000 vehicles per day but in the present study the average was 3,900 vehicles per day (with two sites with more than 7,000 vpd) and an average two-way working flow of 7,300 vpd (with two sites over 10,000 vpd). Vehicle flows at the 13 schemes where reliable before-and-after data were available indicated reduced flows at eight sites, increased flows at three sites and no change at three sites.

Accident data were available for 17 sites, and accident frequencies decreased at 10 sites, were unchanged at four, and increased at three sites. Overall, the reduction was 54%.

Careful consideration of cyclists' needs is stressed. Where possible a cycle bypass around the chicane should be provided.

Author:	Traffic Advisory Unit
Date:	1998
Title:	Speed cushion schemes
Publisher:	<i>Traffic Advisory Leaflet 01/98</i> . London: Department of Transport
Available online:	http://www.dft.gov.uk

Description

This report documents the findings of research conducted by the Transport Research Laboratory on the effects of 34 speed cushion schemes installed by local highway authorities in England. Three types of cushions were studied:

- a series of single cushions with carriageway narrowing (allowing only a single working lane),
- groups of cushions in pairs (allowing two working lanes),
- groups of cushions three abreast (used on wider carriageways).

Method

Speed cushions produce less abrupt vertical movement than speed humps and are often greatly preferred as a result. The dimensions of the speed cushions studied ranged from 1500 mm to 2100 mm in width, 1700 mm to 4750 mm in length, and 60 mm to 1000 mm in height (although 75 mm is a preferred maximum in height to prevent vehicles grounding on the cushions. The gradients on/off ramps ranged from 1:3.5 to 1:12 and side ramp gradients ranged from 1:3.5 to 1:5.25.

Results

The data indicated that speed cushions do not produce the same degree of speed reductions as round-topped speed humps. An overall mean speed of 17 mph (C85 was 22 mph) was obtained at the sites measured, which is higher than mean speeds obtained for 75 mm round-topped speed humps (14.7 mph) or flat-topped humps (12.8 mph). Large vehicles are slowed less than small vehicles, which is an advantage for bus routes. Width of the cushions has a significant effect on vehicle speeds with 1600 mm cushions producing mean speeds of 19.5 mph and 1900 mm cushions producing mean speeds of 15.5 mph (compared to mean and C85 before speeds of 30 and 35.6 mph) (Figure A1.6). For maximum effectiveness speed cushions need to appear more formidable than they are through the use of coloured pavement etc. Speeds between cushions were reduced on average by 10 mph, with overall mean speeds of 22 mph and C85 speeds of 26 mph. Spacing of speed cushions has an effect on speed as shown in Figure A1.6.

Speed cushions should not be placed with pedestrian crossings because of the possibility of pedestrians tripping on them. Where they are used at approaches to pedestrian crossings, care must be taken to ensure pedestrians are directed to cross between the cushions rather than over them.

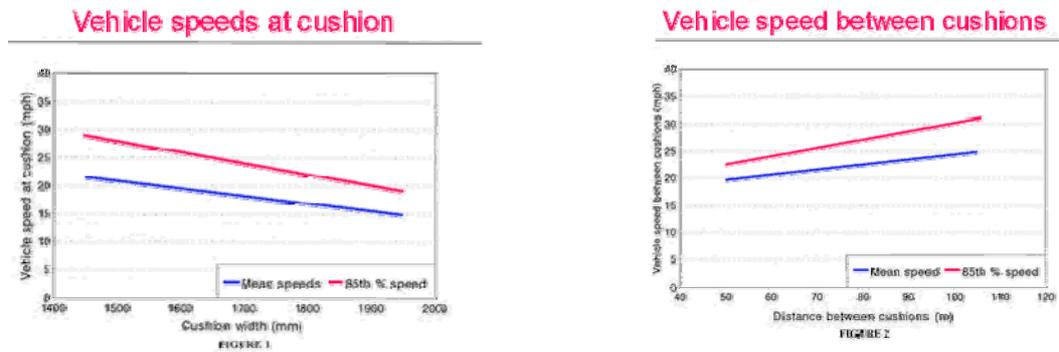


Figure A1.6 Vehicle speeds at and between cushions.

Author:	Traffic Advisory Unit
Date:	2004
Title:	Rural traffic calming: Bird Lane, Essex
Publisher:	Traffic Advisory Leaflet 2/04. London: Department for Transport
Available online:	http://www.dft.gov.uk

Description

When rural communities in the UK have concerns about high vehicle speeds and traffic growth they may seek to have a road designated as a 'quiet lane' to maintain the rural character. In order to receive such a designation, the road must have low traffic speeds and flows. Bird Lane in Essex, a narrow, unlit rural road about 900 m long was increasingly used as a 'rat run' by commuters to a large office complex to the north. Traffic volumes, speeds, and passing vehicles on the 4.5 m wide road were resulting in a degrading of the verges and a threatening environment for pedestrians, cyclists, and horse riders. However, because of the volume of traffic, Bird Lane could not be designated as a 'quiet lane'. In order to address the problems, it was decided to reduce the width of the carriageway (by 33%) and implement a single lane with passing lanes re-design.

Method

The re-design involved narrowing the carriageway to 3 m for 600 m of the lane. The remaining space was re-allocated as a 1.5 m raised way for non-motorised road users. Six passing places, each 17 m long were introduced on alternating sides of the road to encourage drivers to give way in turn. The raised way for non-motorised users was discontinued at each passing point (because of the width of the lane) and all users shared

the road space at these points. The road was designated as a 20 mph zone (previously 30 mph) with signs posted at each end of the lane and, because road narrowing was used to reduce vehicle speeds, repeater signs were not used. At the northern entry to the lane, three small build-outs were introduced on either side of the carriageway with priority signs indicating that drivers should give way to on-coming (northbound) drivers (see Figure A1.7).



Figure A1.7 Northern (left) and southern (right) entries to Bird Lane.

