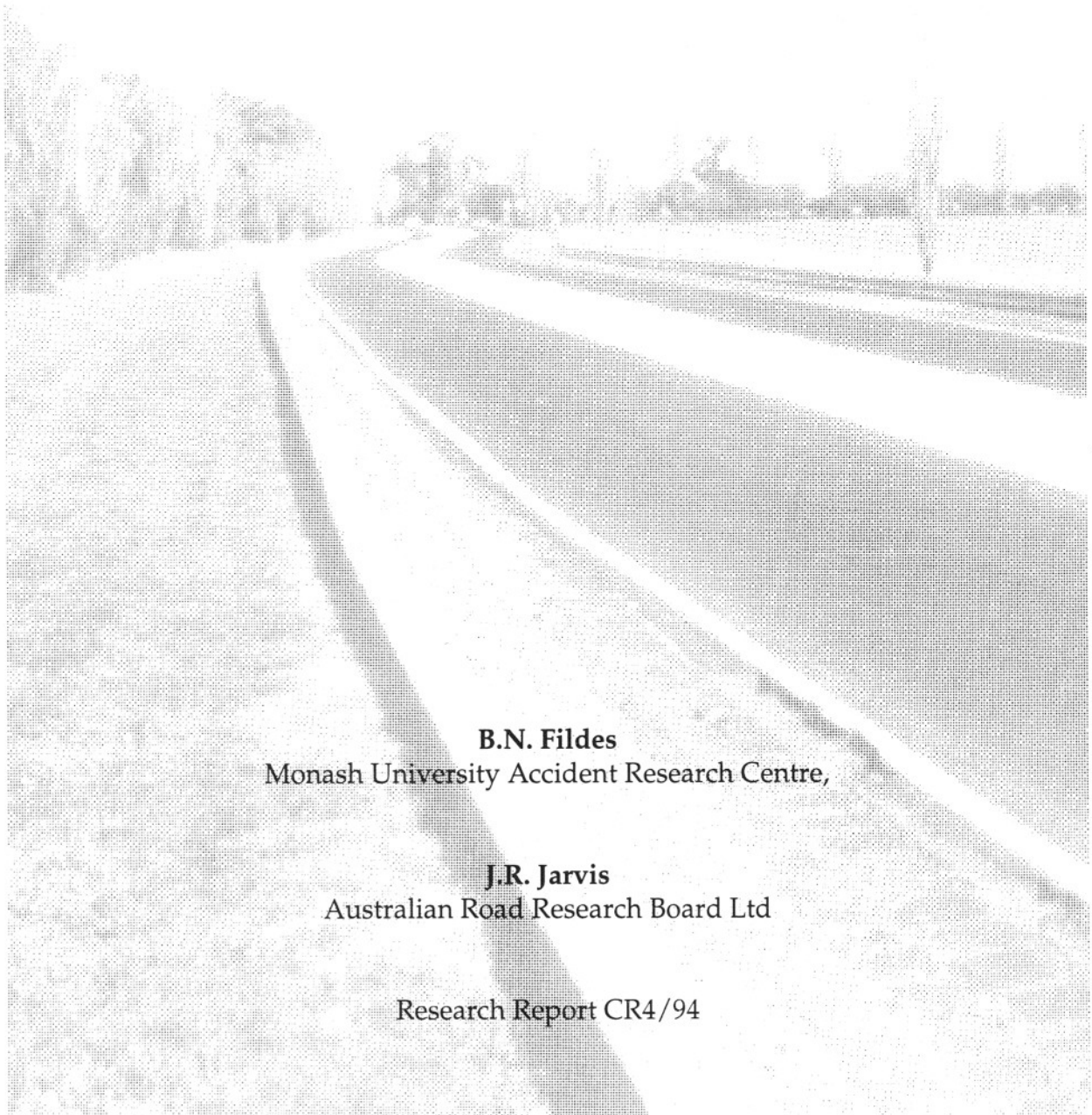




PERCEPTUAL COUNTERMEASURES: LITERATURE REVIEW



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Abstract

A recent review on priority issues to reduce excessive speeding on Australian roads highlighted an urgent need for further research and development into low cost perceptual countermeasures. A preliminary review was therefore undertaken aimed at identifying suitable perceptual countermeasures, either existing or proposed, reported in the literature that could be used immediately or developed for future use in this country. Visits were also made to a number of prominent research organisations in Europe to see first hand what suitable treatments they were developing that could be relevant for use in this country. A number of promising road and roadside treatments were subsequently identified that seemed to have speed and crash reduction potential. However, there were relatively few current developments in this area and a need was identified for a more systematic development, implementation and evaluation program. A detailed plan of research was then developed which included a laboratory research program followed by on-road demonstration trials to ensure that the speed and crash benefits of the more successful of these measures would be implemented and thoroughly evaluated on the road.

Keywords

Speeding, Accidents, Enforcement, Environment, Research Needs, Behaviour, Perception, Countermeasures.

Notes

- (1) This report is jointly produced by RSB and FORS and is disseminated in the interest of information exchange
- (2) The views expressed are those of the author(s) and not necessarily those of RTA (NSW) or the Commonwealth Government
- (3) The Road Safety Bureau publishes two series of reports.
 - (a) reports generated as a result of research done within RSB are published in the RN series.
 - (b) reports conducted by other organisations on behalf of RSB are published in the RSB's CR series

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CHAPTER 1: INTRODUCTION

Speeding has long been recognised as a major factor in many road crashes. Excessive speed was noted as a *definite* cause in 8 per cent of crashes and up to twice that as a *probable* cause in studies overseas (Treat et al 1977). It has been suggested that these findings are conservative by others (eg: Ruschman 1981) who argued that a number of other studies suggest that speeding is really involved in up to 37 per cent of fatal crashes. In Australia, excessive speeding has been noted as a contributing factor in up to 30 per cent of fatal crashes (Haworth and Rechnitzer 1993). On this basis, speed related road trauma is likely to cost the Australian community up to A\$1 billion annually (A\$260 million in Victoria).

A variety of approaches have been adopted to control excessive speeding on the road and these are explained fully in the recent *Speed Review* by Fildes and Lee (1993) and *Enforcement Review* by Zaal (1994). While police enforcement and traffic engineering measures are quite rightly the main weapons against excessive speeding, there have been a number of calls for supplementary measures to help control this deviant behaviour.

Fildes and Lee (1993) undertook an assessment of the needs for further research and action to reduce excessive speeding on the road which involved leading Australian experts. The highest priority in both categories was for further development of low cost perceptual countermeasures, aimed at reducing travel speed on the road. As a consequence, the Road Safety Bureau of the Roads & Traffic Authority of N.S.W., along with the Federal Office of Road Safety commissioned this preliminary review of this topic.

1.1 DEFINITION

Perceptual countermeasures against excessive speeding refer to manipulations of the road scene presented to a driver that can influence his or her subsequent behaviour. For the most part, these treatments tend to be relatively low cost additions or modifications to the road or the immediate roadside setting that can lead to a change in the way the driving environment is perceived by drivers. A typical example would be a pattern painted on the road surface to induce the illusion that one is travelling much faster than without the treatment.

Johnston (1982) referred to these treatments as *perceptual trickery effects* where one attempts to induce a false sense of the environment by manipulation of the visual scene. Often, they are used to offset a misleading illusion that already exists in the visual array (see Fildes, 1986, for a more detailed account of these effects). For the most part, these effects are subtle and go by unnoticed, operating at a semi-conscious level of the sensory system. This is an important characteristic in terms of their acceptance and the long-term success of these measures.

1.2 PROJECT AIMS AND OBJECTIVES

This preliminary study is intended to provide an overview of recent perceptual countermeasure developments against excessive speeding and needs for and directions of further research. It is expected to highlight both existing and potential treatments that have been developed and trialed locally and overseas and to outline a program of research for further developing or refining suitable treatments so that they can be implemented and evaluated on Australian roads

for their speed reduction potential. To expedite the research program, it is expected that the initial development and testing of a range of these treatments will need to be carried out off-road prior to implementing the more successful ones.

1.3 PROJECT METHODOLOGY

A three-part preliminary project was undertaken to address these aims and objectives.

1.3.1 Literature Review Update

A comprehensive literature review of perceptual countermeasures was initially undertaken, which updated an earlier review published as part of FORS report CR60 with more recent literature in this area. The review involved a search of relevant electronic literature databases such as IRRD, LASOR, and MEDLINE over the last 5 to 10 years to uncover recent papers that address this topic as well as other publications sourced at either the Australian Road Research Board or the Monash University Accident Research Centre.

1.3.2 Visits to Overseas Organisations

Much of the research undertaken on this topic of interest for what is proposed in Australia has happened (and still is happening) in Europe. With the vast distances between these two continents and the language barriers that often exist, not much of this information is freely available in Australia. Thus, visits were arranged to a number of key organisations in conjunction with overseas trips already planned by the researchers.

Inquiries suggested that overseas Institutions currently involved in relevant perceptual counter-measure research and development included:

- *TNO Institute for Human Factors Research, Soesterberg, the Netherlands.* This Institute was recently involved in simulation work on evaluating painted road treatment effects for the Dutch Government, similar to that proposed here and reported some positive results in terms of speed reductions in this laboratory setting;
- *Swedish Road and Traffic Research Institute (VTI), Linköping, Sweden.* This organisation has evaluated a number of similar road treatments in recent years and agreed to discuss and demonstrate many of their treatments and evaluation methods;
- *Danish Ministry of Transport (Research), Copenhagen.* In conjunction with the Danish Council for Road Safety, this organisation has been a long-term proponent of low cost road treatments and was recently involved in trials of particular treatments aimed at influencing speed perception; and
- *Transportation Research Laboratory (TRL), Crowthorne, England.* This organisation has been a leader in developing and testing novel road treatments, aimed at inducing changes in road behaviour through perceptual modification, since the early eighties.

1.3.3 Research Design & Project Report

The third and final stage of the study involved designing a more detailed research project to develop and test a range of possible low cost perceptual countermeasures to reduce excessive speeding identified from the literature review and overseas visits.

It was assumed that any future project would consist of both laboratory (simulator) activities early in the development phase as well as on-road trialing and evaluation of behavioural and crash outcomes after development but before the widespread adoption of these measures.

This report outlines the findings of the preliminary study and includes the updated literature review, a summary of the findings of the overseas visits and design and recommendations for further research and development in this area.

CHAPTER 2: LITERATURE REVIEW

There has been a variety of approaches used in an attempt to control excessive speeding on the road to improve road safety. Police enforcement is the most traditional and common approach to speed control (McMenomy, 1984; Vulcan, 1986; Road Traffic Authority, 1987). While this will always be an important and necessary approach to controlling vehicle speeds in general, the fact that a large number of motorists continually drive above current speed limits suggests that it is not a totally sufficient means of speed control (cf., Mostyn and Sheppard, 1980; Cowley, 1980; Elliot, 1981; Sanderson and Corrigan, 1984; 1986; and Stiebel 1986).

Others have argued for alternative (additional) forms of speed enforcement (Klein and Waller, 1971; McLean, 1977; Hogg, 1977; Sabey, 1980; Elliot, 1981; Fildes & Lee, 1993). Engineering the road and its immediate environment has been shown to have long-term effects on changing driving behaviour (Russam, 1979; Silcock and Walker, 1982; Parker and Tsuchiyama, 1985; Wright and Boyle, 1987). Countermeasures, such as speed humps, roundabouts, chicanes, slow points, and gateway treatments have all been used to make drivers slow down in particular locations. However, many of these measures are expensive and are not always totally successful in controlling speeds. Moreover, as they commonly involve introducing additional physical structures to the road or road setting, they can lead to increases in road crashes by their very presence.

A recent review of the relationship between speeding and the environment, behaviour, speed limits, enforcement and crashes was conducted by Fildes and Lee (1993). With the help of a number of specialists in the field of speed control and research, they developed a priority list of areas requiring further research and action. There was considerable agreement of the need for low cost perceptual countermeasures as another supplementary means of controlling vehicle speeds on the roadway.

A literature review, therefore, was undertaken, involving psychological, engineering and traffic safety literature, to illustrate the mechanisms by which perceptual countermeasures are likely to influence driver's speed behaviour and to detail a range of measures which have been used and evaluated in terms of their speed and crash reduction potential. This Chapter describes the findings from this literature review.

2.1 THE PERCEPTION OF SPEED

Driving involves a number of complex tasks including both route and path planning as well as vehicle control (and especially the need to respond appropriately in the face of an emergency). Implicit in performing these tasks safely is the driver's ability to make relatively accurate estimates of his or her own speed and that of other vehicles (Triggs, 1986). Assessing vehicle speed is often achieved through the use of a speedometer, however, on occasion, time does not permit this luxury. Notwithstanding the need to make instantaneous and accurate estimates of absolute speed, often judgements of relative speed are more important to the driving task, and these can not be gained from normal vehicle instrumentation. Hence, speed perception is an ability central to safe and successful driving.

In recent history there has been increasing interest in the effects of changing the appearance of the road environment to manipulate (either increase, or make more accurate) the perceived speed of a drivers own vehicle. When investigating such environmental manipulations an important distinction must be made between manipulations that affect drivers' *perception* of speed and those that affect drivers' *choice* of speed (Triggs, 1986).

Manipulations that affect drivers' choice of speed, often do so through alerting them to the presence of a potential hazard on the road ahead. Speed changes in response to such advice (eg; an advisory speed sign) commonly occur only after a conscious decision is taken by the driver to heed the warning offered. The decision regarding the degree of compliance with a given warning involves a great many considerations (eg. personal, attitudinal, economic, time pressure, mood, etc.).

Conversely, *environmental manipulations can also affect a drivers' perception of speed* without requiring deliberate decisions to comply, such as manipulations that influences the pre-conscious perception of speed. It should be noted that the distinction between the two is not always clear, for example, the way in which reflectorized guide posts affect a driver's perception of speed in a curve may involve both perception and choice.

