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ROAD DESIGN FACTORS AND THEIR INTERACTIONS WITH SPEED AND SPEED LIMITS

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Abstract:

The road environment can affect driver speed choice through influencing both the driver’s perception of their current speed, and the speed that they think is appropriate for the road. These influences and their effects on speed can therefore affect crash rates. This report reviews the influence of various factors within the road environment, including the geometry of the road, the roadside environment, explicit information from road signs and markings, and temporary factors such as lighting conditions and the presence of other road users. The review also covers how these environmental factors interact with other factors related to the driver and the vehicle. The concept of the ‘self explaining road’ is also discussed.

Key Words:
Road environment, speed, crash risk, road geometry, roadside features, signage, self explaining roads, road safety.

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Preface

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Contributorship Statement:

JE researched and wrote the report.

CMR-B provided guidance and direction regarding the selection of material and the writing for the report, and edited the report.

MGL provided guidance regarding the direction of the report.

Ethics Statement

Ethics approval was not required for this project.

Contents

EXECUTIVE SUMMARY

Although traffic speeds are universally recognised as closely related to crash risk, crash rates within the same speed zone vary widely. The aim of the present project is to examine environmental factors which may influence the speeds chosen on a particular road and hence influence the crash rates. These factors may affect speed choice through influencing the driver's perception of their current speed, and/or the speed that they believe is appropriate for the road.

In terms of road geometry, drivers will choose lower speeds on roads that have rough surfaces, are narrow, winding, or hilly, and where the direction of the road and the boundaries of the lanes are not well delineated. These factors affect drivers' perceptions of appropriate speed, and thus will only reduce speeds when they are easily perceived by the driver (e.g. a concealed curve will not reduce speed in advance).

The roadside environment and objects next to the road can also affect speed. Multiple objects next to the road can increase peripheral visual flow and therefore increase perceived speed, which will lead to reduced actual speed. Drivers will also slow down if they feel that they are too close to objects on the side of the road and they are unable to move away. Drivers choose lower speeds on roads with multiple access points to prepare for the possible entry of other vehicles, and in visually complex environments in order to process the higher levels of visual information.

Road signs and some road markings aim to provide the driver with explicit information about the appropriate speed. However, a number of studies have shown that these signs have little effect outside certain circumstances (such as dynamic signs warning of temporary hazards).

A new approach is to provide information to the driver via implicit rather than explicit cues. The concept of 'self-explaining roads' involves designing a road system in which the driver's expectations created by the road environment are implicitly in line with the safe, appropriate behaviour for the road. Manipulating various aspects of the road environment to make a road fit within the subjective road categories used by drivers improves the credibility of the speed limit and can reduce speeds. This approach has also been found effective when used to mark transitions in the road environment, such as a rural highway passing through a country town.

Temporary factors such as lighting conditions and other road users will affect the speeds chosen. Speeds on unlit roads at night may be either faster (if the lack of visual information removes perceptual cues to speed), or slower (if the lack of visual information makes drivers feel less safe) than during the day. Drivers slow down when bad weather reduces visibility and/or affects the slipperiness of the road surface. Congestion due to multiple other vehicles physically reduces speeds, but drivers also slow down in the presence of vehicles parked along the roadside.

The road environment factors identified above will interact with factors involving the driver and the vehicle. The driver's current state (if they are fatigued, stressed, or distracted) will affect their ability to perceive and process information from the road environment, which will therefore affect speeds. Older and inexperienced drivers may also

be impaired in these abilities. There is some evidence that driver gender affects speed perception. Speed perception may also be affected by the size and soundproofing of the vehicle driven.

Drivers who feel under time pressure have more motivation to travel faster. Motivations are also affected by driver gender, personality, perceived driving ability, and social norms (perceptions of what other drivers do). Enforcement can change social norms of acceptable speeds. The capability of the vehicle to travel at high speeds affects driver speed choice. New vehicle technologies may affect speeds physically (e.g. Intelligent Speed Adaptation), or may make drivers feel safer with the result that they drive faster.

Driving simulators are a safe and valid method for determining the effect of road environment factors on driver speed choice, and have been used in many previous investigations in this area. The next phase of the present project will use the MUARC Advanced Driving Simulator to examine variables that may affect speed choice and therefore crash rates within shopping strips.