Results

Both mean and C85 speeds were reduced significantly, although mean speeds remained in the mid-twenties (higher than the posted limit). Greater speed reductions were obtained in the peak morning period and southbound speeds were generally more reduced than northbound speeds. Southbound drivers gave way more often than northbound drivers, although the authors state that this was perhaps partially caused by the higher northbound flows and a downhill gradient for southbound drivers. The authors also note an approximately 20% reduction of traffic flow on Bird Lane, with most traffic diverted onto the nearby highway. No significant increase in the number of non-motorised users was observed, although the authors suggest that the lack of a continuous route (non-motorised users had to cross the road at the passing points to remain on the raised way) may have discouraged some people from using the lane. Some confusion was also reported by cyclists as to whether they should use the raised way or the carriageway and an attitude that the carriageway was less safe since narrowing. Residents' attitudes indicated a reduction in the number of people concerned about speed and 50% of all respondents (drivers and residents) were in favour of the treatment. Drivers' attitudes indicated that the road was more difficult to drive since narrowing.

Although crash data are being collected, long-term monitoring will be required to assess the effects on the re-design on accident rates. Because the treatment was not sufficiently self-enforcing (did not achieve the desired 20 mph speed), Essex County Council has since introduced repeater speed limit signs. The degradation of the verge opposite each of the passing points has continued as drivers move as far left as possible to wait for oncoming vehicles. The cost of the treatment was £90,000.

Recommendations for single track with passing places treatments

- The maximum two-way flow should not exceed 300 vehicles per hour to maintain flow.
- Passing places should have a minimum length of 3 cars, be clearly visible, with spacing no greater than 60 m.
- Curb height should not be too high, to minimise tyre damage, but high enough to discourage abuse by drivers.
- Facilities for non-motorised users should be thought of in terms of 'desire lines', for example linking homes, shops, and off-road routes.
- Road should be clearly delineated, including use of reflective hazard markers to ensure visibility when roads are wet or road markings are obscured by dirt or leaf mould. Signs should be kept to a minimum on country lanes.

Author:	Ullman, Gerald L.; Rose, Elisabeth R.
Date:	2004
Title:	Effectiveness of dynamic speed display signs (DSDS) in permanent applications
Publisher:	<i>Project Report 0-4475-S</i> . Austin, Texas: Texas Transportation Institute

Description

This report describes field studies of speed-reduction effects of dynamic speed display signs (DSDS) at several sites over extended periods of time and discusses whether the signs increased vehicle conflicts or other types of erratic manoeuvres.

Method

Four common sites where excessive speed was a problem were identified and DSDS were installed at these sites:

- at the beginning of regulatory school speed limit zones that are only active during the times that students are arriving or leaving school,
- at speed zones upstream of a school: this was done to transition motorists down to the school zone speed limit,
- upstream of high-speed signalised intersections,
- upstream of sharp horizontal curves.

Speed and erratic manoeuvre data from before the installation (baseline), one week after, and about four months after the installation of DSDS were collected. Data were also analysed separately by different vehicles approach speeds to see if vehicles approaching the signs at different speeds (fast or slow) were affected in different ways.

Results

The greatest effect of the DSDS was at school speed zones. Before installation, speeds were 10 mph (16 km/h) higher than the posted speed limit. Following installation, average speeds were significantly reduced by more than 9 mph (14.5 km/h), and remained low for 4 months after installation. When installed at transition speed zones upstream of school areas the DSDS produced average speed reductions of 3 mph (4.8 km/h) through the transition zone and the effect was reduced to an average of 1 to 2 mph (1.5–3 km/h) after four months.

When installed in advance of sharp horizontal curves, the DSDS were associated with little or no change in average approach speeds. The researchers suggested that this may have been caused by the other curve warnings already present (i.e. chevrons, turn warning and advisory speed signs, and flashing beacons) and that the DSDS may have been "lost in the myriad of other information sources present".

DSDS installed on the approach to signalised intersections produced an initial 3–4 mph (3.8–6.5 km/h) reduction in average speeds, but the effect was maintained long-term at only one of the two sites tested. The researchers noted that this location received more attention from local law enforcement and had limited site distance to the intersection.

The researchers concluded that DSDS were more likely to cause drivers who were over the posted speed limit to reduce their speed (as compared to drivers at or under the posted speed) even after the novelty of the signs had worn off.

The researchers also provided the following recommendations for permanent installation. DSDS are more effective:

- if perception of regular enforcement exists at the site,
- if the sight distance to the condition being treated is less than the decision site distance,
- with other information 'indicators' of a need to reduce speed,
- if used with a regulatory speed limit rather than an advisory speed limit,
- if the DSDS is not overwhelmed with other information already present at the location.

Author:	van der Horst, Richard; Hoekstra, Wytze
Date:	1994
Title:	Testing speed reduction designs for 80 kilometre per hour road with simulator
Journal:	<i>Transportation Research Record 1464</i> : 63-68

Description

This experiment trialed measures designed to slow drivers on 80 km/h rural roads. The underlying principle of speed reduction is that speed will be reduced when the risk or discomfort caused by high speed increases. Perceptual speed adaptation, uncertainty, and task demand may also play significant roles in drivers' speed choice. Negative consequences of speeding (risk, discomfort) work best when they are consistent, real, and, if the involved risk is detectable, verifiable and recognizable. These factors led to the basic design for 80 km/h roads with four main elements: lane width, edge marking, centre marking, and verge reminders.

Method

Different types of countermeasure were tested using a simulator. The countermeasures consisted of two lane widths (2.25 and 2.75 m) and three experimental edge strips: a continuous profiled edge; small lateral rumble strips every 5 m; and rumble strips every 10 m (total road width was constant at 6.20 m). An assumption was that no excessive visual guidance should be present. Therefore tangible, rather than visual edge markings were proposed (no visible edge lines). On contact with the rumble strip both auditory and steering wheel feedback was present. Post-mounted reflectors at a height of 0.60 m every 40 m usually provide guidance in the Netherlands. To reduce visual guidance these were replaced by verge reminders designed for 80 km/h roads at 500 m intervals and centre markings were increased from 0.10 m to 0.30 m with 3 m long lines at 9 m spacing. Participants (32 men) were instructed to drive 'relaxed' or 'under time pressure'.

Results

The narrow lane width (2.25 m and 0.7 m edge) reduced speed the most (especially 'under time pressure') and was relatively immune to adaptation. It may also reduce speed variance. The different edge strips produced only relatively small differences in behaviour.