2.1.1 What is Meant by Perception

Perception has different connotations for different people and professions. On one hand, it is often used to refer to the relatively automatic sensory processes of an individual interacting with his or her environment. In this sense, it is the first stage of the psychological process that occurs between a human being stimulated and subsequently responding and can be referred to as the *sensory perceptual* phase of driving.

Perception has also been used to describe the *deliberate and conscious thought processes* involved in human response, involving an individual's beliefs, motivations and desires. An example would be in the expression "*He perceived that politics was an important factor in the decision*". In this sense, perception involves higher order decision making processes where the social consequences of an action can influence the ultimate response. For convenience, this is referred to as the *cognitive perceptual* stage.

The speed at which a driver chooses to travel can clearly involve both of these perceptual constructs. While sensory perception will determine from the outset what information is available to a human operator in a particular stimulus situation, the internal states or social forces can nevertheless influence the form of the ultimate response to that information. Given that sensory perception is the basis for a human response in his or her environment, manipulating the visual cues involved in sensory perception on the road has the potential to bring about long-term improvements in road behaviour.

2.1.2 Sensory Perception Processes

It was argued that perceptual countermeasures are likely to be effective because they are aimed at modifying the relatively sub-conscious visual information arriving at the driver's eyes. While the evidence about visual perception processes is far from complete, it is worthwhile reviewing what is known about the perception of speed in humans.

There are only a limited number of studies that have attempted to explain how drivers perceive sensory information about speed from their environment. Early studies by Gibson (1950, 1958, 1968) and Calvert (1954) argued that a moving environment is coded on the retina of the eye as a pattern of blurred images, varying from zero blurring at the fovea (area of visual fixation) to maximum blurring at the extremities of the eye. The perception of speed, they claimed, is interpreted from analysing the differences in relative velocity across the surface of the retina.

Other researchers, however, have criticised this rather simple direct account of speed perception (e.g., Johnston, White and Cummings, 1973; Regan and Beverley, 1978; 1982). These researchers reported findings that could not be explained solely in terms of retinal streaming from a fixed point of expansion. They claimed that the visual processes associated with motion perception are more complex than those postulated by the early account by Gibson and his colleagues. However, most authors reporting on visual perception in driving do agree that relative coding on the retinal surface of the eye is an extremely important cue for the perception of speed (Gibson and Crook, 1938; Gordon, 1966; Moore, 1968; Lee and Lishman, 1977; Harrington and Wilkins, 1980). It is the extent of the retinal streaming explanation, rather than the concept itself, that seems to be contentious.

Salvatore (1972) and Triggs (1986) suggested that the way velocity is sensed may be dependent upon the absolute level of speed. They proposed that slow speeds are perceived from successive static observations of changes in position, while fast speeds seem to be assessed relatively directly. This hypothesis is intuitively attractive but needs further development before it can be tested empirically. Moreover, a simple static/dynamic distinction to explain the perception of movement has been criticised by other researchers interested in visual perception per se (Johansson, 1977; 1985; 1986; Warren & Shaw, 1985; Mace, 1985).

In any event, while retinal streaming may not be a totally sufficient explanation of the perception of speed, it does seem to explain many of the effects reported in the literature. In particular, it helps explain why the road surface is a primary cue for speed perception and how the immediate roadside environment can influence a driver's perception of speed. A number of studies have investigated the sensory aspects of speed perception and how visual cues can influence speed perception and these are discussed further.

2.1.3 Visual Pattern

Denton (1971, 1973) reported that speed judgements in a driving simulator and on the road were highly dependent on the nature of the visual pattern presented to the driver's eye. Transverse line treatments were introduced at selected roundabouts in the United Kingdom to induce drivers to slow down during their approach to these intersections. Evaluation studies (Denton, 1973; Rutley 1975; Helliard-Symons, 1981) reported subsequent reductions in speed, speed variation and lateral position, although the speed effects of this treatment tended to dissipate somewhat with time (Denton, 1973; Rutley, 1975).

Cairney and Croft (1985) and Cairney (1986) reported two studies which investigated the effects of various environment and road factors on drivers' speed judgements. Unfortunately, these studies used static photographs of roads and subjects made verbal speed limit responses; the results, therefore, are difficult to interpret solely in terms of sensory perceptions of speed.

More recently, Fildes, Fletcher and Corrigan (1987) and Fildes, Leening and Corrigan (1989) reported on drivers' judgements of safety and speed on urban and rural roads (straight and curved) during daylight and night-time conditions. This research demonstrated the influence of various road and roadside factors in a driver's perception of a safe travel speed and they listed a range of perceptual countermeasures to speeding. Unfortunately though, many of these measures have not been evaluated and their effectiveness is yet to be firmly established.

2.1.4 Road and Curve Negotiation

Tenkink (1988) reviewed the important characteristics of lane keeping and speed choice on straight roads. He noted that sight distance was a critical factor for safe driving performance, although beyond some minimum value, it may have less relevance (Allen, O'Hanlon & McRuer 1977). Minimum sight distance has been shown to vary depending on a number of driving variables including driving situation and vehicle speed where heading angle was highly correlated with driving performance (McLean & Hoffman 1973). Riemersma (1982) and Godthelp (1984) also argued that a derivative of heading angle (Time-to-Line Crossing or TLC) was critical for driving on straight roads. All these models suggest that lane position and sufficient preview of the road ahead are important characteristics of straight road driving.

The curve assessment process has also been shown to commence well in advance of the vehicle entering the curve (Cohen & Studach 1977; McLean & Hoffman 1973; Shinar, McDowell & Rockwell 1977; Vaniotou 1991). These studies showed that drivers typically scan an approaching bend using many brief (300-400 msec) glimpses scattered around the road surface. Hence, the initial curvature assessment process on the road occurs at least 100 metres before the bend where the rate of change of the visual image is relatively low. Gordon (1966) and McRuer and Klein (1976) demonstrated that the majority of curvature on the road is presented by the edges and centre line of the road.

2.1.5 The Effect of Roadway Characteristics

The accuracy with which drivers perceive their environment has been shown to vary under different road and road-side conditions. Shinar (1977) argued for an illusive curve phenomenon in driving where the curvature of an approaching bend in the road can be underestimated under certain curvature conditions. Indeed, Ten Brummelaar (1983) described the critical features of a road curve viewed in perspective for veridical perception. Many of these features were subsequently shown to influence a driver's perception of curvature (Fildes 1986). In particular, the subjects tested in this latter research program showed an inappropriate preference for the curve's angle over its radius when judging curvature.

Fildes et al (1987; 1989) set out to test the effects of various road and roadside characteristics on a driver's perception of speed. They found that the road surface (width, number of lanes, etc) had the strongest influence on judgements of safety and travel speed, while the roadside environment was also influential but to a lesser degree. Night illumination had a marked effect on speed perception and driver experience also influenced safe travel speed judgements in curves. From this research, they argued that manipulating the driving environment was likely to be successful in reducing travel speed in situations where drivers were not feeling overly safe (ie; narrow walled environments).

2.1.6 The Unobtrusive Nature of Perceptual Countermeasures

Unlike either of the other two traditional methods of speed control discussed previously, perceptual countermeasures attempt to bring about a change in behaviour *unobtrusively* (i.e., without the driver being aware necessarily of any change in his or her behaviour). This more subtle approach to speed control has several advantages over the traditional methods. First, by influencing the visual information on display to the driver, it is attempting to address the root of the problem. If drivers perceive a particular road situation to be safe, then applying cognitive restrictions involving conscious thought processes will have only a marginal effect on their behaviour. This is evident from the fact that police enforcement tends to be most effective as long as the deterrent is meaningful and obvious to the driver.

Also, modifying the perceptual environment is less likely to annoy or frustrate the driver and therefore more likely to be of long-term benefit. A change in visual input to appear "less safe" will probably go by unnoticed and less likely to lead to "accident migration" by forcing speed deviants onto other roads. It could be argued that subtle changes to the road or the environment may be the only effective long-term means of influencing drivers who blatantly refuse to obey the law by driving at excessive speeds. In any event, removing restraints which people believe to be unnecessary should result in safer driving for the total driving population.

Finally, perceptual countermeasures do not involve introducing additional hazards on the roads in the same way as Local Area Traffic Management (LATM) devices have in the past. Most of these treatments simply involve paint, plastic or gravel surfaces applied to the road surface to create the desired effect. Apart from the obvious road safety benefit, this can also mean that the measure is likely to be relatively inexpensive, may be easier to justify in terms of cost/benefit effectiveness, and enable more treatments per budget than other methods.

2.1.7 Likely Effectiveness of these Measures

There is a suggestion that these measures are not always likely to be equally effective in reducing travel speed. As reported above, environmental countermeasures to speeding will be very much dependent upon a driver's perception of safety in a particular location. Fildes et al (1987, 1989) found that when perceptions were overly safe such as in spacious environments with high quality wide roads, modifying the environment will to some degree change this perception but is less likely to be translated to slower travel speeds. In these situations, they claimed that other factors, such as a desire to be law abiding or not to be caught and punished for speeding, are also exerting some influence on a driver's choice of travel speed. Hence, sensory perceptual factors are less likely to be critical in these settings.

However, when a driver's perception in a particular location is less safe (for instance, in a heavily walled narrow environment such as a forest), then modifying the environment in this setting is more likely to directly translate to reduced travel speed. That is, speed perception is more dependent upon sensory inputs in these more "*threatening*" settings and less dependent upon other social or enforcement factors. What this means is that the use of perceptual countermeasures may need to be selective for maximum effectiveness. The authors claimed that while they are especially suited to "*black-spot*" speed applications, they may also be useful on particular roads that are over-designed and speed inducing. In the longer term, these measures need to be balanced against the need for high design speeds in road construction.

2.2 SPEED PERCEPTION COUNTERMEASURES

In arriving at a list of potential perceptual countermeasures for speed, evidence was drawn from a range of sources including relevant literature reviews in this area, other studies that have evaluated the effectiveness of particular perceptual treatments on speed or driving performance, and local knowledge of measures that have been or are being contemplated for use in this country or elsewhere.

2.2.1 Transverse Road Markings

Perhaps the most well known and widely used perceptual road treatment to reduce vehicle speed at roundabouts and intersections is the transverse line treatment introduced in the U.K. by Denton (1973). The treatment consists of a series of contrasting lines painted across the road on the approach to a road hazard that increase in frequency as the hazard approaches. It is assumed that they provide a systematic perceptual aid for drivers as they decelerate on approach to the roundabout or intersection (Denton, 1971). Figures 2.1 and 2.2 shows some examples of this particular road treatment in the U.K. and more recently in Australia.

Several authors have attempted to evaluate the speed and crash consequences of these treatments. Denton (1973) reported reductions in mean travel speed of 23 per cent and 37 per cent reduction in speed variance immediately after installation of the treatment. However, mean speed reductions subsequently fell to only 8 per cent one year later, presumably because of a "novelty effect" with this treatment (Rutley, 1975). Agent (1980) also found a large decrease in vehicle speed after transverse lines were installed at several hazardous locations in the USA, but noted a subsequent increase in speed one year later (crashes, however, remained consistently lower, although he commented on interpretation problems due to central tendency effects and other statistical difficulties). Havell (1983) reported a 10 per cent reduction in mean vehicle speed one year after installation of transverse bars in the approach zone of a roundabout at Fountains Circle in Pretoria, South Africa. Unfortunately, though, none of these researchers examined speed reduction effects beyond 12 months.

Helliar-Symons (1981) examined the crash consequences of 42 transverse bar installations in the U.K. and claimed a decrease in speed related crashes of 57 per cent over 4 years. Furthermore, he showed this treatment to be highly cost-beneficial. Silcock and Walker (1982) argued that crash reduction from bar markings was more apparent in the U.K. for access roads than in local streets. This finding, however, was deduced from other studies and did not involve collecting any new data.

More recently, Jarvis (1989) reported on the effects of yellow bar markings on driver speed and braking behaviour in Victoria and reported that the markings did reduce approach speeds, including excessive speeders over 12 months. However, he argued that these speed reductions were not through manipulation of the visual field (modified speed perception) but rather that *"the effect of the markings is that of a very large hazard warning device which is impossible for the driver to disregard."* However, this still needs to be firmly established.

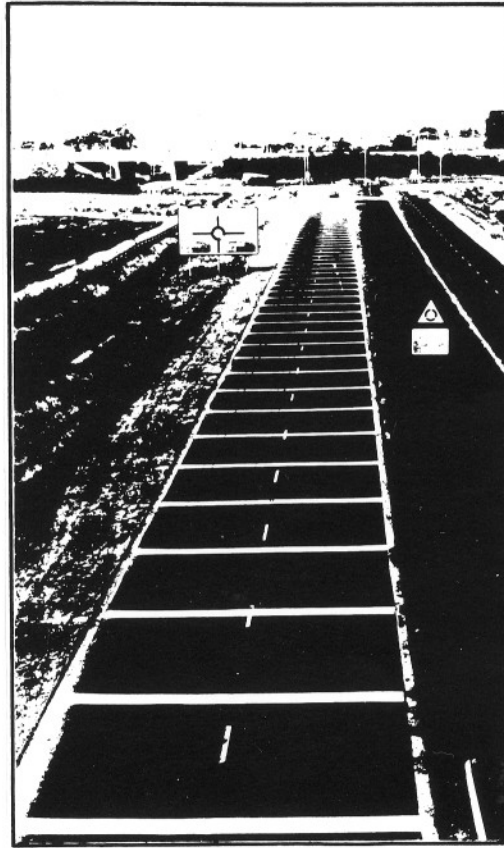


Figure 2.1 Transverse line treatment at the approach to Windsor, England (Denton 1973)



Figure 2.2 Transverse lines using different road metal on Northern Highway in Victoria (from Fildes, Leening & Corrigan 1989).

Lee and Jamaluddin (1990) also reported on a study of a series of yellow bar carriage markings on drivers' speed behaviour suggesting that thermoplastic markings resulted in speed reductions, both mean and 85th percentile, immediately after installation (no longer term follow-up was conducted though). They reported that their results were highly variable from site to site, suggesting that sensory perception had some influence here.