1. INTRODUCTION

1.1 THE BASELINE PROGRAM

MUARC's Baseline research program is sponsored by VicRoads, the Transport Accident Commission, the Department of Justice, and Victoria Police. The aim is to conduct fundamental research into major issues that will support the Victorian Government's road safety strategy.

1.2 PROJECT OVERVIEW

Speed limits across Victoria are determined using a highly prescriptive set of guidelines outlined in Chapter 7 of the VicRoads Traffic Engineering Manual (VicRoads, 2006). Criteria used to determine the appropriate speed limit for each road segment include:

- Road characteristics (including road classification and function, geometric characteristics, alignment, pavement condition, footpaths etc);
- Extent and nature of abutting development (including number and type of developments and traffic generated);
- Road users, their movements and potential number of conflicts;
- Crash history; and
- Seasonal influences such as holiday traffic.

The process of determining the most appropriate speed limit is assisted through use of the VLIMITS program developed by ARRB Group. VLIMITS uses the above general site characteristics as input data and applies these to an algorithm to produce a recommended speed zoning. The aim behind the process is to produce speed zones that take into account safety and mobility needs, and that are recognised as being consistent and fair by motorists. More recently, variable speed limits have also come into use in Victoria where the speed limit on a road length is lowered at certain times of the day or under certain conditions where increased risks are encountered due to factors such as increased presence of vulnerable road users or inclement environmental conditions.

The VicRoads Traffic Engineering Manual (VicRoads, 2006) notes that 'adjustments to the outputs from VLIMITS may need to be made to reflect local issues and conditions'. However, while guidance is given into situations in which VLIMITS should be used to assess the appropriate speed limit, there is no information on when it might be appropriate to adjust outputs from VLIMITS, except when reviewing the consistency of speed limits along a road length or across a road network.

Research by MUARC carried out for VicRoads in 2004 examined the distribution of crash rates per traffic volume in Victoria within specific speed zones (MUARC, 2004). Within the same speed zone estimated crash rates varied across the bulk of sites represented by a factor of over 100 times. This result strongly suggests that the current speed zoning guidelines are not achieving uniformity in crash risk. A research program could be used to identify the factors contributing to the risk variation. Once these factors have been identified, research would determine appropriate solutions to reduce the crash risk at sites with these factors.

The overall aims of this research program are: (1) to investigate the relationship between environmental, infrastructure and behavioural factors and their interaction with speed to determine crash risk; (2) to examine the influence of those factors identified as potentially influencing speed on driver speed choice measured in a driving simulator; and (3) to evaluate selected countermeasures designed to influence speed choice.

The purpose of the present literature review is to identify environmental and infrastructure factors that affect driver behaviour, particularly focusing on those that impact on speed and crash risk. The review involved a comprehensive search of databases including Australian Transportation Index, TRANSPORT, TRIS, PsychINFO, and additional internet searches. In addition, subject matter experts were consulted to ensure coverage of the relevant literature.

1.3 HOW SPEED AFFECTS CRASH RISK

There are several ways through which speed can affect the risk of a crash occurring. The literature distinguishes between excessive speed (driving faster than the speed limit) and inappropriate speed (driving too fast for the conditions, although speed may be under the posted speed limit). Driving too fast can increase crash risks by reducing the available time/distance to recognise and respond to hazards in the road environment, as well as making lateral control more difficult (Davis, Davuluri, & Pei, 2006; Liu & Popoff, 1997). In addition, crash severity is highly affected by impact speed (Organisation for Economic Co-operation and Development, 2006). The focus of the present report is on crash risk rather than crash severity, however it is recognised that the relationship with crash severity may determine speed limits in some environments (e.g. those with vulnerable road users).

As would be expected from the physical laws described above, increases in travel speed correlate with increases in crash risk. This relationship has been documented by a variety of studies for different road environments and crash types; in different countries; using different techniques including comparing the same road over time, comparing similar roads with different speed limits/travel speeds, and comparing individual speeds for vehicles who crashed and control vehicles; and using various statistical methods including relative risk ratios, regression, and Bayesian analysis (Aljanahi, Rhodes, & Metcalfe, 1999; Davis et al., 2006; Kloeden & McLean, 1998; Kloeden & McLean, 2001; Liu & Popoff, 1997; Transportation Research Board, 1998; Vorko-Jovic, Kern, & Biloglav, 2006).