Differences between subjects contributed most (56% of explained variance). Instruction had an impact on speed, with subjects under time pressure driving 15 km/h faster on straight road sections [113 v 98 km/h, 17.3% of variance] and 14 km/h faster on curves [110 v 96 km/h, 14.3% of variance]. The main effect of lane width was not significant. Under time pressure narrow lanes significantly reduced speed. The three edge line configurations differed only for the narrow lane width. Combined with the narrow lane width, the continuous profiled edge line reduced speed more than the other two treatments. Speed variation was only influenced by instruction (relaxed 3.23 km/h versus time-pressure 5.54 km/h).

Only lane width significantly affected lateral position, 72.9% of explained variance. The distances participants drove from the centre line were 1.22 m for the wide lane, 0.99 m

for the narrow lane, and 1.18 m for the control road. The standard deviation of lateral position was independent of repetition, instruction, and edge line configuration. Compared with the control road the experimental lanes reduced standard deviation, 18.2% of explained variance, with the narrow lane having the strongest effect (SD for control, wide and narrow lanes were 0.18, 0.15, 0.12 m, respectively).

Author:	van der Horst, Richard; Kaptein, Nico
Date:	1998
Title:	Self-explaining roads
Publisher:	Proceedings of the 11 th ICTCT Workshop, 15-32. Vienna, Austria: ICTCT

Description

One of the 'classic' papers on the subject of self-explaining roads (SERs) and sustainable safety, this paper describes the logic of the approach and describes one of the earliest experiments examining the relationship between cognitive road classification and driving behaviour.

Briefly, the logic of SERs is the employment of a road design that evokes correct expectations from road users. People structure their world by gaining maximum information with the least cognitive effort possible, i.e. cognitive economy. The SER concept uses this idea, creating similar categories of road (i.e. a mixed model of categorisation). According to the SER concept, road users classify road scenes into categories. In order to obtain SERs, it is important that the design of the infrastructure is adjusted to the way the road environment is stored the 'head' of the user. This would bring about successful categorisation and, as a result, correct behaviour for that road. Inadequate categorisation can lead to errors of judgment and undesirable behaviour (e.g. poor anticipation of pedestrians crossing the street). At present, road elements that are prototypical for a specific road category are hard to find. The authors argue that combination of SER and Inherent Safety (the reduction of potentially dangerous encounters) are the most important aspects of achieving a sustainable safe traffic system.

Method

A picture-sorting task was used to investigate the effect of road characteristics on cognitive road classification and a simulator task was used to investigate the effect of road characteristics on driving behaviour. The effect of cognitive road classification on driving behaviour was investigated. Four road categories, forming a hierarchy, were used as stimuli.

Table A1.2 Four official categories of road outside the built-up area in The Netherlands. For each category the speed limit and the occurrence of possible other traffic is given.

Category	Speed limit	Cyclists	Slow motor vehicles	Oncoming traffic	Crossing traffic
A Motorway	120	–	–	–	–
B Motorroad	100	–	–	+/-	+
C 80-km/h road for fast traffic	80	–	+	+	+
D 80-km/h road for fast + slow traffic	80	+	+	+	+

Condition one (16 subjects) used a database of photos of 8 current roads per road category. As can be seen in Table A1.3, there was little overlap of characteristics within road categories but much across categories. A second group of 16 subjects were shown photos of 8 SERs per category, with overlap of characteristics within road categories, but not across. Condition 3 (16 subjects) had a database that contained six current roads and 2 SERs per category.

Table A1.3 Road characteristics of the CR design and the SER design, according to the official guidelines and the SER-concept, respectively. (All measures are in metres.)

Characteristic	Current roads				Self-explaining roads			
	A	B	C	D	A	B	C	D
Width of carriageway	8.35/7.95	6.75	6.75	5.50/4.50	8.45	6.80	6.20	5.50
Width of lanes	3.50	3.10	3.10	2.75	3.50	3.10	2.75	2.75
Edge lines	0.15/0.20	0.10	0.10	–	0.20	0.15	0.15	–
Recovery lane	1.10/0.60	0.35	0.35	–	1.10	0.35	0.20	–
Emergency lane	3.50/4.00	–	–	–	4.00	–	–	–
Guard rail	+	+	+	–	+	–	–	–
No. of carriageways	2x2	2x2/1x2	1x2	1	2x2	1x2	1x2	1
Centre-line markings; Space in between	0.10/0.15 3-9	0.10 3-9	0.10 3-9	0.10/- 3-9	0.15 3-9	0.10 3-9	0.10 9-3	– –
Bicycle lane width	–	–	–	–	–	–	–	1.25

Results

Picture sorting. Each subject had to sort 32 pictures (without thinking too long) in accordance with the type of behaviour they would expect from other drivers on the road. For all three conditions (current roads, SERs, and mixed roads) a similarity matrix was made, in which the similarity between pictures x and y was defined as the number of subjects who put x and y in the same pile. The cognitive road classification for SER design roads was more in accordance with the official category system. Motor-roads, which were not well categorised in the current roads category, were categorised correctly when the SER design was used. When SER designs were by themselves, they led to better

categorisation than when they were part of the mixed design, indicating that a more selective and systematic approach to road design led to a cognitive road classification that was more in accordance with the official road category system.

Driving simulator. The network of roads used in the simulator experiment had no other traffic, no signs indicating speed limits or road categories, and no sharp curves. Each subject drove for three 40-minute sessions. One session consisted of a sequence of 32 drives at 1.3 km each. During each drive the average and standard deviation of driving speed over the road section between 800 and 1100 m were recorded.

Significant main effects for average speed of road category and repetition occurred (on each higher official road category and, with each repetition, participants drove faster). A significant interaction effect between road design and category was found in that for categories B and D, participants drove faster on the SER roads. Road category A had a significantly lower standard deviation than other categories while category B had a significantly higher SD than other roads (but SER-B was significantly lower than current-B). Standard deviations became significantly smaller for each repetition.

The authors concluded that cognitive classification is a robust phenomenon, and SER designs led to more accurate classification. The effects on driving were not on absolute or relative speed, but rather on homogeneity or consistency of speed within road categories.

Author:	van Schagen, Ingrid
Date:	2003
Title:	Traffic calming schemes: opportunities and implementation strategies
Publisher:	<i>Report number R-2003-22.</i> Leidschendam, The Netherlands: SWOV Institute for Road Safety Research

Description

This report, commissioned by the Swedish National Road Authority, aims to provide an overview of knowledge and experiences with traffic-calming schemes. It presents a series of chapters contributed by international experts on various characteristics of the urban network that are relevant for traffic calming, such as the functional classification of the network, the network structure of residential areas, and the need for an attractive and safe network for pedestrians and cyclists.