Uber (1992) interestingly tested the differential effects of white and yellow road markings (both longitudinal lines and rumble bar enhancements) on the alternative approaches to one or two rural township in Victoria. They found greater reductions in both mean speed and the 85th percentile speed for *WHITE* over *YELLOW* and this seemed to be consistent for both longitudinal and lateral treatments. This raises the possibility of colour dependent perceptual effects which needs to be thoroughly investigated.

2.2.2 Transverse Markings and Rumble Bars

Many of these visual treatments are "*enhanced*" with rumble effects from the vehicles crossing these bars through the use of raised markers, varying grades of road metal, or road scoring procedures (Figure 2.2 is in fact one such combined treatment installation on the approach to a dangerous tee-intersection in rural Victoria).

Enustun (1972) evaluated a combination line and rumble bar installation on the approach to a freeway interchange in Michigan, USA. Using a series of contrasting plastic strips adhered to the road surface to provide the required visual and rumble effects, he reported an immediate drop in mean speed of 12km/h (15%) and an 8km/h (10%) one month after installation without any change in before and after speed variation. He further claimed that this process was extremely durable to wear and tear (including snow plowing operations, with special precautions). Interestingly, though, when compared with the research reported earlier, this combination road treatment does not seem to have produced any additional speed reduction benefit over that of the lines alone.

Zaidel, Hakkert and Barkan (1986) tested the effects of rumble strips and painted stripes separately at a cross intersection in Israel. They reported that painted stripes had only a minor influence on behaviour while rumble strips lowered speeds by 40 per cent on average. They also noted that both treatments had a small but positive effect on compliance rate (with the speed limit) and that crashes were down during the 4 years after treatment. Importantly, they reported that rumble effect benefits persisted one year after treatment. As the rumble strips were similarly painted yellow to the painted stripes, these authors claimed that these results show the efficacy of rumble strips over painted stripes. This needs to be moderated somewhat by the fact, though, that painted stripes did, in fact, lead to improved speed compliance.

A number of reports were uncovered which reported positive benefits of rumble bars or grooves "alone" on driver speed behaviour (Gupta 1991; Thompson & Coles 1990; Uber 1992), run-off-the-road crashes (Tye 1988; Hall 1991) and drink-driving performance for those with low (0.07) BAC's (Gawron and Ranney 1988). In addition, many of these improvements persisted long after implementation of the treatment. However, Cynecki, Sparks and Grote (1993) failed to find any benefits whatsoever for rumble bars alone on the approach to a pedestrian crossing in Phoenix, although this was a rather scant treatment with little probability of success. Gupta (1991) reported increases of 6 to 8 decibels in noise resulting from their grooved treatment and many authors noted that residents in the near

vicinity often complained about the added noise from these treatments. Tye (1988) further claimed substantial injury cost savings from these treatments which, while not computed or stated, would appear to be highly cost-beneficial.

The degree to which rumble bar treatments are "independent" of visual effects is difficult to assess from these studies. Many of the rumble treatments included painted finishes which would have a marked perceptual and auditory effects. Others would still have some perceptual effects from differences in contrasts, either from the use of different gravels (size and colour) or marking effects in the case of grooving. The singular benefits of paint to rumble effects is rarely evaluated in these studies. Several authors also remarked about the need to use these treatments scantily to avoid losing the novelty effects. This assumes that their benefits are exclusively from novelty and this has not been clearly demonstrated. There is a need for further research into what causes these speed reduction and crash benefits.

2.2.3 Lane Width Reductions

If road surface has a primary role in drivers' perceptions of speed (as found in this program of research), it seems logical to expect the width of the travel lane to have a strong influence on perception and travel speed. Indeed, speed perception research by Fildes, Fletcher and Corrigan (1987) demonstrated that reduced lane width and number of lanes were generally associated with lower safe operating speed responses on urban and rural straight roads (and in some instances actual lower free speeds), although this result was often confounded with different classes of roads and varying speed limits.

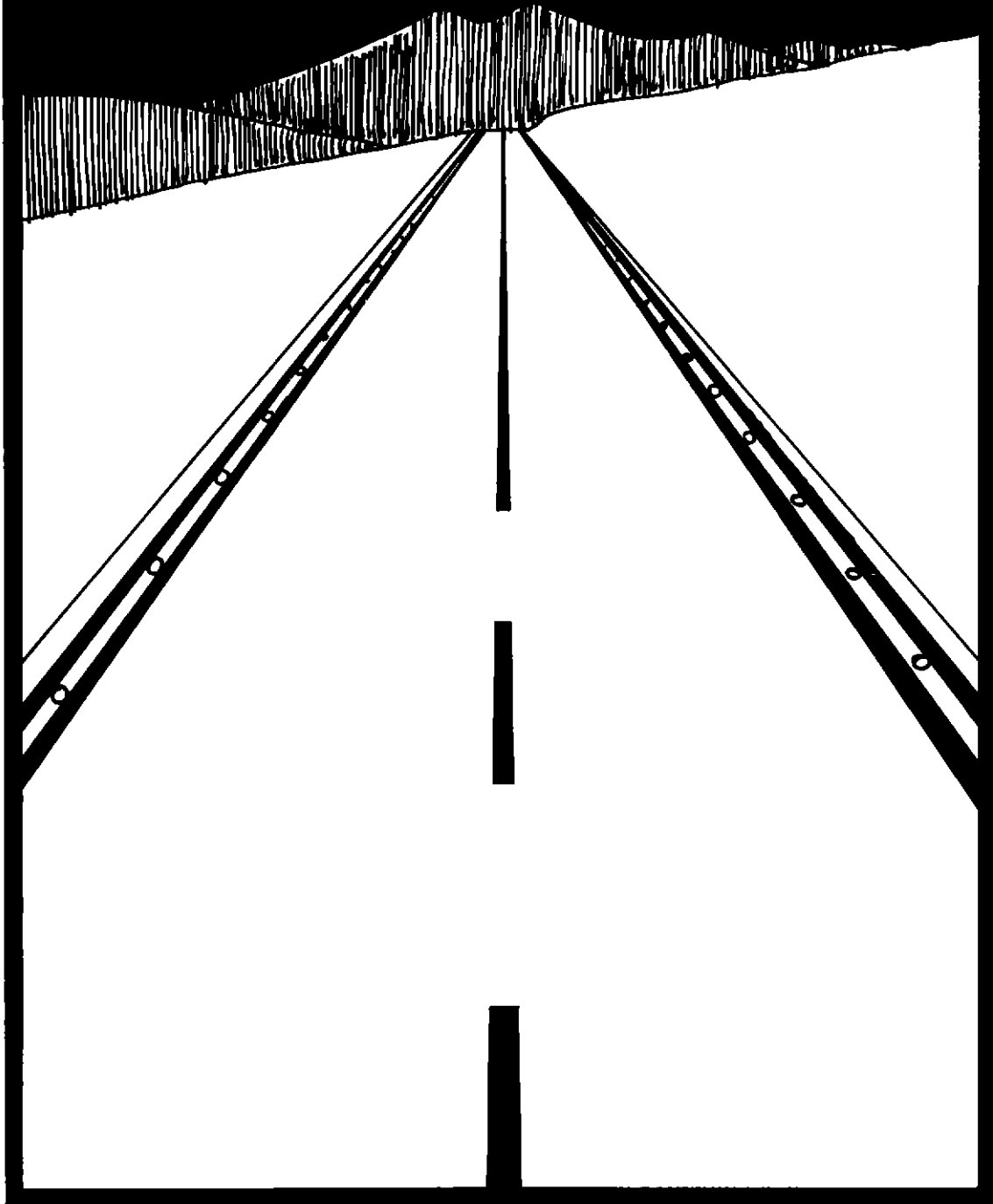
McLean and Hoffman (1972) reported a change in driver steering behaviour from wide lanes (3.7m) at low speeds (42km/h) to narrow lanes (2.5m) at high speeds (80km/h) that they attributed to a perceptual difference in vehicle control for straight road driving on these different lane widths and vehicle speeds. In addition, they reported that shoulder width also influenced steering strategy (through perceptual differences apparently), although this was never evaluated in their research. There was some suggestion in Fildes et al (1987) that speeds on wide divided road pavements was perceived differently than that on equivalent narrow surfaces, although opposite to that predicted by McLean and Hoffman (1972).

Lum (1984) showed that duplicate longitudinal pavement markings with raised pavement markers set between them and the original lines to create an impression of a narrower residential street had no effect on vehicle speed (see Figure 2.3). He did, however, report a tendency for drivers to stay within narrow lanes (2.7m), but their conclusion that drivers' perceptions of road width remained unchanged was, at best, speculative using their methodology. It would be interesting to test this particular treatment more fully, especially its effect without a plain, wide verge area.

2.2.4 Longitudinal Edge line Treatments

Several studies have attempted to assess the effect of the presence or absence of standard edge line treatments on the side of the road on vehicle speed, performance and road crashes. Witt and Hoyos (1976) found that edgelines in the approach zones of rural road curves resulted in drivers adopting a more suitable curve entry speed and travel path in a driving simulator. This difference, however, was dependent on the type of treatment and the speed findings were not particularly robust. They noted that:

DUPLICATE LANE MARKINGS
(Lum 1984).



*Figure 2.3 Duplicate longitudinal pavement markings used at one residential site
(from Lum, 1984)*

"The question remains open as to whether the effect was due to the fact that the advance information directly influenced speed perception or whether the driver decoded the information and consciously selected a more appropriate speed."

Triggs and Wisdom (1979) and Triggs (1987) reported differences in the pattern of lane-keeping and lateral position behaviour between matched road sections with and without centre line and edge line treatments. Edgelines and centrelines enabled drivers to maintain a more consistent travel path and safer travel strategy, especially at higher speeds. However, they did not test for travel speed differences directly (travel speed was used as a control rather than an independent variable in this study).

Potter Industries (1981) argued that wide edgelines in the USA, Germany and UK reduced road crashes in these countries, particularly those crashes involving drinking drivers. However, most of their evidence was derived from other studies, some of which are unavailable. Johnston (1983) also reported a perceptual advantage for wide edgelines in conjunction with chevron signs on rural curves for drinking drivers. However, neither of these two studies reported specifically on the speed consequences of variable edge line types.

Willis, Scott and Barnes (1984) applied solid and broken edgelines on two hazardous sections of roads in south-west England. They found a significant reduction in the number of single vehicle loss of control crashes (especially in dry weather) but less impressive reductions in other crash types. Unfortunately, they didn't evaluate the perceptual, speed behaviour or other performance effects of these treatments in their study either.

2.2.5 Lateral Edge line Treatments

A number of investigators have examined the effects of novel painted treatments to the edges and shoulders of straight and curved roads. Parker and Tsuchiyama (1985) reported on the effects of several edge-of-the-road treatment evaluations by other researchers. In particular, they noted the use of a herringbone pavement marking pattern of decreasing frequency in the approach to a roadside hazard which they claimed resulted in a reduction of mean travel speed (although no reduction in speed variance).

Figure 2.4 illustrates the herringbone pavement marking system listed in this report (unfortunately, the reference to the original source of this treatment is not clear from this report).

In their report on speed-reducing devices in residential areas, the Swedish Road Safety Office (1982) describe a painted line treatment used in conjunction with speed humps that could have interesting perceptual effects for drivers. The treatment consisted of a chequered pattern that they prescribe for transverse application on speed humps (see Figure 2.5). However, it could conceivably be used for both transverse and longitudinal treatments, either on the edges or centre line of the road. Unfortunately, the perceptual effects of this treatment do not appear to have been evaluated by this organisation.

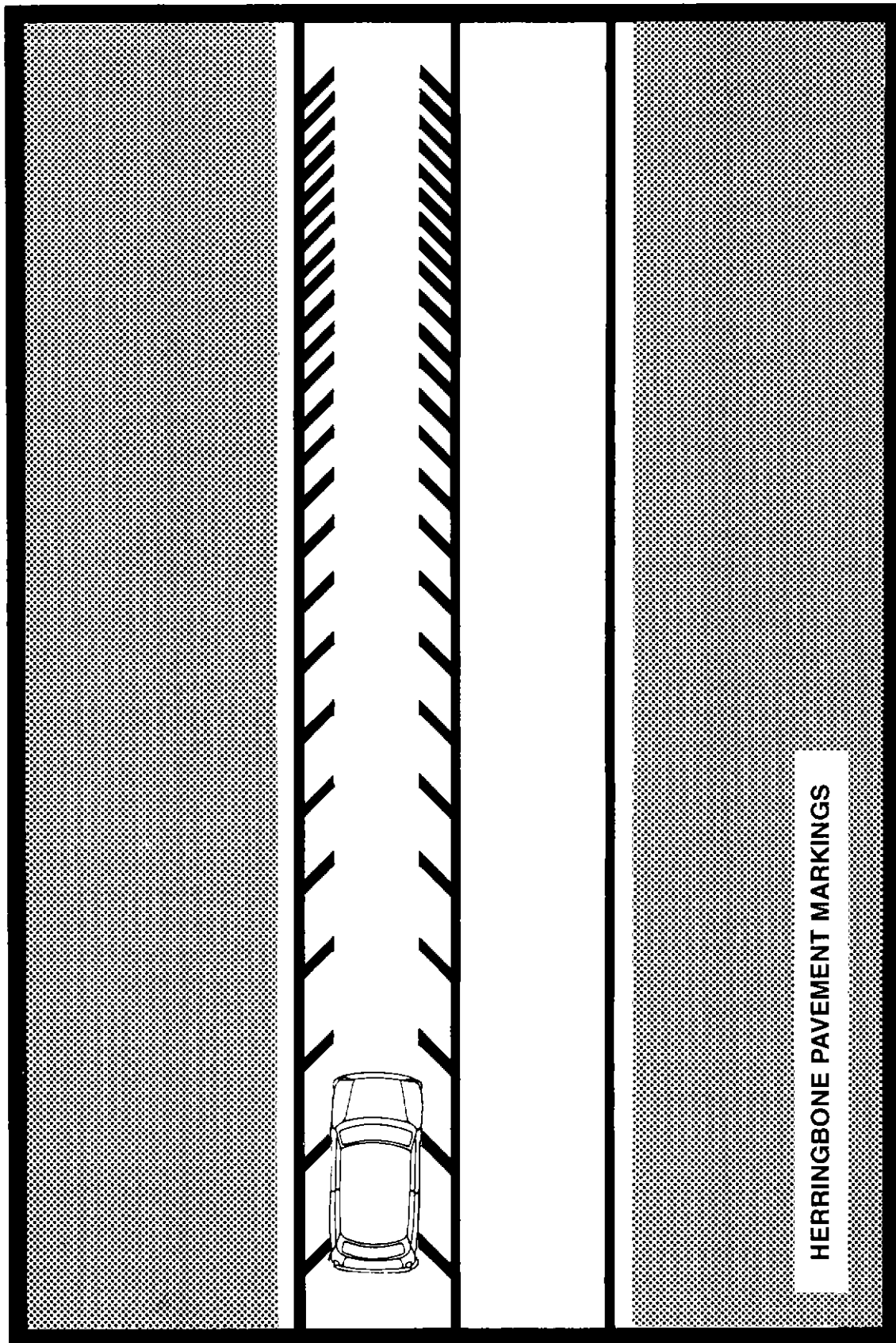


Figure 2.4 Herringbone pavement markings used to create a more desirable deceleration pattern on the approach to a road hazard (reference source unknown).