Changes in speed limits and enforcement would be expected to change travel speeds independently from the design/condition of the road, and studies investigating the results of such changes have found that crash rates follow accordingly (e.g. Elvik, 1997; Lund, Wells, & Baum, 1989; Mourad, Patrick, & Francoise, 2005; Transportation Research Board, 1998). A meta-analysis of several studies of increased speed limits found that a 15km/hr increase in speed limits leads to an increase in average speed of 4.4km/hr and a 26% increase in fatal accidents, while a 14km/hr decrease in speed limits results in a 7.1km/hr decrease in mean speeds and a 15% reduction in fatal accidents (Elvik & Vaa, 2004).

There is mixed evidence on whether driving more slowly than the surrounding traffic increases the risk of a crash. It might be expected that slow-moving vehicles would be involved in more rear-end crashes as other drivers may not anticipate the interruption to the traffic flow. Early studies seemed to show that vehicles travelling more slowly than average speeds were more likely to be involved in crashes; however more recent research has found linear relationships between speed and crash rates, and questioned the validity of the earlier results (Davis et al., 2006; Fildes & Lee, 1993; Kloeden & McLean, 1998).

The evidence does however point to a relationship between speed variability and crash risk. Liu and Popoff (1997) examining provincial highways in Saskatchewan and Aljanahi et al (1999) examining English highways both found that increasing speed variability increased crash rates more than increasing average speed. Factors that increase speed differentials between vehicles may therefore have as much, or more, effect on crash risks as factors that increase speeds chosen by all drivers. It has been suggested that high speed differentials may reflect the effect of poor road conditions, in that some drivers will adapt their speed to the conditions less than others and thus will be driving at both a different speed to the mean speed and an inappropriately high speed for the conditions (Liu & Popoff, 1997).

Some jurisdictions have differential speed limits for different types of vehicles. Heavy vehicles (trucks) are often limited to a speed below that of the speed limit applying to other vehicles. Garber et al (2005) surveyed data from three USA states and found that both changes from a uniform to a differential speed limit for trucks, and changes from a differential to a uniform speed limit, were associated with higher crash rates. Johnson and Pawar (2005) note that changes in speed limits will be adapted to more quickly by some drivers than others, resulting in higher speed variability for a period immediately after the change in limits. The issue is complicated by the fact that some trucking companies use speed limiters which restrict the maximum speed of their trucks regardless of the state speed limit for heavy vehicles. So even with a uniform state speed limit, some trucks will be driving below the speed limit.

Toledo et al (2007) used traffic microsimulation to determine the likely effects of introducing speed limiters more widely into the vehicle fleet. When 10% of the vehicle fleet is equipped with speed limiters, the average speed and speed variability drop, however the number of lane changes increases. Speed variability is increased by limiters under free traffic (uncongested) conditions; the speed distribution in these conditions becomes bimodal, with one mode centred around the limiter-set speed and the other mode centred around the mean speed chosen by unlimited drivers. For this reason, limited speeds would need to be set very carefully and be in accordance with the perceived safe speed for the road.

1.4 HOW THE ROAD ENVIRONMENT INFLUENCES SPEEDS

Drivers are assumed to choose their speed based on their perception of the appropriate speed for the road environment, their perception of their own speed, and their motivation to comply with legal and/or safe speeds. The latter is not influenced by road environment factors, therefore it is outside the scope of the present review and will not be discussed further. The road environment can however affect drivers' perceptions of both their own speed and of the appropriate speed for the road, via explicit information such as signs, and implicit information (see below).

Drivers' perceptions of their own speed (in the absence of explicit information from a speedometer or vehicle-activated sign) seem to be determined mainly by the optical flow rate in the peripheral visual field (Gibson, 1958). Perceptual countermeasures to speeding are often implemented to exploit this fact by increasing the visual flow rate without changing the quality of the road. In contrast, the perceived appropriate speed for a given road is affected by a more complex set of factors. These include the level of information about upcoming required manoeuvres, and a driver's willingness to tolerate uncertainty and risk.

An important factor contributing to the perception of appropriate speed is the 'information density' of the road environment. Senders et al (1967) showed that drivers need to obtain information from the road ahead at such a rate so as to reduce uncertainty about the upcoming manoeuvres required, but not so fast as to allow insufficient time to process the information. When limited information is available, or when the amount of information to be processed is large, drivers compensate by slowing down in order to adapt to the information flow rate. Importantly, this requires that the information content of the environment be clear to drivers so that they can modify their speed choice behaviour appropriately.