Of greatest relevance to the present report is the chapter on engineering measures, including what they should look like and where they should be placed. Traditionally, traffic-calming engineering measures are grouped into horizontal measures (e.g. road narrowing) and vertical measures (e.g. speed humps). Another way to classify engineering measures is based on the level of coercion:

- Informative measures alert road users that a particular type of behaviour is expected from them (e.g. a maximum speed sign).
- Suggestive measures do not physically enforce particular behaviours, but attempt to achieve this by visual suggestion or illusion (e.g. road narrowing by using lines).
- Persuasive measures persuade motorists to behave in a certain way (e.g. speed humps: although strictly speaking speed is not physically enforced, the inconvenience does make drivers slow down).
- Obstructive measures make higher speeds physically impossible (e.g. chicanes used to force drivers to follow a specific course).

The chapter then presents four general principles regarding the location and design of traffic-calming measures:

- Measures should not distract the driver too much (as they may cause drivers to miss other important information).
- Drivers should recognise the measures and immediately understand their meaning (promoting acceptability).
- Measures should be placed in 'natural' locations where their purpose is easily understood.
- Measures should be visible at all times (e.g. by using proper lighting).

Residential areas. As accidents in residential areas are generally scattered over a wide area it is best to use an area-wide approach. Traffic-calming measures in residential areas are generally focused on making it unattractive for through traffic to use the roads. Road sections that have frequent discontinuities of alignment, width and height help to induce lower speeds. Changing materials and colours and the use of street furniture help to break up the impression of a thoroughfare. Vertical and horizontal calming measures should be alternated and calming measures at curves should be avoided. Measures should be spaced so that they create a constant speed that is at the speed limit. Measures at intersections are important as many accidents in urban areas occur at intersections. The measures should not block the view of crossing streets. The measures with the most substantial effects on speed reduction are raised pedestrian crossings, speed humps, one lane chicanes, and roundabouts. Speed humps, one-lane chicanes, roundabouts and full closure have the greatest effects on accident rates.

A study of the effects of fifteen 30 km/h areas on speed, accidents and traffic volume, found that traffic volume decreased by 5–30%, with the largest reductions in areas that had high traffic flow and where engineering measures affected traffic flow. The application of horizontal and vertical measures in residential streets reduced the speed of 85% of cars to 30 km/h or less. Speed humps were seen as the most effective measure. Several other studies have found that speed reduction measures (30 km/h zones and speed humps) have reduced accident and injury rates. A meta-analysis of 33 international studies on the effects of traffic calming found that the number of injury and material-damage-only accidents in residential streets with speed-reducing devices decreased by about 25%.

Distributor roads. Traffic-calming measures are best placed in areas where different road user categories mix (i.e. intersections). Too many measures would disrupt traffic flow and horizontal speed reduction measures are preferable to horizontal measures on these roads. Roundabouts at intersections are an effective way to reduce speed and the impact of accidents. Plateaus can also be used at intersections, with or without traffic lights. Buses and trucks also use distributor roads, so these vehicles should be taken into account when considering different types of measure. The evaluation of calming measures in 21 Danish small towns showed that roundabouts in the vicinity of an intersection reduced speeds by about 30 km/h compared to conventional intersections. Various measures at road sections resulted in an average speed reduction of 10 km/h. Speed humps, raised pedestrian crossings, chicanes and roundabouts placed on distributor roads at four locations in the UK produced mean speed reductions of 11 mph (18 km/h) back to the 30 mph speed limit. Traffic volumes also reduced by 13–65%. Accidents were also reduced, but not significantly (statistically).

Transition zones. The gateway should be the most prominent element in the transition zone and should be located at the beginning of the lower speed zone. Public lighting should be placed at the gateway to warn users about the transition at night. Residential gateways should have measures in line with other elements of the traffic-calming scheme. Horizontal measures at the gateway should be avoided because oncoming traffic can block the entrance. When a town or village is located on a busy through-route, measures beyond a speed limit sign are needed to reduce speeds. The chapter cites two principles for transition zones in these areas:

- Complementary measures along the through-route are required within the urban area.
- Measures in the transition zone should achieve a cumulative effect, culminating at the actual gateway to the town (achieved by a combination of road narrowing and trees and other vertical elements at the gateway). This relies on the driver's speed perception: speeds are lower where the height of the vertical elements is greater than the width of the road.

The chapter cites many of the TRL studies of British villages in the VERT programme (reviewed elsewhere in the present report).

Author:	van Vliet, Pieter; Schermers, Govert
Date:	2000
Title:	Sustainable safety: A new approach for road safety in The Netherlands
Publisher:	Rotterdam, The Netherlands: Traffic Research Centre

Description

Another 'classic' SER paper describing the history and logic of the approach. Since the early 1970s The Netherlands has been implementing road safety strategies to reduce the road toll. To date, the most effective measures have been (in order of effectiveness): new traffic legislation, expansion of the freeway road network, vehicle safety, influencing road user behaviour, and stimulating decentralisation. Further research has led to the development of the sustainable safety strategy. A sustainable safe traffic system comprises:

- a road environment with an infrastructure adapted to the limitations of the road user,
- vehicles that have equipment to simplify driving and protect vulnerable and other road users,
- road users who are adequately educated and well informed.

Sustainable safety distinguishes between three road categories:

- roads with a through function (for the rapid movement of through traffic),
- roads with a distributor function (for the distribution and collection of traffic to and from different districts and residential areas),
- roads with an access function (providing access to homes and shops).

There are three safety principles for each road category:

- **functionality** (preventing unintended use of the infrastructure),
- **homogeneity** (preventing major variations in the speed, direction, and mass of vehicles at moderate and high driving speeds),
- **predictability** (preventing uncertainty among road users).

Functionality can be achieved by ensuring that a clear difference exists between roads with a through function and an access function. For example, roads with an access function should not offer time-saving connections to through traffic, and through roads should not offer direct access to homes, schools etc.