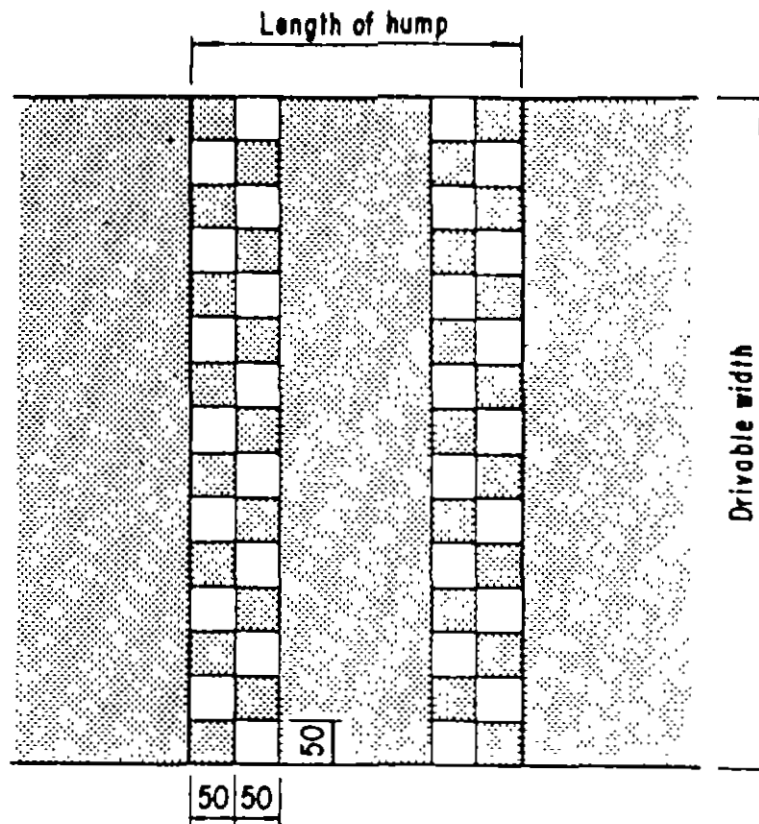


Figure 2.5 Chequered road markings used to delineate the edges of a speed hump (from Swedish Road Safety Office, 1982).

Rockwell, Malecki and Shinar (1975) applied a painted line treatment to the inside edge of a rural road curve to increase apparent curvature by enhancing the inside perspective angle on the approach to the curve (see Figure 2.6). This treatment resulted in speed reductions in the approach zone of the curve but not in the curve itself. However, they did note significant reductions in speed variance for all vehicles negotiating the curve as a result of this treatment. Their evaluation unfortunately did not extend beyond 30 days after the treatment was applied.

In a later report, Rockwell and Hungerford (1979) also reported the effects of applying a modified form of transverse striping to the outside lane only of a two-way rural road curve for up to 30 days after application (see Figure 2.7). They found that this treatment caused a marked reduction in approach speed and curve negotiation speed for the full evaluation period and attribute this to a modification in curve perception.

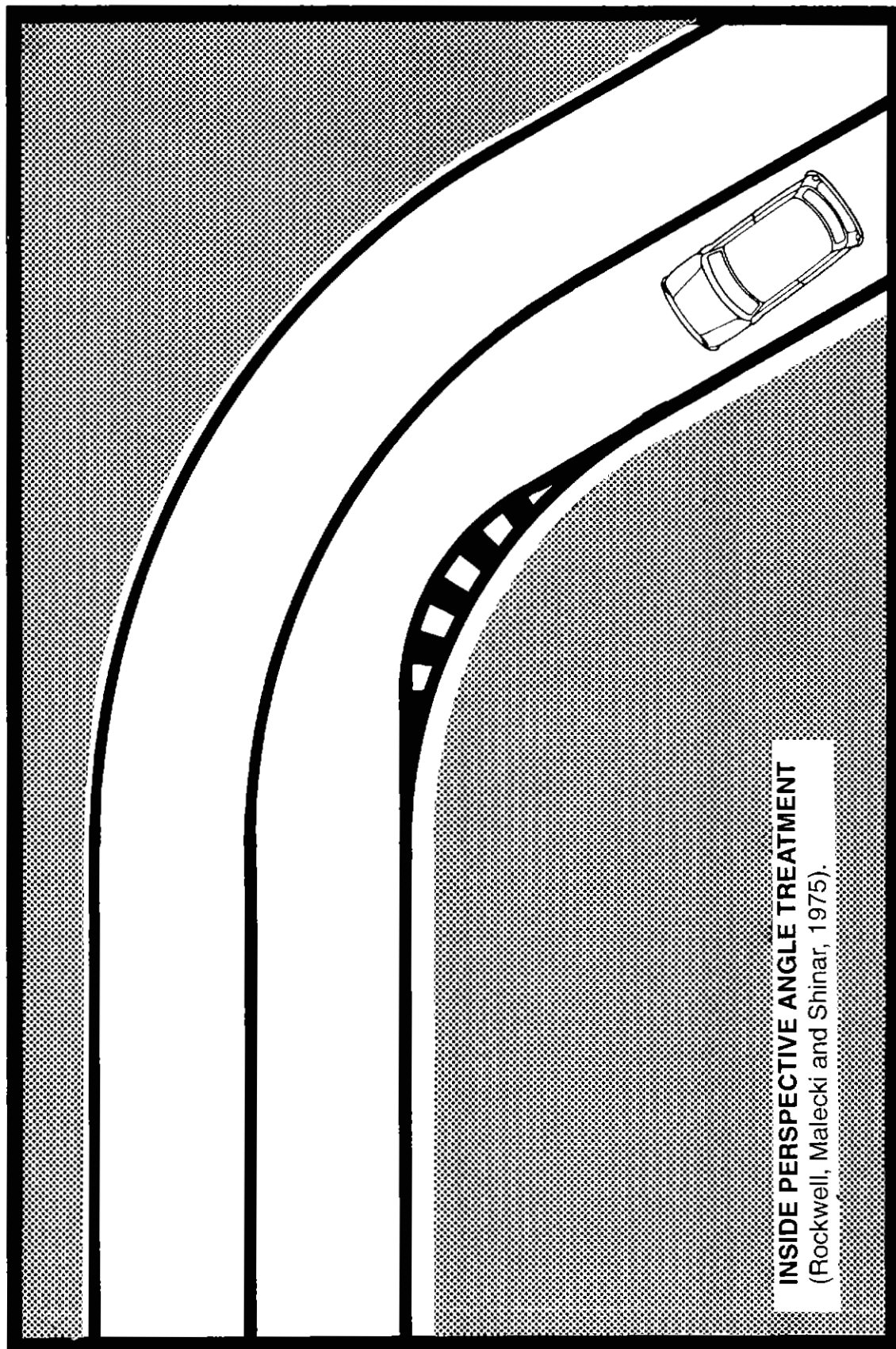


Figure 2.6 Inside perspective angle treatment (from Rockwell, Malecki & Shinar 1975)

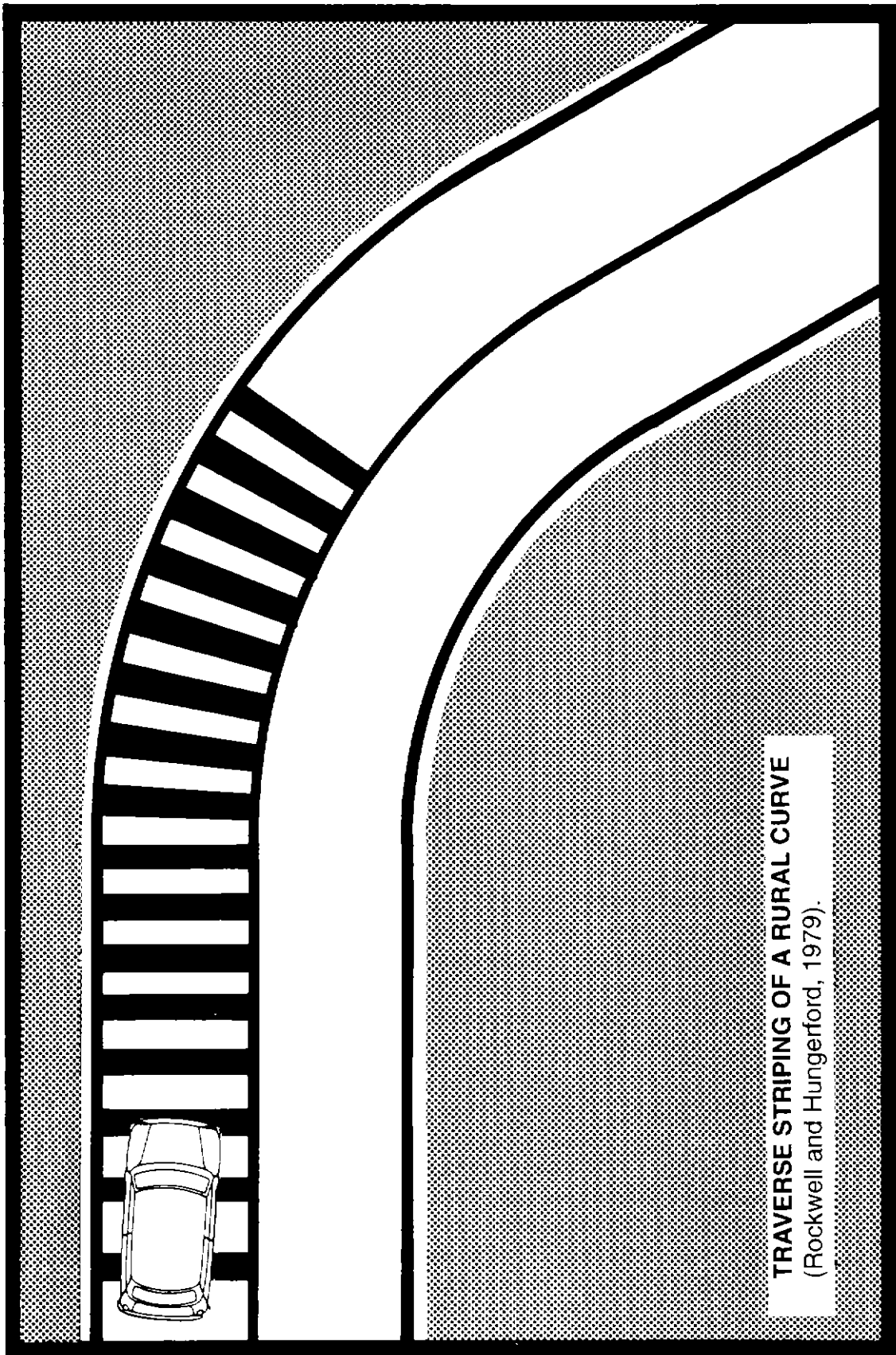


Figure 2.7 Transverse striping of a rural road curve (Rockwell & Hungerford, 1979)

2.2.6 Guideposts and Chevron Signs

Hungerford and Rockwell (1980) also attempted to modify drivers' behaviour at rural road curves by the use of novel guidepost and chevron sign delineation systems. At 2 rural road curves, they varied the height of post delineators from ground level to 10 feet high from the approach to the exit positions and also manipulated the perceived radius of the curve by relocating the guideposts to appear to give the appearance of a tighter radius road curve. Three large chevrons were also applied at an additional 2 road curve sites (Figure 2.8 shows the treatment layout adopted at these curves diagrammatically).

Their results showed reduced vehicle velocities (especially for high speed vehicles) for the novel guidepost system at night immediately after installation, but there were no significant speed benefits for chevron signs. These speed differentials, however, were not apparent during the day and were not tested beyond 1 month after installation.

Agent and Creasey (1986) also tested a variety of curve delineation treatments comprising variations in pavement delineation (raised pavement markers, transverse stripes and rumble strips) and shoulder delineation (post delineators and chevron signs). Figure 2.9 shows one sample site treatment used in this research. They found significant decreases in vehicle speed at the point of entry of the curve for a number of pavement treatments but fewer for shoulder treatments. Moreover, they reported that pavement delineation treatments did reduce the number of lane encroachments and crashes at most test sites. They argued that while chevrons had more influence on speeds and encroachments than post delineators, pavement delineation generally had a greater effect on driver behaviour than shoulder delineation. This is consistent with the findings of Fildes et al (1987). They also confirmed Hungerford and Rockwells' claim of a perceptual advantage when varying the height of the post delineator in laboratory tests, but this did not appear to have been tested on the road itself by these authors.