Information, in this sense, is considered in terms of its capacity to reduce the driver's uncertainty. Anything that blocks a driver's forward visibility will decrease the amount of available information and will increase uncertainty. The presence of other road users (vehicles, cyclists, pedestrians) will also increase uncertainty, as the driver may not be able to predict how these other road users will behave. Even the *potential* presence of other road users (for example parked cars that may move off or conceal pedestrians about to cross the road) will increase uncertainty. The presence of signs showing the sharpness of bends or the possibility of hazards ahead both increases the information available to drivers, and allows them to modify their behaviour appropriately.

Another important concept with regards to perceived appropriate speed is the idea of risk tolerance, or acceptance. Wilde (Wilde, 1982) proposed that drivers would behave so as to maintain a certain preferred level of risk over all road environments. Thus, improving a road by providing clearer edge lines, for example, may lead to drivers choosing higher speeds as they feel such a speed is now safer to maintain. Similarly, Fuller (2005) argued that drivers act to maintain a certain level of difficulty in the driving task, and that adjusting speed is the primary method of adjusting task difficulty. Summala (2002) notes that when speed is limited, drivers may respond by adapting their behaviour in other ways, for example by paying less attention to the road ahead and more attention to in-vehicle tasks. It is therefore important that drivers have an accurate perception of the level of risk or difficulty in a road environment. As will be discussed in the following sections, many speed/safety countermeasures are based on the manipulation of drivers' perception of risk or difficulty.

This review has been divided into sections based on different aspects of the road environment that can affect speed choice in drivers. The first section discusses road geometry, which imposes physical constraints on speed as well as affecting speed perception. The second section examines roadside development or objects next to the road, which can affect drivers' perceptions of the road and their expectations about upcoming hazards. In addition, some objects have the potential to create driver distraction and overload, which may also have negative effects on safe driving. Expectations and driver workload are also influenced by the explicit information given in road signs. Both road geometry and roadside environment can affect drivers' mental categorisation of roads, and the section on self-explaining roads discusses attempts to make roads congruent with driver expectations. Temporary factors, such as the presence of other road users and weather conditions, will also affect driver behaviour in some situations. Finally, the review examines potential interactions between road environment factors and driver/social environment factors.

It should also be noted that a further objective of this research program is to evaluate the effect of novel road design interventions on driver speed selection in a series of driving simulator experiments. For this reason, previous research using driving simulators is identified at the end of each section.

2 ROAD GEOMETRY

Road geometry refers to the physical features of the road itself. This includes the surface of the road, its width, whether it is straight or curved, flat or sloping, and the clarity of the division between the road and the area next to the road.

2.1 ROAD SURFACE

Rough road surfaces lead to greater noise and vibration inside the vehicle. Drivers tend to slow down to minimise the discomfort caused by a rough surface (Martens, Comte, & Kaptein, 1997). This may be modified by vehicle factors such as size and soundproofing (see section on interactions); however, it has been suggested that road surface may be one of the most important factors in the determination of speed choice.

Rough road surfaces can also make controlling the vehicle more difficult (Elliot, Mccoll, & Kennedy, 2003). As such, they are not usually recommended as an engineering intervention for speed control. Baldock et al (2008) found that unsealed shoulders and problems with the road surface were a common cause of rural road crashes, particularly when combined with curves. This suggests that unexpected changes in road surface may be particularly dangerous if drivers are not able to adapt their speed to an appropriate level in time.

2.2 ROAD WIDTH

The effect of road width on driver speed choice seems to depend on the amount of pavement the driver perceives as usable. This is affected by the lane width, number of lanes, shoulder width, presence of parked cars on the road edge, and presence of vertical elements on the roadside. Wide lanes and/or multiple lanes increase the area of road available to drive on (Elliot et al., 2003). Sealing and/or widening the shoulder creates more perceived space for drivers, while the presence of parked cars reduces the area available for continuous driving without manoeuvring around obstacles (Martens et al., 1997).

Road width has mixed effects: when the road is (perceived as) wider, drivers increase speed, and thus crash risk increases. However, narrowing lanes as a speed control countermeasure is not always recommended, otherwise the risk of head-on and run-off-road crashes may increase (Fildes & Lee, 1993).