Homogeneity has a large safety effect: freeways, 30 km/h, and residential areas have the safest roads because of the uniformity of speeds on the freeways and low speeds in residential areas. To improve safety on intermediate roads, motorised and non-motorised traffic needs to be separated (e.g. cycle lanes). This reduces variations in speeds and mass of vehicles. Where the two types of traffic intersect, lower speed limits need to be introduced, or traffic has to be separated time-wise (e.g. traffic signals, roundabouts etc.). At intersections, roundabouts are preferable to traffic signals as these can cause large variations in driving speeds.

Predictability (preventing uncertainty) can be achieved by roads that are 'self-explaining', enabling road users to have a better idea of what is expected of them and what to expect in terms of driving behaviour. The number of road categories must therefore be limited, and their design and layout as uniform as possible.

The Netherlands developed two sets of design criteria for SERs, one for application outside built-up areas, the other for roads inside built-up areas. Phase 1 (1998 to 2001) began by preparing detailed road classification plans and changing the infrastructure only at those locations that are deemed to be dangerous or potentially dangerous. Phase 2 (2002-2010) entails implementation of the sustainable road safety principles over the entire Dutch road network.

Based on earlier research, expansion of 30 km/h and 60 km/h speed limits was expected to reduce accidents by 10–20%. Conversion of intersections to standardised roundabouts and assigning priority at all intersections on traffic arterials (via road signs & infrastructure) was expected to produce a further 10% reduction in accidents.

Studies of roundabouts have shown, where intersections are converted to roundabouts, a 57% reduction in accidents has been reported and a 76% reduction in casualties has occurred. Where separate cycle tracks were created around roundabouts, a 90% reduction in casualties occurred. Where roundabouts replaced signalised intersections there was a 35% reduction in accidents. Roundabouts *always* reduce accidents and accident severity.

Roundabouts in the Netherlands have several important features:

- approach roads connect radially (90 degrees) to the roundabout,
- the central island is raised and has a diameter of 13–30 m and the outer edge is mountable,
- lane width of 5–6 m,
- traffic on the roundabout has priority,
- maximum capacity: 20–52 thousand vehicles per day (3,500–4,000 vehicles per hour).
- ideally, the roundabout has a separate cycle track.

In the Netherlands, a 30 km/h zone may be created only if the road environment supports a maximum speed limit of 30 km/h (possibly including traffic-calming measures). A study conducted in 13 pilot areas found that:

- The number of movements by motor vehicles fell by 20 – 30%.
- Accident casualties fell by an average of 30%.
- Residents satisfied with the creation of a 30 km/h zone amounted to 80%.
- Traffic-calming measures are needed to achieve the appropriate behaviour in residential areas.

- If higher speeds are possible, the maximum distance between measures should be around 80 m.
- The 30 km/h speed limit must be a product of the road's character and appearance.
- The entrance to a 30 km/h zone must be clearly defined. Several ways can be used to do this: In the Netherlands a raised construction is used where the cycle track and road merge with each other. Other measures include: intermittent road narrowing; humps; plateaus; full or partial diagonal closures; informal street furniture; chicanes.

In one region, an approach based only on roundabouts and traffic-calming infrastructure (enforcement and education are not a part of the approach), slight injury accidents in the region have been reduced by 19% and serious injuries by 35% in less than four years.

Authors:	Wheeler, A.H.; Taylor, M.C.
Date:	1999
Title:	Traffic calming in villages on major roads: Final report
Publisher:	Report TRL 385. Crowthorne, Berkshire, UK: Transport Research Laboratory

Description

This report describes field trials at 9 speed reduction sites in villages in the UK. The schemes aimed to reduce the C85 speeds at least to the village speed limit. All but one of the schemes were on trunk roads and several had two-way daily flows of more than 10,000 vehicles and the weekday percentage of heavy vehicles ranged from 10–20%. All sites were in single-carriageway roads (of width typically 7.0–7.5 m). One site had one dual-carriageway approach. Four villages already had a 30 mph speed limit, but two had a 60 mph speed limit. After scheme installation, no speed limit exceeded 40 mph.

Method

The speed calming treatments are described in detail in the report. For all schemes measurements were made of vehicle speeds and flows (no flows at Copster Green) before scheme installation, about 1 month afterwards, and about 1 year afterwards. Monitoring of noise levels was undertaken at the most extensive schemes.

Results

In the trunk road villages, no changes in overall traffic flow levels were apparent. Vehicle speeds were reduced almost everywhere, ranging from 3 to 15 mph for C85 speeds, both at inbound gateways and in the villages themselves. However, speeds generally remained above the new/retained speed limit, albeit by only a few mph within the village. Mean speed reductions were up to ~2 mph below C85 reductions. Physical measures had the greatest effect on speeds. Strong visual impacts were also necessary to create larger

reductions in speed. Additional signs (e.g. countdown signs) were beneficial, as were speed camera signs.

At Craven Arms and Thorney, journey times increased. The shorter 'before' times resulted from many drivers exceeding the speed limit.

The speed reductions resulted in decreased noise levels at the locations in Hayton, Costessey, Craven Arms and Thorney where noise was measured. Maximum noise levels were reduced by up to 10dB(A), and traffic noise levels by up to 5dB(A). No changes in the noise environment resulted from the introduction of vertical deflections (speed cushions, mini-roundabouts) and textured surfacing. However, many residents were of the opinion that noise levels increased. This may be because of:

- vertical deflections which may increase the incidence of short-duration, high-noise events (e.g. from heavy vehicles 'clipping' the measure),
- changes in driver behaviour (e.g. increased acceleration/deceleration),
- variability of low frequency noise from heavy vehicles.

Heavy vehicles at Craven Arms produced 'worst case' vibration levels in a house near the speed cushion that were no greater than those generated by normal household activities, and below the threshold for human perception. Soil conditions in Thorney resulted in ground-borne vibrations that marginally exceeded the threshold for human perception in a house adjacent to the imprinted surface at the gateway. The vibration was not strong enough to cause structural damage.

Reactions from residents in the villages with schemes that had extensive physical measures were less encouraging than the measured speed reductions would have suggested. Even reasonably large speed reductions were largely unnoticed. Costessey residents were disappointed that speed limits were not reduced below the new 20 mph speed limit. In Thorney, the scrapping of a proposed bypass probably influenced views.