2.2.7 Special Road Treatments

The South Melbourne City Council in Victoria have recently been experimenting with various perceptual road treatments as an alternative crash countermeasure to Local Area Traffic Management devices. One measure they adopted in several locations includes a road marking system comprising a white gravel medium strip and a one-metre hatched edge line marking (both in conjunction with solid edge lines) to create a perceptually narrow road surface and travel lane. Figure 2.10 shows an example of this particular treatment.

Fildes, Leening and Corrigan (1989) conducted a simple before and after speed evaluation of a new installation using a variation of this treatment on Kerford Road, South Melbourne, Victoria. The treatment consisted of a white gravel perceptual separation strip and associated edge line markings being applied between the moving and parked vehicles (which was also used as a bike path on occasions). This separation strip effectively reduced the travel lane width from 5.0m to 3.7m. Corner bollards and bluestone paving at the intersections were also added subsequent to the speed observations (see Figure 2.11).

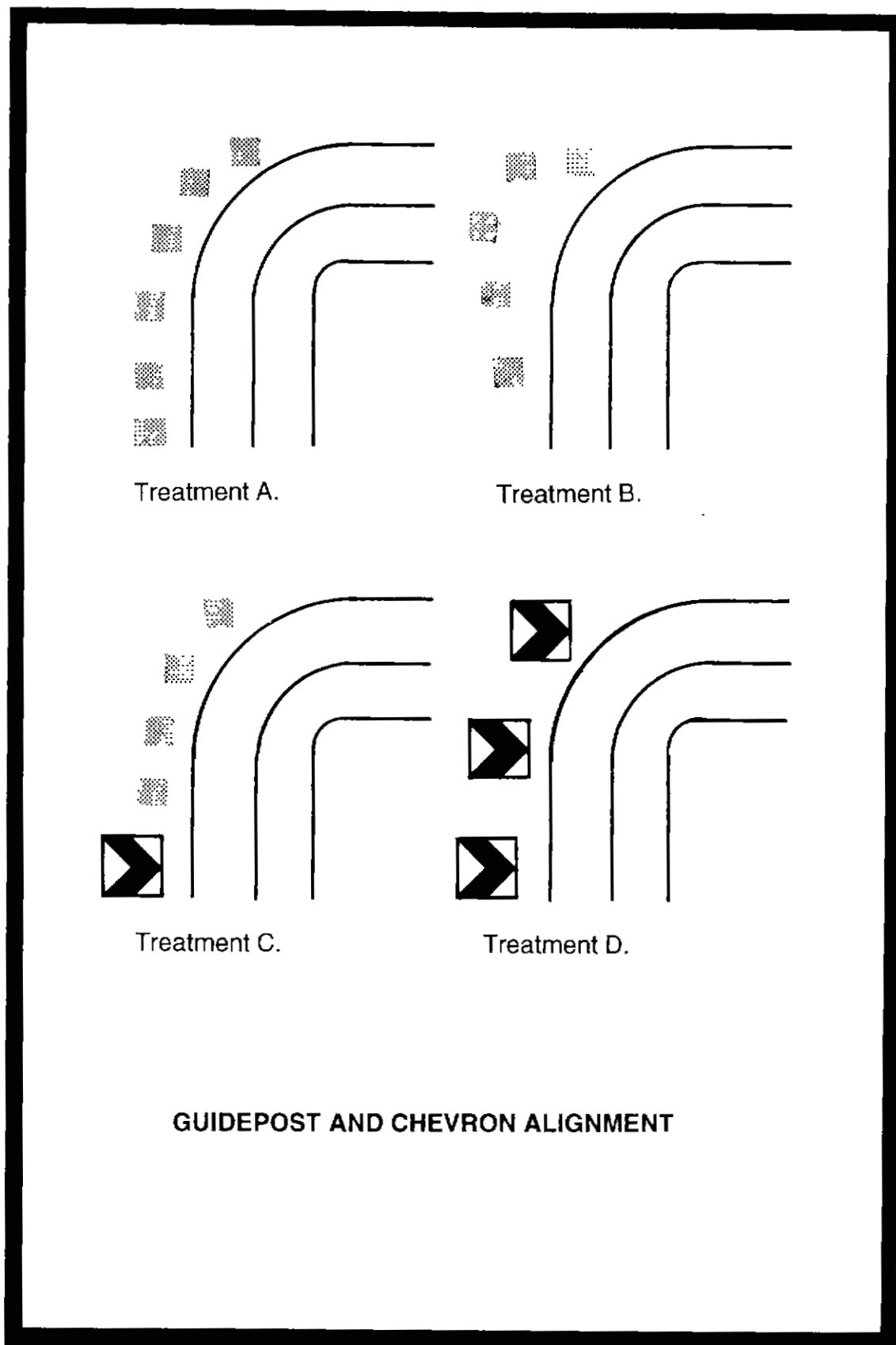


Figure 2.8 Guidepost & chevron arrangements tested by Hunderford & Rockwell (1980)

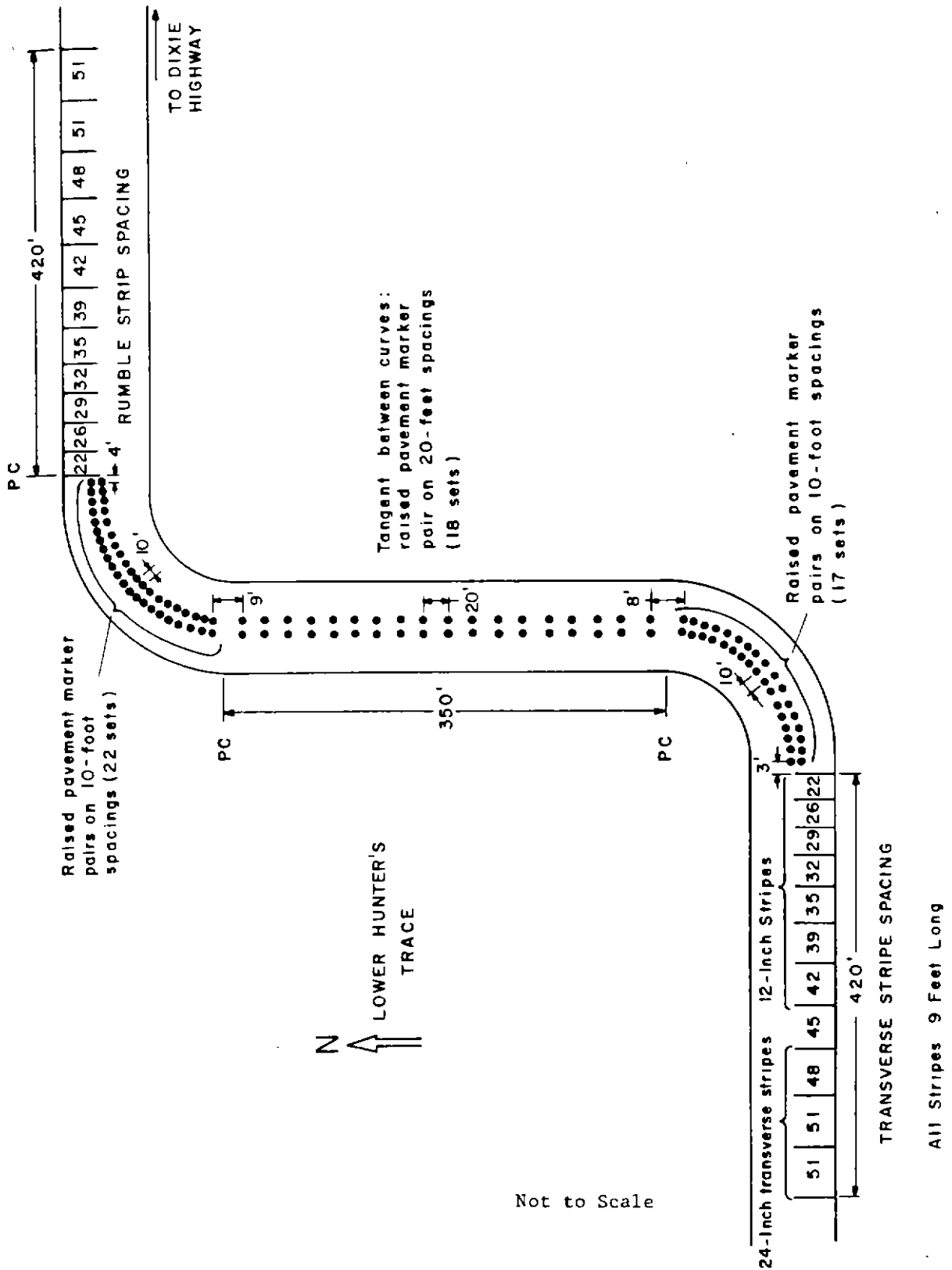


Figure 2.9 Sample road layout tested by Agent & Creasey (1986)



*Figure 2.10 Median & edge treatment used on Lakeside Drive, Albert Park, Melbourne
(from Fildes et al 1989)*



*Figure 2.11 Perceptual narrowing treatment applied to Kerford Road, South Melbourne
(from Fildes et al, 1989).*

A major finding of this study was a reduction in free speeds of 3km/h (5%) after installation of the treatment with no appreciable change in traffic volume. Control sites had no similar change in free speeds over the same period. It was not possible to evaluate the perceptual effect of this road treatment on drivers' speed judgments, unfortunately, because of time constraints. This result, therefore, needs to be tested further to demonstrate its long-term speed perception and road crash effectiveness.

Nevertheless, this simple evaluation demonstrates the potential for this particular road treatment to reduce vehicle speed in these locations. Moreover, the findings generally support many of the previous finding on lane width reductions and edge-of-the- road treatments. As the treatment cost is minimal compared to other physical speed management devices, it further suggests that reducing vehicle speeds through perceptual treatments at hazardous locations may be particularly cost-beneficial.

2.2.8 Bridge Treatments

A few papers specifically addressed speed reduction treatments on bridges which have potential for more widespread use. Vey and Ferreri (1968), for instance, reported lower speeds for 3m compared to 3.4m lane widths on two bridges in the USA. DeLuca (1985) also examined the effect of reducing lane width on an urban freeway in Miami from 3.7m to 3.4m. He reported no significant difference in vehicle capacity (presumably this meant similar vehicle speeds), but he did find subsequent crash improvements. Neither of these studies, though, assessed perceptual consequences directly. Interestingly, these findings complement the research discussed earlier on road narrowing effects for all roads.

None of these researchers, though, discussed the implications of narrow lanes in terms of increases in crash rates. There is clearly a need to relate narrow lanes with driver tracking behaviour and lateral separation requirements. It could be that narrow lanes lead to increased vigilance and improved tracking with no crash consequences but this needs to be established.

Emmerson and West (1985) applied shoulder rumble strips on the approach to bridges on two Oklahoma turnpikes. This treatment consisted of 3m long, concrete high contrast bars, 15cm x 3cm sections, applied to the sealed shoulder region of the road surface to provide a visual and auditory warning for drivers as they approached these narrow bridges. They reported a reduction of up to 56 per cent in the numbers of crashes at these sites over a 4 years before and 4 years after time period, which yielded an average benefit/cost ratio of between 29:1 and 73:1. Unfortunately, they failed to report speed differences before and after at these sites so it is difficult to know whether these crash improvements may have had a perceptual basis.

Bowman and Brinkman (1988) examined the effectiveness of low cost countermeasures in reducing vehicle speeds at nine narrow bridge sites in US. The treatments comprised variations in edge line width, number and spacing of post-delineators, raised pavement markers and object markers in the approach zone, different centre line treatments and sign variations. They concluded that there were no statistically significant reductions in the mean speed or lateral placement for any treatment. However, these countermeasures did produce significant reductions in speed variation for all vehicle types and time periods which they noted resulted in more uniform driving behaviour. Obviously, this variance reduction would translate into speed reductions for excessive speeders (85th percentile reductions), although this was not specifically reported on by these authors.

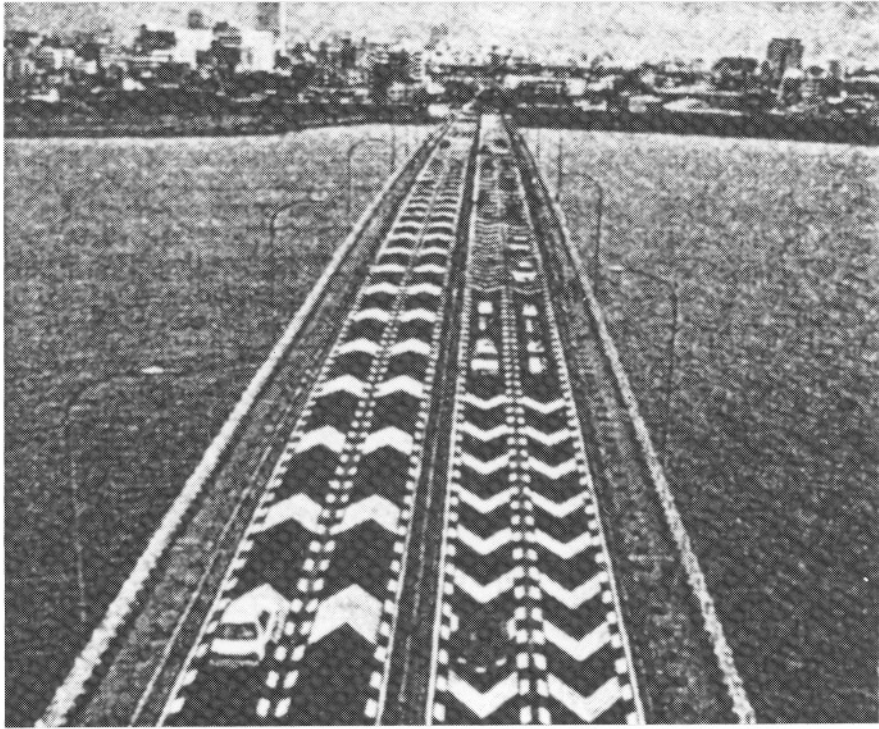


Figure 2.12 Illusory road treatment on the Yodogawa Bridge Osaka (from the Journal of the International Center, Academy for State & Local Government (USA))

A more marked bridge treatment was briefly discussed in a recent article in the Journal of the International Center, Academy for State and Local Government (US) of the Yodogawa Bridge, Osaka, Japan (see Figure 2.12). This "optical illusion" treatment comprises heavily painted geometric arrows and broad "hatched" edgelines which "*makes the bridge deck roadway seem narrower to motorists than it actually is*". The article reported that in the 6 months since the treatment was installed, no accidents had occurred compared with 2 deaths and 9 injuries from 10 crashes in the year prior to treatment. While they noted that the treatment "*made drivers slow down*", no data was provided to support this claim.