Coloured surfaces are sometimes used to define lanes for cyclists or buses. These lanes decrease available space for drivers, leading to lower speeds; however, it is not certain whether drivers respond in this way to a simple change in the colour of the pavement. There is mixed evidence as to whether drivers reduce speed in the presence of cycle and bus lanes that are empty of cyclists and buses (Elliot et al., 2003).

De Waard et al (1995) evaluated a speed reduction treatment involving blocks of gravel chippings along the centrelines and edges of roads. The gravel provided unpleasant auditory and haptic feedback when driven over, effectively reducing the usable width of the road. This treatment resulted in a higher cognitive load for drivers (as measured by heart rate variability) and lower vehicle speeds.

2.3 HORIZONTAL CURVATURE

The smaller the radius of a curve (i.e. the sharper it is), the slower drivers will approach and drive through it. However, this assumes that drivers can adequately perceive the sharpness of the curve; in reality, curvature is often underestimated (Martens et al., 1997). The availability of cues about curve radius depends on sight distance on approach to the curve as well as whether the curve turns to the left or right, so that the driver is driving on the inside or outside of the curve (Fildes & Lee, 1993). Curves themselves decrease the sight distance ahead, so a wide curve followed by a sharp curve may lead to inappropriate speed as the sharp curve will be concealed by the previous curve. Drivers also tend to enter curves too fast when the curve follows a long section of straight road as the driver has built up speed on the straight section (Dietze, Ebersach, Lippold, Mallschutzke, & Gatti, 2005).

It should be noted that lower speeds due to curves do not equate with lower crash risk when compared to straight roads. Anderson et al (1999) found that the greater the speed reduction experienced on a horizontal curve, the more crashes were associated with the curve. So while sharper curves require drivers to reduce speed more, this is not always sufficient to avoid crashes. In particular, curves that were of an inconsistent radius to the average curve radius on a road (i.e. sharper than drivers were likely to expect) were associated with more crashes.

2.4 VERTICAL CURVATURE

Crests affect sight distance, which means that drivers cannot perceive information about the road ahead and slow down if this is necessary (Fildes & Lee, 1993). Sags or dips affect sight distance at night, as headlights have a restricted vertical range (Dietze et al., 2005). Vertical alignment can alter the perceived width of a road’s horizontal curves, making them appear less sharp than they actually are when superimposed on a sag vertical curve (Hassan & Easa, 2003). This means that drivers are likely to enter such curves at an inappropriately high speed.

2.5 GRADE

Fildes et al (1987) noted that it is difficult to separate the effect of grade from the influence of sight distance restrictions caused by crests. Due to the effects of gravity, a vehicle will tend to travel more quickly when driven downhill, and drivers tend not to compensate for this increased speed on downhill slopes (Martens et al.,1997).

The Interactive Highway Safety Design Model Crash Prediction Module uses a value of a 1.6% increase in crashes with every 1% increase in grade (Harwood, Council, Hauer, Hughes, & Vogt, 2000). However, this model does not take into account the sign of the grade as one direction will be travelling up and the other down, and the crash likelihood is calculated for both directions in a segment. Dietze et al (2005) cite some studies that showed an increased risk of crashes on downgrades, and some studies that showed a decreased risk of crashes on downgrades and an increased risk on upgrades. Recent research from Italy found an increased risk on downgrades and a decreased risk on upgrades (Montella, Colantuoni, & Lamberti, 2008), which is consistent with research from Germany (Lamm, Beck & Zumkeller, 2000, cited in Montella et al., 2008). Taylor et al (2002) found that the group of rural roads with the highest crash risk were very hilly and had lower speeds than other rural roads.

While the precise nature of any effects of downgrades and upgrades on speeds and crash risks may not be clear, it does seem that steeper roads where there are multiple changes in speed caused by uphill and downhill slopes are associated with higher crash risks.

2.6 DELINEATION

Delineation of lane boundaries that indicate the width of the lane and the future direction of the road can be accomplished by installing centre markings, edge markings, and median strips. This guidance increases the ability of drivers to stay within their lanes (particularly on curves); however drivers may overcompensate and drive faster when delineation is improved (Elliot et al., 2003). Drivers may judge their performance by the ability to maintain lane position at a particular speed, without considering whether they would be able to stop in time for an unexpected hazard. This may particularly be a problem at night.