Some components were regarded favourably, but this differed from scheme to scheme. In the three villages with extensive physical measures, about 40% of residents expressed concerns about the appearance of the scheme.

A small overall reduction (not significant) in injury accident frequency occurred in the periods immediately following installation (between 1 and 3 years). The reduction for the three schemes with extensive physical measures is much greater (about 25%). However a much larger reduction in accident severity occurred, with only one serious accident occurring since scheme installation, across all nine schemes.

Author:	Whitty, Larry; Boyack, Sarah; Law, Peter
Date:	2000
Title:	Tomorrow's roads: safer for everyone
Publisher:	London, UK: Department for Transport
Available online:	http://www.dft.gov.uk/stellent/groups/dft_rdsafety/documents/divisionhomepage/029352.hcsp

Description

This article describes the UK's official speed change management policy. The key elements of the strategy are:

- Publicise the risks of speed and reasons for limits.
- Develop a national framework for determining speed limits on all roads and ensuring measures are in place to achieve this.
- Research a number of speed management problems to gain information to develop and test new policies.
- Take into account environmental, economic and social effects of policies when assessing policy effectiveness.

Although speed and accident severity are linked, many drivers still exceed the speed limit, even when they are concerned about speeds around their homes or when they are walking. Drivers also do not understand the reasons for speed limits and will drive faster down a straight road. Speeding is not seen as criminal. Vehicle improvements and experience are also seen to improve the safety of speeding. Changing public opinion and an increase in education are needed. The government's action plan is composed of the following elements:

- **Increasing awareness:** Increased publication of the dangers of excessive speed and research into speed motivation.
- **Appropriate vehicle speeds:** Sensible speed limits in-line with road use should be set. Increased guidance for setting speed limits for local authorities. Provide better information for drivers including: more effective speed limit signing, speed activated signs at hazards, additional signing for speed cameras.
- **High speed roads:** Compliance with existing speed limits is the main issue. Done by increased targeted enforcement activity for both general speed limits and those at work areas.
- **Rural single carriageway roads:** Although the 60 mph speed limit is appropriate for good quality sections of rural roads, there are sections where it is not appropriate. Using the normal classification of A, B, C and unclassified is not appropriate for speed management as these roads define routes rather than the function or nature of the road. A new hierarchy of roads defined by their function and quality is proposed. This hierarchy would give consistency to the road network, but would require further research. Among the features of this hierarchy would be: a normal speed limit of 30 mph in villages and lower speed limits on country lanes, where needed. These changes will require changes in legislation to simplify making of speed limit orders by local authorities, including some form of overall package.

- **Speed reduction measures:** These include road marking, signing, road engineering, and targeted interventions at speed related accident sites.
- **Urban areas:** Keeping the 30 mph speed limit in most urban areas should remain the norm. However certain areas where the risks of accidents (schools etc.) are higher should have a speed limit of 20 mph, with self-enforcing measures (i.e. traffic calming). High streets with diverse usage and traffic remain a problem and more research is required. It is intended to develop an urban hierarchy of roads to provide clearer guidance in higher risk areas.
- **Speed management:** Speed management strategies should be developed to maintain free flowing traffic and maintain safe speeds.
- **Self-explaining roads:** Designing roads that clearly indicate appropriate speeds by their appearance, in combination with a new road hierarchy would be beneficial.
- **Signing:** On all roads better driver information is required (i.e. more effective speed limit signing, more vehicle-activated signs to warn of hazards and speed limits, additional signing for speed cameras). Local authorities should set speed limits with consistent guidelines that suit the road. Alternative speed limit signing conventions for rural areas will be investigated.

Authors:	Winnet, M. A.; Wheeler, A. H.
Date:	2002
Title:	Vehicle-activated signs – A large scale evaluation
Publisher:	Report TRL 548. Crowthorne, Berkshire, UK: Transport Research Laboratory

Description

While a small number of drivers refuse to follow rules, research suggests that most drivers can be encouraged to change their behaviour with appropriate, sensible and relevant advice. TRL investigated the use of automatic signs in the late 70s and early 80s. The signs gave information on following distance or excessive speed. Results of this early work indicated that a close-following sign reduced by 30% the number of vehicles following with a gap of less than one second, the effect was maintained 80 m downstream, and the sign remained effective after five years.

The current generation of vehicle-activated signs display a message delineated by either fibre-optic cables or LEDs mounted on the front panel of the sign. Recently used signs have been either speed enforcing or warning signs. Research on the speed signs has shown that they have achieved speed reductions of up to 7.5 mph, with the larger speed reductions achieved at sites where speeds were higher initially. Warning signs also generated speed reductions and no sign of habituation had occurred.

Method

Four types of vehicle activated signs were tested: speed roundel; junction warning; bend warning; and safety camera logo. The sites in this study were selected on the basis of either having a recent history of accidents where speed was a factor or where excessive speed for the conditions was believed to be a potential problem. Locations covered in this study cover A-, B-, and C-class roads with two-way flows ranging from 10,000 to 60,000 vehicles per week. All signs were installed between 1995 and 2000. No physical engineering measures to encourage compliance were introduced at sites.

Results

Before-and-after speeds were collected for at least one week at each site. The 30 mph roundel signs yielded mean speed reductions between 2.6 mph and 7.1 mph; the proportion of vehicles exceeding 30 mph reduced between 18 and 34 percentage points, and those exceeding 35 mph by 15 to 51 percentage points. All the 40 mph roundel signs yielded speed reductions between 1.2 and 4.4 mph. Vehicles exceeding 40 mph reduced by between 7 and 35 percentage points and 45 mph by 1 and 17 percentage points. At the 50-mph site mean speed fell by 4.6 mph in lane one and 3.6 mph in lane two. Vehicles exceeding 50 mph fell by 26 percentage points in lane 1 and 22 percentage points in lane 2. Vehicles exceeding 55 mph fell by 31 percentage points in lane 1 and 10 percentage points in lane 2. At all of these sites accidents were reduced by 16% – 100% with a 58% mean reduction overall. The proportion of accidents involving fatal or serious injury was unchanged.