2.2.9 Road Signs

The final category of delineation treatments likely to induce a reduction in speed perception includes advisory speed signs and other dynamic sign systems. While some of these devices tend to require a deliberate conscious decision about travel speed rather than to influence speed perception automatically (that is, perception at a basic sensory level excluding higher cognitive levels of human information processing), they have been included here nevertheless for completeness.

Summala and Hietamaki (1984) reported speed changes of 2185 drivers' responses to an experimental road curve sign advising either danger, children crossing, or an advisory speed limit of 30km/h. They found reliable speed reductions to all signs dependent to some degree on the position of observation before the curve, but they did report greater speed reductions for danger and children signs which they classified as "more significant".

They argued that the effectiveness of road signs at reducing speed was therefore dependent upon motivational factors of the drivers involved (Summala and Naatanen, 1974; Summala and Hietamaki, 1984), a view shared by other researchers in the perception of road signs (Hughes and Cole, 1984).

Koziol and Mengert (1978) conducted a before and after study to evaluate the effectiveness of "dynamic sign systems" to alert motorists to the presence of narrow bridges on two lane rural highways in the USA. Of the four sign systems tested, they found that a strobe light sign combination reduced mean vehicle speed by 3km/h during the day while a flashing beacon sign combination had a similar effect on vehicle speeds at night. None of the other signs had a significant speed effect over the existing standard static sign and there were no appreciable differences in lateral position for any of the four signs tested.

While its unclear the precise nature of the perceptual influence they were measuring, they noted that signs were not as effective on driver behaviour in their study as the presence of opposing vehicles or roadway geometry.

2.3 SUMMARY OF TREATMENT EFFECTS

The review of the effects of potential speed perception countermeasures is summarised in Table 2.1 and the following discussion:

1. Transverse road markings appear to have had a significant long-lasting influence on driver's perceptions of speed and road crashes at hazardous intersections and roundabouts. The addition of rumble bar effects at these locations appears to have additional speed reduction benefits over just the lines themselves, although whether this is purely a visual perception effect or something else is not clear at this stage. Rumble bar effects are long lasting but increase noise and not always well received by local residents.
2. Transverse striping on the edges and shoulder regions of the road may also have a positive influence on vehicle speeds at specific hazardous locations. The approach zones of certain intersections and dangerous curves seem especially suited for this treatment. Rumble bars would seem to have an added advantage in some cases, although their full effects need to be established further in the perception of speed on the road. The mechanism by which transverse treatments affect driver behaviour still needs to be firmly established.
3. There seems to be some evidence of speed and crash reductions benefits from reduced travel lane widths, but the effects may be dependent upon the lane widths and class of road involved. It seems that travel lanes of 3.0m or less are necessary to induce sufficient perceptual effects to ensure free speed reductions on the road.
4. A slight advantage in speed perception may be gained from the presence of enhanced centre line and edge line treatments on the road. Standard edgelines, however, seem less likely to produce significant reductions in travel speed and road crashes than other kinds of road surface treatments. There might be some added perceptual advantage in the use of novel edge and centre line treatments, although the performance and safety effects of these treatments needs to be carefully evaluated prior to their use on the road.

TABLE 2.1
Summary of Reported Effects of Perceptual Countermeasures

TREATMENT	INSTALLATIONS	PERFORMANCE	SAFETY
		EFFECTS	EFFECTS
1. Transverse lines	urban & rural roundabouts, curves, intersections, dangerous bridges	speed reductions & improved lane travel	crash reductions
2. Transverse lines & bars	rural intersection and a freeway interchange	speed reductions	unknown
3. Rumble bars alone	hazardous locations, intersections, pedestrian crossings	some speed reductions performance enhancements increased traffic noise	crash reductions
4. Lane width reductions	urban & rural straight roads residential streets, bridges	better lane keeping improved steering speed reduction ?	crash reductions
5. Longitudinal edgeline treatments	straight road treatment rural curves	minor speed reductions better lane keeping	crash reduction (esp. drunk drivers)
6. Lateral edgeline treatments	approaching roadside hazards, curves, narrow bridges	speed reductions before & during curves (bridges ?)	crash reductions (bridges)
7. Special bridge treatments	narrow & hazardous bridges	speed variance reductions (speed reductions unclear)	crash reductions
8. Guideposts & chevrons	rural curves	speed reductions (chevron - unknown effects)	some for chevrons
9. Special treatments	urban & residential roads & streets,	speed reductions	crash reductions ?
10. Road signs	residential streets, rural highways & bridges	some speed reductions	unknown

5. There seems to be some potential for novel guidepost arrangements and innovative use of chevron signing to influence speed perception and road crashes on rural curves that are particularly hazardous at night. However, these shoulder effects may not be as marked as on-road delineation treatments.

6. Special road treatments such as the white gravel median with edge line marking, too, has potential for reducing travel speed in some locations. In addition, a number of other novel road treatments show some promise for reducing travel speeds and crashes in certain locations. However, the perceptual benefits and range of effects of many of these treatments need to be tested further.

7. While signs may have a marginal effect at reducing vehicle speeds in some locations, they seem dependent on a driver's motivation and expectation and the "element of surprise". These are hardly desirable characteristics for any long-term benefits in the perception of speed.

8. There was some evidence that reducing vehicle speeds through perceptual treatments at hazardous locations may be particularly cost-beneficial. Further testing is warranted to show the full crash reduction potential of perceptual countermeasures.

CHAPTER 3: RECENT DEVELOPMENTS OVERSEAS

To catch up with recent perceptual countermeasure developments in Europe which are not well reported in Australia, visits were made to several organisations as part of the review of existing measures and technology. These visits were made in conjunction with prior planned overseas trips to keep costs to a minimum. The authors are especially grateful to these organisations and the many people who gave so willingly of their time to discuss recent developments at their organisations.

Centres visited included TNO Human Factors Research Institute, Soesterberg, The Netherlands; The Swedish Road & Transport Research Institute (VTI), Linköping, Sweden; The Institute of Roads, Transport & Town Planning, Technical University of Denmark, Lyngby, Denmark; The Danish Road Directorate, Ministry of Transport, Copenhagen, Denmark; The Danish Council of Road Safety Research, Gentofte, Denmark; and Transportation Research Laboratory (TRL), Crowthorne, England. Information was also obtained about simulator testing of a number of treatments recently carried out at the Institute for Transport Studies, University of Leeds. Specific details of the visits and the discussions are described below.

3.1 HUMAN FACTORS RESEARCH INSTITUTE (TNO)

The visit to TNO was organised by Dr. Richard van der Horst and discussions were also held with Willem Verwey, Jeroen Hogema, Dr. Hans Godthelp and Dr. Johan Riemersma. TNO have been developing and testing in their driving simulator a road treatment aimed at reducing travel speed in 80 km/h speed zones (van der Horst & Hoekstra 1994). Discussions centred on the proposed treatment, developments leading up to refining and choosing the final treatment, the testing program and what is being proposed for the next phase of research.



Figure 3.1 TNO 80 km/h road treatment.

The final treatment from their work turned out to be a gravel surface which is applied to the edges and centre line of the road to create a rumble and small visual effect to reduce lane excursions and travel speed (see Figure 3.1 above). This treatment came after human testing in their simulator and was chosen it appears mainly because of its ability to reduce lane excursions off the sealed surface (this seemed to be a strong requirement for them in assessing the effectiveness of the treatment). A video was generously provided by TNO showing the treatment from a moving vehicle.

On-road testing of this treatment is the responsibility of the Dutch Transport Ministry. Preliminary trials have been conducted on a test road in Holland and early results reported by Waard, Jessurun, Steyvers, Raggatt and Brookhuis (1994). From a field experiment in which 28 subjects drove an instrumented vehicle over the test and control sites, they found a decrease in driving speed and swerving behaviour, coupled with a decrease in heart rate variability which they attributed to an increase in mental load at the treated site. They argued that the benefits were gained from increased mental load leading to better tracking and higher vigilance. The auditory and haptic discomfort from treatment encroachments appeared to bring about the desired reduction in vehicle speed. They concluded that the trial was promising and warranted wider application, although questions about long-term implications of these treatments and the speed and safety consequences were not addressed by these researchers.

3.1.1 Simulators

TNO's driving simulator consisting of a fixed based vehicle capsule (with auditory feedback and some vibration capabilities through the wheels) and a video projected image covering approximately 150 deg viewing angle from the drivers position was demonstrated. The image is computer generated using a combination of their own and some U.S. software which is responsive to accelerator, brake and steering inputs from the capsule. It gives a very strong visual image and varying road surfaces can be well simulated, although the fixed base does not allow perfect simulation of the driving task.

3.2 SWEDISH ROAD & TRANSPORT RESEARCH INSTITUTE (VTI)

The visit to VTI was arranged by Göran Nilsson and discussions focussed on road treatments of interest and a demonstration of the VTI simulator which is renown for being one of the best vehicle simulators in current use, today. Discussions at VTI also involved Sven-Olof Lundkvist (traffic engineer), Dr. Håkan Alm and Dr. Lisbeth Harms (human factor psychologists), and Professor Staffan Nordmark (vehicle simulation and dynamics).

3.2.1 Road Treatments

Site visits were arranged and conducted by S.O. Lundkvist about ½ hour from Linköping of a particular treatment VTI are currently experimenting with. In Sweden, there seems to be a considerable amount of 13 metre two-lane roads which is causing them some concern. They are experimenting with several ways of better utilising these roads.

On busy roads, they are trying 3-lane sections (with alternative 1 km passing lanes in each direction), and also 4-lane sections (where the kerb lane is only 3 metres wide and used for slow moving traffic). However, these designs cause merging and overtaking problems and are

not seen as total solutions. On lower volume roads, they are maintaining 2-lanes but are trying reduced travel lane widths (to around 5 metres) and provide a centre marked medium (as shown in Figure 3.2) with a narrow emergency lane on the kerb side. This treatment closest resembles a perceptual treatment and was of most interest here.

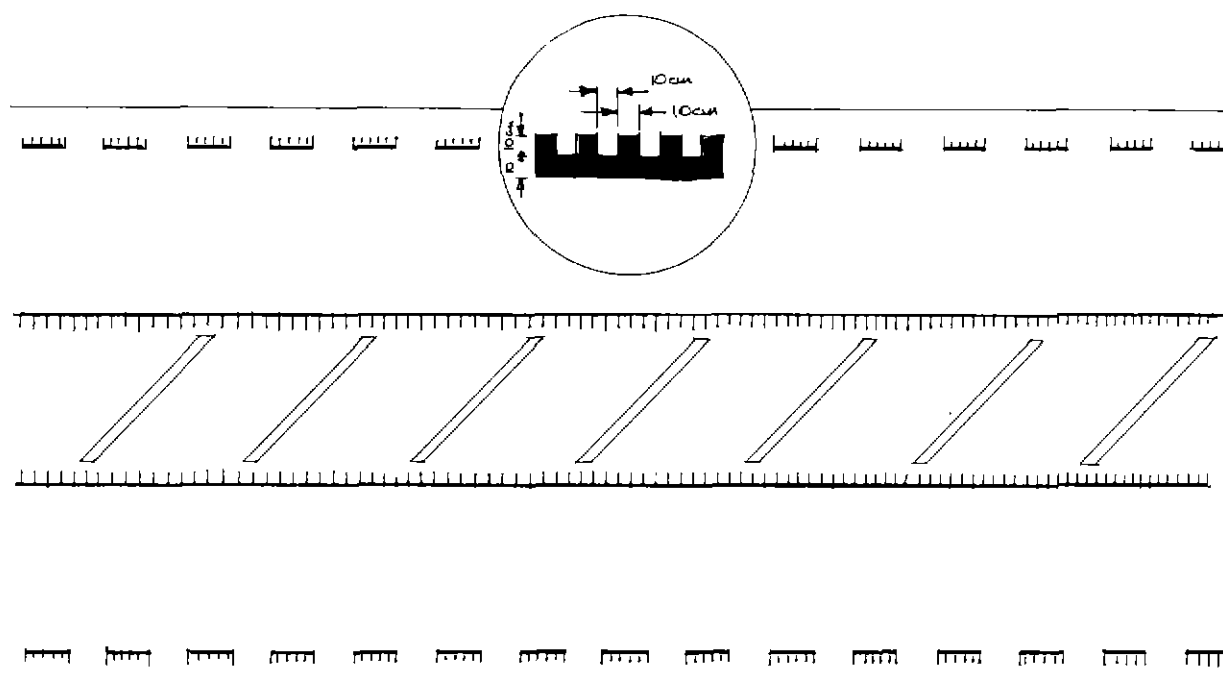


Figure 3.2 Road narrowing treatment used in Sweden.

The treatment was reported to have had some positive benefits in these low volume locations. First, it helped separate the traffic and no crashes had been observed to date (there was no immediate plans to undertake a more thorough evaluation of its crash benefits because it was only a few kilometres long and unlikely to show any real accident savings). Second, drivers felt good about this road (from surveys they had conducted) and claimed to travel more slowly (early indications are that there are some speed reductions and they are hoping to undertake a thorough speed measurement assessment of this road, using a control). Third, it is expected to last for 2 or 3 years, even with extensive snow ploughing during the winter. Finally, it helped distribute wear and tear across the road surface which is a particular problem in Sweden from studded tyres.