It should be noted that adding road markings at the edge and centre of roads does not always lead to increased speeds. For example, if hatch markings are used at the edge of a road to decrease the perceived lane width, speeds decrease (Elliot et al., 2003). Similarly, peripheral transverse lines and a herringbone pattern at the road edge were both associated with reduced speeds in a driving simulator experiment (Godley, Fildes, Triggs, & Brown, 1999).

2.7 SIMULATOR EXPERIMENTS ON ROAD GEOMETRY

Not all elements of road geometry can be investigated using driving simulators; for example, it is difficult to create the acceleration forces involved in changes in grade, and the use of sharp curves may lead to simulator discomfort. Nonetheless, there have been a number of studies investigating aspects of road geometry in driving simulators.

An early study investigated the effects of reduced sight distance caused by horizontal curves on driver’s speed choice in a driving simulator (Tenkink, 1988). Reduced sight distance resulted in reduced speeds, however the speed reduction was not sufficient to maintain lane keeping through curves.

Godley et al (Godley et al., 1999) examined several perceptual countermeasures designed to increase the level of peripheral visual flow, make the road appear narrower, or enhance curve perception. They found that transverse lines (painted all the way across the lane or just at the edge), hatched medians, and enhanced reflector post spacings were effective in reducing speeds.

De Waard et al (2004) examined the effects of delineation on rural driving. They found that adding a centreline affected lateral position but not speed. Adding edge markings had little effect, but adding lampposts to the side of the road caused speed to decrease but speed variability to increase.

Bella (2005, abstract only) examined potential interactions between road width and curvature on speed, and found that they appear to be independent. That is, drivers do not take into account the width of the road when adjusting their speed on approach to a curve.

Charlton (2007) examined lane markings and signage in the context of overtaking lanes. The effect of different treatments (combinations of markings and signs) was to change the lateral displacement of drivers at certain points during the diverge/merge, but there was no effect of the treatments on speed choice.

3 THE ROADSIDE ENVIRONMENT

The roadside environment consists of all of the surroundings that are visible from the road, particularly those objects near to the road that have the potential to become obstacles in the path of vehicles that run off the road. Although not part of the road geometry, these aspects can be considered part of the road design.

3.1 OBJECTS NEXT TO THE ROAD

Objects immediately next to the road (posts, railings, walls, vegetation) may affect speed and crash risk in several ways. First, they may provide improved guidance as to the direction of the road, which would be expected to increase speed. However, certain patterns (for example clumps of trees) may lead to an increase in peripheral visual flow, which should increase the driver's perception of their own speed and lead to speed decreases (Martens et al., 1997). Objects next to the road are also potential obstacles, and drivers may adapt their speed in response to the potential severity of the consequence.

Objects further away from the road, but still visible, can also affect speed. Roads with open fields and no prominent side features on either side have little stimuli to create peripheral visual flow and thus speeds are likely to be underestimated (Fildes & Lee, 1993). The presence of trees or buildings can decrease this effect, allowing drivers to better calibrate their speed to the conditions. The presence of houses implies the presence of other road users (pedestrians and cars that may pull out of driveways) and this could be a reason why drivers tend to slow down on roads with houses (Elliot et al., 2003). Tall buildings can also create the impression that the road is 'walled in' and therefore less safe, leading to lower speeds; however this effect is not consistent. Some studies have found no effect of building height (Elliot et al., 2003), while others have found lower speeds when building height (or the height of other vertical elements) is greater than the width of the road (Allsop & European Transport Safety Council, 1995).

3.2 SETBACK

Another important moderating variable in the effect of roadside objects on drivers' speed choice is the distance at which objects are set back from the road. The setback between the road edge and any buildings, trees or other objects affects the perceived width of 'driveable area'. Where possible, drivers will move away from the edge of the road if they feel the lateral clearance is too narrow; however, where this movement is not possible drivers may compensate by slowing down (Martens et al., 1997; van der Horst & de Ridder, 2007).