At all junction warning sign sites but one, mean speeds were reduced 0.8–9.2 mph. The proportion of vehicles exceeding the threshold speeds also reduced at all sites. All vehicle-activated bend-warning signs yielded reductions in mean speed ranging from 2.1–6.9 mph. The proportion of vehicles exceeding the threshold speeds was also reduced. Except for one site where there was no change, accident reductions ranged from 45–100%, with a 26% mean reduction. Fatal or serious injury rates remained largely unchanged. At the safety camera warnings mean speeds were reduced by between 0.5 and 3.7 mph. The percentage of vehicles exceeding various thresholds also reduced. At these sites, accident reductions ranged from 8% to 31%, with a mean reduction of 17% overall. Fatal or serious injury accidents remained largely unchanged.

Nearly 450 drivers took part in opinion surveys at three locations in Norfolk and one in Wiltshire. There was overwhelming approval of the signs. Most drivers made the connection between their speed and the triggering of a sign. Nearly all drivers thought the main purpose of the junction signs was to slow them down or to warn of a hazard. Over half the drivers thought they would incur a penalty for triggering the safety camera repeater sign.

Conclusions

Speed limit roundel signs reduced mean traffic speeds by an average of 3–9 mph. The average reduction where there was no change in the speed limit was 4 mph. Junction and bend warning signs reduced mean speed by up to 7 mph and safety camera repeater

signs reduced speeds by up to 4 mph. There was a statistically significant one-third reduction in accidents across all Norfolk sites when compared with the number of accidents that would have been expected without the signs. Camera repeater signs appear to give a small additional accident reduction over speed cameras alone.

Author:	Womble, Joseph E.; Bretherton, W. Martin
Date:	2003
Title:	Traffic calming design standards for new residential streets: a proactive approach
Journal:	<i>ITE Journal</i> 73(3): 50-54

Description

Gwinnett County in Georgia, USA, has developed a proactive approach to traffic calming that involves developers ensuring that neighbourhood streets have reasonable speeds. This is currently being achieved using design standards promoting street design layouts that discourage higher speeds.

Method

Gwinnett County has had an aggressive programme of residential speed control since 1985. This included street closures until they were found to be too controversial. A scheme called 'neighbourhood speed watch', involved achieving compliance with speed limits through peer pressure, increased awareness and a greater sense of responsibility. This worked well, with C85 speed reductions of 11–13 mph. However, because of the expense of the programme it was discontinued. Subsequently, new low-speed design standards have been created for new roads that should result in C85 speeds in the 25–30 mph range.

Before developing the standards, speed studies were done on eight residential streets with 24 tangent sections. Studies were conducted over 24 hour periods with electronic tube counters. Tangent lengths ranged from 300–2,510 feet and C85 speeds ranged from 25.5–41.2 mph. A regression analysis was conducted to determine the relationship between speed and tangent length. The model ($R^2 = 0.83$) found the following relationship:

$$V = 16.6 + 0.03484 L - 0.0000138 L^2$$

where:

V = C85 speed (mph)

L = length of straight residential street (ft).

Based on this analysis the new standards dictate that the maximum length of a roadway section between speed control points should be 500 ft. A speed control point can be defined as either a design construction that requires a complete stop (e.g. an

intersection), a horizontal curve with the design features to achieve the required speed, or a traffic-calming device (i.e. speed humps, traffic circles, median islands and roundabouts).

Conclusion

Although it is possible to retrofit traffic-calming devices to residential developments, it is preferable to design streets to maintain lower speeds. Low-speed design should satisfy the following criteria:

- When applied, the standards should result in C85 speeds in 25–30 mph.
- Standards should be specific, simple and easy to understand and apply.
- Standards should offer maximum flexibility and choice to subdivision designers and developers.

Author:	Zakowska, Lidia
Date:	1997
Title:	Dynamic road view research for road safety aesthetics evaluation
Journal:	<i>Journal for Geometry and Graphics 1(1): 51-57</i>

Description

This study was designed to study the effect of road category, geometric road design, and road environment elements, as well as driving speed, on subjective assessment of road characteristics and speed choice. The experiment involved a real-time dynamic road visualisation study of subjective safety evaluation.

Method

The independent variables were geometric road parameters, road environment characteristics, and experimental driving speed. Dependent variables were subjectively perceived road parameters (fluency, legibility, safety, aesthetics and speed) measured on a 7-point rating scale. Sixty second video clips of 18 road segments selected from southern Poland (I class freeways to V class minor roads) were shown to 21 participants on a 2 m X 3 m screen.



Figure A1.8 The laboratory environment.

Results

Road safety, legibility and fluency assessments increased with higher road category (freeways); road aesthetic assessments increased slightly with increased road category; road environment attractiveness assessment does not relate to road category; for higher road categories (Types I & II) speed and safety assessment correlated, but for lower categories speed choice was higher than safety assessments.

Speed choice was closely related to road design. Although V class roads had a low safety rating, speed choice generally corresponded to design speed. IV class roads were perceived as unsafe, but speed choice was much higher. This may explain the high accident rate in this road category. For II and III class roads safety and speed are correlated. For I class roads drivers are more likely to drive above the speed limit, but no higher than safety scores.

Appendix B: Experts' Survey Form

2 May, 2005

Dear Colleague,

We are seeking your assistance as a road safety researcher who has published in the area of speed management. The New Zealand Ministry of Transport has recently introduced a National Speed Management Initiative that places a greater emphasis on perceptual measures and psychological principles in the design of our roads, in effect a 'self-explaining roads' initiative. Like sustainable safety, self-explaining, and self-enforcing roads strategies elsewhere, an important component of the initiative seeks to influence drivers' speed choices by manipulating road design features.

We would like to support the implementation of the initiative by helping to identify road design features that have the greatest promise for generating appropriate driver behaviour. Based on our review of the research literature, we have already identified a number of candidate design features. We would now like to use expert opinion to further refine that list so that we will be able to manipulate and monitor a relatively constrained set of design features during the initial implementation phases. For a set of three to four design speeds, we hope to produce speed management treatments that: can be readily distinguished by drivers; will resist habituation and behavioural adaptation; and will increase the homogeneity of drivers' speeds (minimise individual differences).

Accordingly we have developed a survey form that asks road safety researchers to help us identify and rank the most promising design features. The survey is composed of two parts: treatments for speed maintenance (i.e., treatments that encourage drivers to maintain an appropriate speed in the zone), and treatments for speed change (i.e., threshold treatments that clearly indicate a change in speed zone). For each section of the survey we are asking the respondents to first indicate the design features they feel are appropriate for use in specific road categories and then to rate those design features according to their effectiveness, sustainability, and suitability.