3.2.2 Entrances to Rural Villages

Lisbeth Harms reported on the work she was involved with as a researcher who had previously worked in Denmark on the EMIL project. This research involved experimentation with a number of treatments on the approach to 3 small rural villages in Denmark to reduce travel speed within the village. Most of the treatments involved physically restructuring the road to reduce sight distance (by installing swerve points and trees) with some minor line treatments to supplement these effects. They found considerable speed reductions in the 3 trial locations, although it would be overly ambitious to attribute these effects entirely to the perceptual treatment.

3.2.3 Simulator

There was considerable interest in the lateral moving base simulator that VTI have developed and refined considerably over the years. A test run in the simulator was most convincing and it clearly illustrated the capacity to provide real-life simulation of driving in a number of full colour geometric environments with ability to introduce adverse conditions such as fog, rain, snow and ice conditions. Auditory and kinesthetic feedback was excellent when running over varying road surfaces, although braking was a little unrealistic. Considerable resources have been spent on this unit and it requires a staff of 4 support people to maintain it. They seem to have significantly reduced motion sickness, commonly experienced with these units, since previous visits and drives of this unit.

3.3 TECHNICAL UNIVERSITY OF DENMARK

The first visit in Denmark was to the Technical University of Denmark's Institute of Roads, Transport and Town Planning for discussions with Professor Niels O. Jørgensen, Director. Professor Jørgensen was the former Director of the Centre for Traffic Safety and has considerable experience with traffic calming and associated problems in this country.

He noted two projects which had perceptual implications. The first involved the use of trees to create a less spacious environment (as described by Lisbeth Harms earlier) which had speed reduction benefits but also hazard disbenefits (objects on the side of the road that vehicles could collide with). Second, a hatching treatment that had been used to reduce travel speed and lane excursions on a poorly designed exit ramp on a freeway in Copenhagen. This site was also visited to see first hand the hatching treatment they had used. Unfortunately, the studies reporting this treatment were all in Danish and difficult to interpret the results of the trials.

3.4 DANISH ROAD DIRECTORATE

The Acting head of the Danish Road Directorate, Mr. Erik Randrup, and Mr. Michael Nielsen agreed to met to discuss road treatments in Denmark that had a perceptual quality. They are currently experimenting with reduced travel lane treatments to try and reduce travel speeds in a number of urban townships in the North of Denmark. These treatments consisted of edge lines, hatchings and edge rumble strips (3mm thermoplastic material consisting of solid lines plus comb fingers similar to that used in Sweden). They maintained that the rumble effects was as important as the visual effect in these situations as preventing lane excursions was a key requirement, given the preponderance of bicycles in this country.

Another treatment they were trying was similar to the low volume road markings described earlier in Sweden. They noted two major differences between their approach and that of the Swedes. First, while they use a similar comb-like edge lining treatment, they use it in reverse (ie; with the comb fingers facing inwards to be the first contact with the car tyres). This, they claimed gave a better alerting feature to the motorist and the technical problems associated with water build-up they overcame with additional drain slots. Second, they also used the comb line treatment on the centre as well as the edges (either with or without a painted median strip). This, they argued, reduced the number of lane excursions onto the other side of the road which are significant for head-on crashes.

3.5 DANISH COUNCIL OF ROAD SAFETY RESEARCH

Niels Helberg and Liselotte Larsen of the Danish Council of Road Safety Research willingly gave of their time to discuss current plans and countermeasures, although their interest was more in behavioural aspects of road safety, rather than traffic engineering. Nevertheless, there was an interesting exchange of speed research items of common interest.

3.6 TRANSPORTATION RESEARCH LABORATORY

Initial discussions were held with Archie Mackay and concerned non-perceptual methods of speed control. In order to bring about a targeted 30% reduction in accidents, the UK has identified speed as a major issue for countermeasure consideration. One initiative has been an experiment where a coordinated approach to road safety has been undertaken in five towns, including a number of initiatives in the speed area:

- mini roundabouts
- 20 mph zones which utilise a range of measures to restrict speed to 20 mph without the need for speed signing except on entry to the treated area. These zonings are centrally authorised, with approximately 100 currently in force. The current experience has been up to 60% reductions in total accidents.
- there have been new initiatives in the speed hump area: standards for modular rubber hump designs have been prepared and speed cushions are being evaluated for use on bus routes.
- treatments are being introduced for the calming of main streets, particularly through villages, with the use of 'speed tables' (raised pavements) and entry 'gates' to the calmed road section.

Having had discussions with Ray Brindle during Ray's last visit to the TRL, Archie Mackay agreed that in many areas Australia's practice was in advance of that currently being introduced into the UK.

3.6.1 Perceptual Treatments

Information on the latest UK initiatives in the perceptual countermeasures area was obtained during discussions with Robin Helliar-Symons of the TRL Road User Group.

3.6.2 Transverse Bar Markings

Transverse bar markings are the only perceptual treatment for the control of speed currently being pursued by TRL. However, despite the long standing nature of the devices, stemming from TRL work in the 1960's, the Laboratory is currently exploring enhancements to the treatments.

LOCATION: In the past such devices have only been used on rural divided highways on approach to roundabouts. An experiment is currently being carried out at sites on fast rural approaches to cross roads with high accident levels. Other sites under consideration are high speed approaches to sharp bends and chicanes, and with other methods of speed control through villages, as mentioned earlier.

PATTERN: Two changes to pattern type are being considered. Both still maintain the original concept of decreasing spacing through the pattern to hopefully create an impression of increasing speed. However, it is acknowledged that the original patterns resulted in considerable marking material being placed on the carriageway. For the new sites being considered the changes to the pattern are either to remove every other bar from the original layout or apply a shorter pattern of between a half and two-thirds the length of the original.

COLOUR: Due to traffic regulations associated with white transverse lines on the carriageway, an alternative colour had to be used when bar marking patterns were first introduced. To maintain an adequate level of conspicuity, a dark yellow-designated 'lemon' in the UK standard colour range, was used. With subsequent experience, the use of this colour has been called into question: its brightness makes it visually intrusive, and it is the same colour as that used for parking restriction line marking throughout the UK.

Two alternative colours are being trailed. The first is a pale yellow-designated 'primrose' - which is considered to maintain conspicuity levels while leading to a reduction of the intrusiveness of the treatments and breaking the nexus with parking restriction markings. The second colour being trailed is pale green - 'sea green'. It is thought such a colour may remain visually effective for drivers but be less intrusive, particularly if there are environmental sensitivities associated with particular sites.

TESTING: Testing is being carried out at 10 sites. While it is intended to use accidents as the ultimate measure of effectiveness, an additional aim is to look at the effect on driver speeds. Somewhat surprisingly, TRL do not have the technical facilities to effectively monitor speed profiles over the range of sites and treatments being investigated. The speed investigation will therefore be at a single location at the centre of the pattern being used. The use of accident data is likely to be required since similar single-location studies of speed shed little light on behaviour changes when the original markings were introduced.

Attention was drawn to the comprehensive speed profile work carried out on transverse bar markings in Australia and the conclusions drawn. These were that the nature of the effectiveness of transverse bars is as if they were a large hazard warning device rather than a perceptual treatment. Helliar-Symons agreed that TRL had long acknowledged that a significant component of transverse bar effectiveness was due to the visual impact of the treatment, but the extent had not been quantified. It was still intended to retain the perceptual element of the pattern design in the proposed testing, however.

OTHER USERS: There is no intention to use transverse bar markings or any derivatives in locations other than those already defined. The aim is to use the bars for clearly identifiable reasons only, and it was thought the use actually through high speed bends might not be understood and would devalue their use at other locations. Other, more direct, measures would be used if such problems were identified.

The TRL did not have any plans to test any other form of perceptual treatment for the control of speed, nor were they aware of any other new work proposed elsewhere or currently underway in the area.

3.6.3 Close Following Trials

One associated visual treatment is currently being trailed by TRL with the intention of reducing close following high speed, high level of service roads, usually motorways (freeways). Given the high speeds and increasing traffic demands on British motorways, close following has been identified as a major safety issue and it is hoped the proposed visual treatment will change close following habits by directly affecting following behaviour.

The system to be used originated in France primarily as an aid to driving during fog. The treatment involves the painting of a chevron design in the centre of the treated lanes at a spacing such that if the driver maintains a minimum of two chevrons in view at all times then a minimum time headway of two seconds is maintained. This is considered an appropriate headway for a speed of 65 mph (105 km/h) taken as an overall operating speed for most UK motorways for the purposes of this treatment design. Support signing is provided, but since this signing, provided every half km. is only on the near side, when three lane carriageways are being treated chevrons are only laid in the two nearside lanes. Both chevron from and layout and signs are shown in Figures 3.3 and 3.4.

The chevron markings and signs are installed on level sections of motorway for periods of half an hour travel time (approx. 30 miles or 50 kms). Sections of high accident concentrations are targeted where possible. Following a non-treated section of similar travel time period the treatments are re-introduced as both a reminder to drivers and what is hoped will be part of an overall education process. It has been found to be important to select sections carefully with appropriate traffic flows. Too low a flow results in treatment redundancy while too high a flow leads to a breakdown in free following conditions and chevron information is necessarily disregarded.

The experiment has been supported by a reasonably extensive advertising campaign (although not of relative TAC proportions) based on the slogan 'only a fool breaks the two second rule'! Two extended motorway sections were introduced some four years ago and, although not yet ready for publication, the results of a three year study are currently being finalised. These results suggest:

- control sections were difficult to establish and monitor
- there is a 15 to 18 km 'halo' effect on following behaviour (time headways) - although TRL do not appear to be intending to integrate this into the layout design.
- accident results are promising
 - 56% overall reduction in accidents on treated sections.
 - 42% reduction in multi-vehicle accidents.
 - single vehicle accidents all but eliminated, the cause for which has yet to be established.
 - some small carry over of effect into untreated lanes.

It is expected that as a result of the study outcomes further chevron marked motorway sections will be introduced.

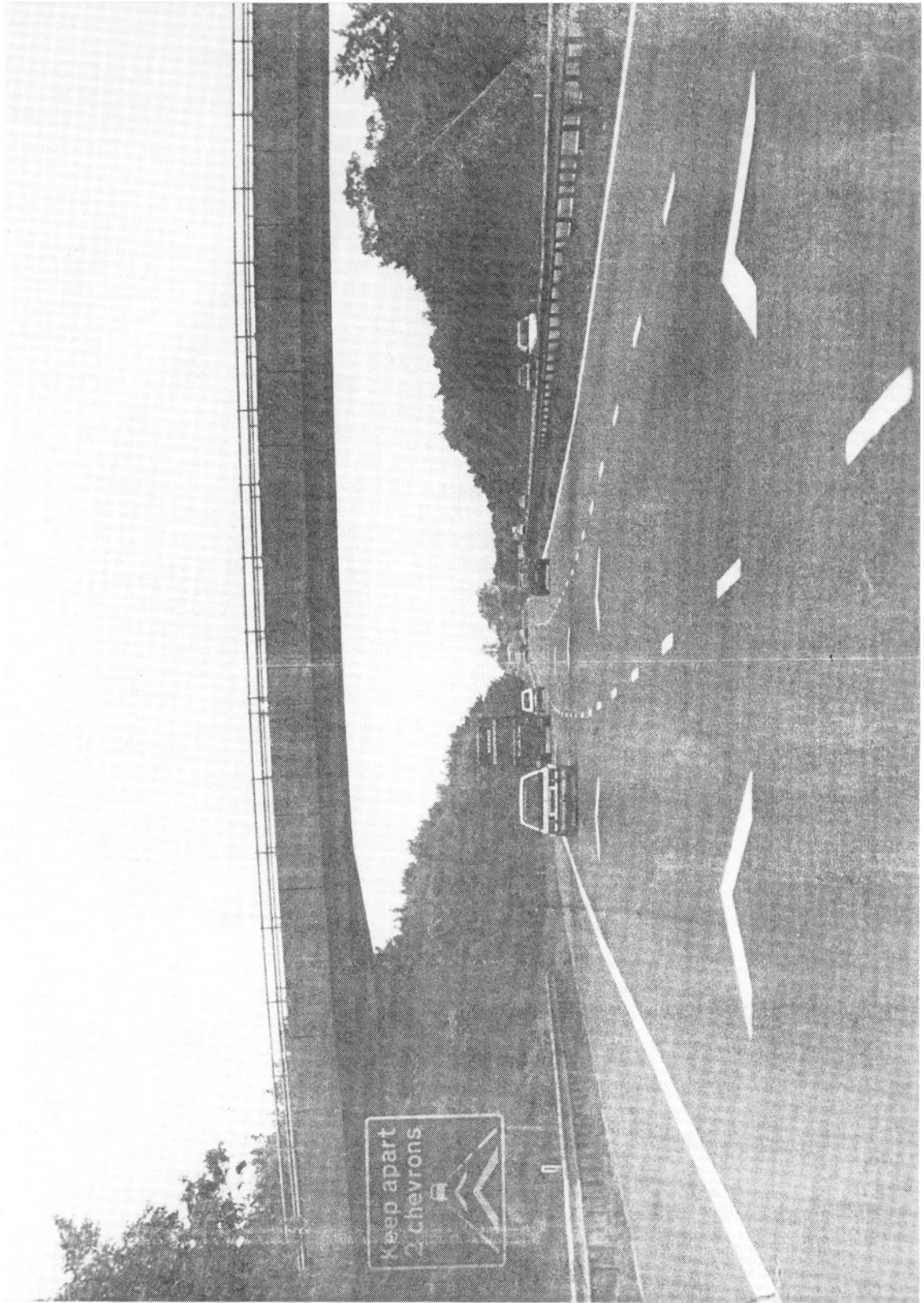


Figure 3.3 Chevron Markings on the M1 Motorway (from Webster & Helliar-Symons, 1992)



Figure 3.4 Layout of alerting signs (from Webster & Helliar-Symons, 1992)

3.7 UNIVERSITY OF LEEDS

The Institute for Transport Studies at the University of Leeds have also been actively researching suitable treatments for reducing driver speeds on rural single-carriageway arterial roads with the aim of identifying practical and cost-effective combinations of measures that will reduce the frequency and severity of speed related accidents on these roads (Pyne, Carsten & Tight 1994). This research is still current and not all treatments are "perceptual". Of special interest, they have also used a silicon graphics driving simulator to test these effects.