We have pre-tested the questionnaire to make it as short and easy to answer as we are able and anticipate that it will not require more than 10-15 minutes of your time to complete. We would be happy to keep you informed of the progress of the work should you so desire and of course we would welcome any additional suggestions or comments you may wish to offer.

Once you have completed the survey please "save" your answers and return the file (electronically) to me at: samiam@waikato.ac.nz

If you would prefer to complete a paper copy let me know or print out a copy of the survey and return it to me at the address shown below. Our sincere thanks in advance for assisting us with this worthwhile project.

Dr Samuel G. Charlton
Department of Psychology
University of Waikato
Private Bag 3105, Hamilton
New Zealand

Part A -- Treatments For Speed Maintenance

For this part of the survey we are asking respondents to let us know which road features are most appropriate for various types of roads, and then tell us which of those features are most effective. So in the example below, a respondent has shown us what she thinks are the appropriate speeds for each road category and then how many lanes there should be ideally, how wide they should be, how they should be marked, etc. For each feature, she then rated how effective, sustainable, and suitable it was. Rather than thinking of a specific road, these ratings ask how big an effect the feature (e.g. lane width) has on drivers generally.

The survey form for your responses is on the next page.

Please indicate the design features you feel are most appropriate for each road category. (e.g., write "100" for 100 km/h, "2" for two lanes, "3" for 3 metre lane width, etc.)							Then rate how well treatments that employ these design features work.			Comments
Design features	Road category					Effectiveness (speed compliance)	Sustainability (resistance to habituation)	Suitability (road user acceptance)		
	Through roads		Distributor roads		Access roads					
	Urban	Rural	Urban	Rural	Residential					
Design speed (km/h)	100	80	60	60	30-40					
Road width (# of lanes, 1, 2, 2+1, 2+2, etc)	2+2	2+1	2+2	2	1-2	4 good	4 good	4 good	<i>2+1 means overtaking lanes</i>	
Lane width (m)	4	3.5	3.25	3.25	<=3	4 good	4 good	3 medium		
Median (none, flush, barrier, raised, etc)	barrier	none	raised	none	none	3 medium	3 medium	3 medium		
Centre line (none, dashed, solid, double)	solid	double	solid	dashed	none	2 slight	3 medium	2 slight	<i>Double = double yellow except at overtaking lanes</i>	
Edge line (none, dashed, solid, etc)	solid	solid	dashed	none	none	1 none	No opinion	No opinion		
Other (please specify)	Street trees	none	none	Between road edge and footpath	none	At road edge	3 medium	4 good	4 good	

Part A -- Treatments For Speed Maintenance

Please indicate the design features you feel are most appropriate for each road category. (e.g., write "100" for 100 km/h, "2" for two lanes, "3" for 3 metre lane width, etc.)					Then rate how well treatments that employ those design features work.			Comments
Road category								
Design features	Through roads		Distributor roads		Access roads			
	Urban	Rural	Urban	Rural	Residential			
Design speed (km/h)					Effectiveness (speed compliance)	Sustainability (resistance to habituation)	Suitability (road user acceptance)	
Road width (# of lanes, 1, 2, 2+1, 2+2, etc)								
Lane width (m)								
Median (none, flush, barrier, raised, etc)								
Centre line (none, dashed, solid, double)								
Edge line (none, dashed, solid, etc)								
Clear zone (m)								
Cycle lane (y/n)								
Sidewalk/footpath (y/n)								
Road surface (smooth, rough, coloured, etc)								
Other (please specify)								



Part B -- Treatments For Speed Change (thresholds)

For the second part of the survey we are asking respondents to tell us kind of treatments they think are most appropriate for speed change thresholds. So in the example below, a respondent has shown us what she thinks are the appropriate things to include in a change from a through road to a distributor and from a distributor to an access road. For each feature, she then rated how effective, sustainable, and suitable it was. As before, these ratings ask how big an effect the feature (e.g. perceptual narrowing) has on drivers generally rather than for any specific road.

The survey form for your responses is on the next page.

Please indicate the design features you feel are most appropriate for each threshold type
(e.g., write "chicanes" if you feel they are appropriate, or write "none" or leave blank if not)
and then rate how well treatments using that design feature work

	Through road ⇒ distributor road				Distributor road ⇒ Access road			
	Design features	Effectiveness (speed compliance)	Sustainability (resistance to habituation)	Suitability (road user acceptance)	Design features	Effectiveness (speed compliance)	Sustainability (resistance to habituation)	Suitability (road user acceptance)
	Threshold type							
Physical narrowing (raised medians, chicanes, build outs, etc.)	none				Chicanes where road narrows	4 good	4 good	2 slight
Perceptual narrowing (edge lines, hatching, etc.)	Hatching where lanes narrow	3 medium	3 medium	3 medium				
Signage (static, dynamic, oversized)	Large signs	2 slight	2 slight	2 slight				
Edge posts, vertical poles	none							
Speed tables, speed humps	none				Change in road surface	4 good	4 good	4 good
Judder bars, rumble mats	none				See above			

Part B -- Treatments For Speed Change (thresholds)

Please indicate the design features you feel are most appropriate for each road category. (e.g., write "100" for 100 km/h, "2" for two lanes, "3" for 3 metre lane width, etc.)					Then rate how well treatments that employ those design features work.			Comments
Road category								
Design features	Through roads		Distributor roads		Access roads			
	Urban	Rural	Urban	Rural	Residential			
Design speed (km/h)					Effectiveness (speed compliance)	Sustainability (resistance to habituation)	Suitability (road user acceptance)	
Road width (# of lanes, 1, 2, 2+1, 2+2, etc)								
Lane width (m)								
Median (none, flush, barrier, raised, etc)								
Centre line (none, dashed, solid, double)								
Edge line (none, dashed, solid, etc)								
Clear zone (m)								
Cycle lane (y/n)								
Sidewalk/footpath (y/n)								
Road surface (smooth, rough, coloured, etc)								
Other (please specify)								

Please feel free to add any additional comments, suggestions, etc. (take as much space as necessary):

Be sure to save your answers when you close the file!

Our thanks again for participating.

Speed change management for New Zealand roads

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