3.7.1 Perceptual Treatments

This research has focussed on speed reductions in 3 rural road environments; entrances to villages, curvature treatments and general road treatments. The perceptual treatments they used include transverse lines (to create an illusion of acceleration), wundt illusion and roadside trees (to create an illusion of the road narrowing), and variations in the level of road delineation (numbers of lines, hazard marker posts and intensity of gaps). They also included road and roadside signage and some traffic calming measures (chicanes, parking zones, etc) but these are of less interest for this report.

There were a number of statistically significant differences in travel speed and lateral position reported, although the results were very much dependent upon the treated environment. Moreover, while they did show significant differences in the effects of the "treatments" at particular positions on the road (eg; entering and midway through the curve), they did not report a thorough statistical analysis evaluating the individual benefits of each treatment which would have been a powerful demonstration of their effectiveness. However, they did note that several of the perceptual treatments resulted in reductions in mean speed, 85th percentile speed and speed variance.

On straight roads, these included centreline treatments, wundt illusion and hazard marker posts (as well as count-down signs, chicanes and additional lanes). For curves, some transverse line treatments and edgeline hatching resulted in speed reductions, although road markings and warning signs were also equally effective. Interestingly, trees on the roadside especially in curves, were not particularly effective which is counter to what other evidence would suggest, raising questions about how rigorous some of these treatment effects might have been.

3.7.2 Use of a Driving Simulator

Testing in this study was undertaken using a Silicon Graphics Reality Engine workstation advanced simulator, comprising a complete car with basic controls and instrumentation in front of an unspecified size and structure video projection screen. This appears to be a relatively new unit at this Institute for conducting research in driver behaviour. More information has been sought from these investigators.

In their recent paper, they noted that the computer continuously receives feedback from the driving controls and provides updated images using a complex vehicle handling model. They found this approach to be an extremely convenient, safe and controlled method for testing these treatments which enabled novel treatments to be thoroughly evaluated away from the road and any possible safety disbenefits.

3.8 CONCLUSIONS

Overall, it can be concluded from the meetings that there has not been a substantial amount of research or development work undertaken in this area. While a few treatments of immediate or potential interest were highlighted during the visits which have been described above, it was clear that there has not been any concerted effort in the organisations visited to address this topic systematically. There was, however, considerable interest expressed in the project and the desire to be kept informed on any developments that come from our research that might be relevant for these countries.

The work conducted by the University of Leeds Institute for Transport Studies was especially interesting and more details are currently being sought. It confirms the possibility of speed reduction from low cost on-road treatments and the usefulness of driving simulators to evaluate novel treatments prior to their implementation on the road itself. This is an effective and safe method for evaluating driver behaviour effects.

TRL are not currently active in developing perceptual treatments for speed management apart from some minor modification work of their transverse bar markings pattern types and colours. TRL acknowledge that their main work has been done and that current effort is only at the margins. A further visual technique has been trailed to assess its effect on close following on heavily trafficked motorways and results to date are promising.

CHAPTER 4: DIRECTIONS FOR FURTHER RESEARCH

A number of low cost road and roadside treatments likely to influence a driver's perception of speed were highlighted from the literature review and the overseas visits. Some of these treatments, while seemingly very promising, are not well developed and in a number of instances, their speed reduction and crash potential is yet to be firmly established. In addition, the perceptual mechanisms by which some of them influence driver behaviour is not well known about or soundly demonstrated. As these treatments have a great deal of potential as an additional road safety countermeasure and likely to be highly cost-effective, further research seems warranted to illustrate their speed and crash reduction effects.

4.1 THE MOST PROMISING TREATMENTS

As noted in the review, these treatments can apply either to the road surface or the shoulder or roadside setting. Thus, it is useful to consider them as two separate groups, namely *Pavement Treatments* or *Shoulder Treatments*. From the evidence presented here, the former group seem more likely to have a marked influence on travel speed than the latter, although this may be dependent upon particular measures and environments. Given the nature of this evaluation, only those measures which appear to have a likely sensory perceptual influence and those which need further research and/or development are considered here.

4.1.1 Edgeline & Centreline Treatments

A number of treatments to the road pavement surface were described earlier which seemed promising but, in many instances, still require further development and testing. These treatments seem to offer the most promise and warrant further research and development. They are listed below in no fixed order of importance:

- ***Herringbone Pattern.*** A reducing herringbone pattern on the edge and centre line of the road appeared to lead to positive speed (and crash) reduction benefits when used in the approach zone to hazards. However, the effectiveness of this treatment relative to transverse lines has not been assessed (there would seem to be some potential for significant cost savings if these treatments were shown to be equally effective). Also, situations where they are likely to be of most use has not been fully determined.
- ***Chequered Pattern.*** While this treatment has not been used as an alternative edge and centre line treatment, it would appear to have significant potential as a means of providing a wide line at the material cost of a narrow one. This could be useful where wide lines are required and possibly as a means of perceptually narrowing the travel lane when necessary. However, the effectiveness of this treatment needs to be demonstrated, along with any difficulties created for the motorists or for implementing the treatment.

- ***TNO Centreline & Edgeline Treatment.*** The effectiveness of this as a low contrast perceptual (rumble) treatment seems to have been proven from simulator tests in Holland. However, there does not seem to have been much experimentation with different types of treatments or sizing and/or spacing. Also, it is not clear why they finally decided on a low contrast treatment. Given its effectiveness in reducing travel speed, it would be well worth further work in development and trialing this treatment in this country, too.
- ***Edgeline Comb & Hatching Effects.*** The Swedish and Danish edge and centre line treatments are innovative and promising for use, both as a perceptual and as an alerting treatment for lane encroachments. Yet, they have not been systematically tested and evaluated in terms of their speed and crash reduction benefits. This would also seem to be a fruitful area for further research in designing a low cost treatment that would yield optimum behavioural and safety returns.
- ***Centreline (Median) Treatments.*** There were examples described in Scandinavia, the UK and in Victoria, Australia of wide centre line treatments which introduced a low cost median and acted to reduce the width of the travel lane. These treatments involved both line hatching and the application of white gravel to the road. The relative effectiveness of these two approaches would be worth further examination as the treatments have both perceptual (behavioural) and cost and maintenance implications. Either treatment would also appear to have substantial crash benefits, given the proven benefit of improved separation of traffic in opposing directions.
- ***RPM's Versus Line Treatments.*** One or two earlier studies used Raised Pavement Markers (RPM's) as an alternative treatment to thermoplastic or paint or to improve delineation and/or perceptual effects. These devices (buttons or retro reflective types) are cost comparable with other treatments and have a considerable in-service period in Australia. It would be helpful to demonstrate their relative safety benefits with painted surfaces and to compare their relative benefit-cost ratios.
- ***Curve Enhancements.*** Several curve enhancements were uncovered during this review which are aimed at improving curve perception and reducing travel speed and crashes, especially at night. These include innovative shoulder treatments such as novel post spacings and variable delineator height as well as road treatments to the edge line (and the reversal curve) as well as transverse lines in the approach zone. The safety effects from the use of chevrons to enhance curve perception is somewhat equivocal and needs to be clarified. Given the high propensity for crashes on curves, there would be merit in further evaluating the perceptual and safety benefits of all these treatments.

4.1.2 Transverse Road Markings & Rumble Effects

The benefits of these measures seem to be well proven and documented and do not require further elaboration here. There was some doubt raised about whether they exert a perceptual or an alerting influence and whether they should be used with or without rumble treatments. It would be useful addressing these issues in future research efforts as these results would provide guidance for their use in the field (and help minimise implementation costs).

4.1.3 Special Application Treatments

There were one or two special application treatments that may have positive perceptual effects for excessive speeding and crash reduction. However, they would seem to be of lower priority, given that they have limited application and/or are not specifically directed towards speeding motorists. They are listed below for completeness.

- **Osaka Bridge Treatment.** This treatment consisted of painted or thermoplastic large road chevrons and broken centre and edgelines and reportedly led to both speed and crash reductions on a long span bridge in Osaka, Japan. It would be useful to undertake a detailed evaluation of the full effects of this treatment in terms of driver perception and behaviour as well as crash benefits before it is widely adopted. However, it does offer some promise for special hazardous applications such as the one it seems to have been developed for initially.
- **Close Following Chevrons.** It was noted during the overseas visits to TRL that researchers in the U.K. have recently trialed the use of chevrons at 40 metres at two sites on the M1 motorway measuring vehicle spacing and speeds. These treatments were devised and first used in France and aim to help drivers choose a more safe following distance. Preliminary results showed reductions in close following immediately after installation which tended to dissipate slightly with time. It would be worthwhile considering a similar trial in Australia of this treatment, although not necessarily as a speed reduction measure.

4.2 THE RESEARCH PLAN

The final objective of this preliminary study was to present a plan of research aimed at developing an inventory of perceptual countermeasures that could be used as a road safety countermeasure against excessive speeding. This research plan comprises initial off-road testing of a number of the more promising treatments, followed by the implementation on the road and speed and crash evaluation of the successful ones. A three stage program of research is outlined below, although this could be modified to suit a more preferred option.

4.2.1 Simulation & Validation

It was noted in the review that the effects of perceptual countermeasures are very subtle and not always easily simulated off-road. Discussions with overseas organisations suggested that these effects could be accurately represented in the laboratory with sufficient attention to the method of presentation used. In short, a high-level vehicle simulation was essential to ensure that the laboratory responses are representative of what happens when driving on the road.

The Monash University Accident Research Centre is fortunate to be the home of two new vehicle simulators (one fixed and the other portable) which are owned by the Transport Accident Commission of Victoria. These units cost around AS3 million and represent the very latest technology in vehicle simulation world-wide. Although they are only fixed-based,

they are capable of providing realistic off-road driving conditions. Indeed, driving simulation with this degree of sophistication has not been available before in Australia and represents a major break through for off-road driving behaviour studies in this country.

When conducting off-road studies of driver behaviour of new road treatments, it is essential to test the degree of authenticity of the tests being planned first. Hence, validation testing is proposed as the first phase of the research program. A few road treatments currently in existence that are known to have behavioural consequences (transverse lines, rumble effects, etc) will be simulated for laboratory presentation. A sample of drivers will then be tested on the road and in the simulator to see how closely their responses mirror each other in both environments. Statistical correlation will be carried out on these two sets of data as a measure of the validity of the simulation method. Any anomalies or quirks in these data will be highlighted for either correction or to take into account in subsequent testing.

Simulator studies overseas suggest that testing of these types of treatments has high validity with road trials and this is expected to be the case with the new TAC simulators as well. However, in the rather unlikely event that validation should show that simulation failed to generate normal driving responses, then the program of research described further on here would need to be subsequently reviewed.

4.2.2 Experimental Program

Assuming that the validity of the off-road test procedure is proven, the next phase of research would involve developing, testing and modifying where necessary a number of the potential treatments listed above. The treatments ultimately chosen would depend upon a number of considerations, such as those that are amenable to simulation, those which have a high likelihood of success in reducing excessive speeding and crashes, and those which seem likely to be of widespread use. The selection of appropriate treatments would be done in conjunction with the views of a Project Advisory Committee.

Treatment effects would be programmed into a suitable driving course to permit their effects to be judged against similar control (no-treatment) sections of roadway. Licensed drivers covering a range of different ages and sexes would be elicited to "drive" the simulator and their responses (driving performance) would be analysed. Dependent measures are likely to include such things as steering performance, lane excursions, travel speed, errors, etc. and where necessary, subjective responses might also be recorded. Normal experimental procedures and analysis techniques would be used here to test these effects.

Simulation testing of the kind proposed here has been undertaken by a number of organisations overseas (see Chapter 3) as an appropriate first step in developing on-road countermeasures, testing their preliminary behavioural effects and assessing the likely road safety consequences before applying these treatments to the road itself.

At appropriate times during the course of this simulation research effort, it may be possible to prescribe some treatments that could be applied to roadways for trialing. This activity is described further in the next section. Estimates of the likely cost-effectiveness of these treatments would be prepared at this time as a demonstration of their attractiveness.

4.2.3 On-Road Testing & Evaluation

Once a number of treatments have been pre-tested in the laboratory and shown to be safe, effective and worthy measures, it is then proposed to apply them to suitable locations and evaluate their effectiveness in reducing travel speeds and crashes on the road. This represents the final phase of the research program in perceptual countermeasures.

Suitable sites will be selected in New South Wales and Victoria (if not in other states, too) and the local road authorities will be approached to implement these treatments. Sites will be selected on the basis of their speeding history, crash history, and/or other suitable criteria, ensuring that at all times, control sites are available to enable a thorough evaluation of their effectiveness to be undertaken. Members of the research team will work closely with the authorities to ensure that the treatments implemented are appropriate and that the implementation strategy does not jeopardise the evaluation.

Funding for implementing these measures will need to be sought independent to this research program budget. However, it is assumed that this will not be a major difficulty, given that the off-road trials will demonstrate the effectiveness (and likely cost-effectiveness) of the chosen measures and the amount of interest already shown by these authorities previously in promoting the use of perceptual countermeasures.

4.2.4 Proposed Program

The research program outlined above will be a collaborative effort involving the Monash University Accident Research Centre, the Australian Road Research Board and the Department of Psychology, Monash Clayton. MUARC will be the Principal Consultant for the experimental research and the research effort will be undertaken principally by graduate students of the Psychology Department as part of their research study requirements.

The program is planned to commence early in 1995 and to run over a number of years. Most of the initial experimental work on the simulator should be completed within 1 to 1½ years during which time some of the more promising of these treatments could actually be installed on the road for final evaluation. Initial behavioural effects can be measured soon after installation of the various treatments but sufficient time will be necessary for a comprehensive assessment of the crash consequences.

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