3.3 ACCESS POINTS

The number of entries and exits on the side of a road (including side roads and driveways) affects speed, presumably because drivers anticipate the need to slow for other vehicles pulling onto the road in front (Elliot et al., 2003). Likewise, the presence of a service road (running parallel to the main road such that driveways and minor roads access the service road rather than the main road) is associated with increases in overall traffic speed (Fildes & Lee, 1993). Some studies suggest that this effect occurs only when junctions are located on the driver's side of the road (Martens et al., 1997), perhaps because vehicles emerging from these junctions are more likely to interfere with the driver's path.

3.4 SIGNS AND SIGN LEGIBILITY

Road signs are an important source of roadside information for drivers. Unlike the other factors discussed in this section, road signs give drivers information explicitly rather than implicitly. Signs can provide drivers with information about the speed limit of the road, upcoming hazards, curves in the road (perhaps with advisory speeds), or navigation information, all of which may result in drivers changing their speed. The effect of explicit information from signs on speed choice will be discussed further in section 5.

Another important aspect of signs is not the content, but the format. Signs that are not legible from a distance may force drivers to slow down in order to read them. If only some drivers do this, the speed variability between vehicles will increase, which will increase the crash risk. Similarly, the amount of information on a sign affects the time needed to identify the sign (Liu, 2005), so drivers may slow down to give themselves more time to read the information.

A study into the effects of variable message signs (VMS) of over 4000 vehicles on Norwegian motorways found that when the signs were displaying a message, up to 19% of vehicles braked and average speeds dropped by 5-6 km/hr (Sagberg, Hagman, & Erke, 2005). Sudden braking or slowing is likely to cause shorter headways and potential conflicts between vehicles. The authors note that these effects could have been due to difficulties in reading the sign at a distance, or in processing the message text. Using large fonts and symbols where possible rather than words could minimise these impacts. Increasing the size of signs and using symbols can also improve the conspicuity of the sign: i.e. drivers are likely to notice the sign against the background earlier and thus will have more time to read it (Hughes & Cole, 1984).

Early research into sign legibility found that although highway signs can be read at a distance of 800 feet (~240m) without performing any other activity, participants who were driving did not call out signs until they were 200-400 feet (60-120m) away (Forbes, 1939). The same research also suggested that highway signs should contain no more than three words to ensure drivers can read the sign with sufficient time.

The Australian Manual of Uniform Traffic Control Devices sets out the sign and font sizes that should be used in various speed zones. The formula used in Victoria takes into account the number of words on the sign and the lateral distance from the driver’s path as well as the approach speed; it also suggests increasing font size by 25% in urban areas in order to increase conspicuity (VicRoads, 2007). However, it is not clear what research these standards are based on, and whether they are sufficient to ensure sign conspicuity and legibility in today’s cluttered road environments.

Kline and Dewar (2004) note that the visual decline faced by older drivers may make these drivers particularly vulnerable to the effects of unclear signage. Strategies which will help the increasing numbers of older drivers, such as increasing sign conspicuity and font size, will also assist other drivers who have difficulties reading signs.

3.5 DISTRACTION AND OVERLOAD

The level of visual information or visual clutter in the environment is an important factor that may affect speed and crash risk. For example, it is known that as the number of signs present in a road scene increases, the number of signs that observers can correctly identify in a limited observation time decreases (Oyama, 1987). It would be expected that drivers would slow down in order to process a higher level of information from road signs or similar objects. In fact, two MUARC simulator studies found that, compared to less complex environments, drivers chose lower speeds when driving through complex environments (Horberry, Anderson, Regan, Triggs, & Brown, 2006) or near advertising billboards (Edquist, 2008).

The level of visual clutter is determined by interactions between the amount and complexity of signage, how difficult it is to pick out important objects from the background, distracting objects like shops and advertising billboards, and other facets of the environment that influence driver workload such as the amount of traffic (Edquist, 2008).

Visual clutter may result in driver overload, which occurs when the demands of the driving task exceed the driver's attentional resources, and often results in impaired driving performance. Visual clutter in the form of background complexity impairs the selection of relevant information from the environment. This ability is required for hazard detection (Lee & Triggs, 1976) and maintaining situation awareness (Endsley, 1995). In particular, visual clutter in the form of irrelevant signage interferes with visual search for traffic signs (Ho, Scialfa, Caird, & Graw, 2001; McPhee, Scialfa, Dennis, Ho, & Caird, 2004; Shoptaugh & Whitaker, 1984). These effects will increase the demands placed on the driver. The increased cognitive load may result in slower speeds, which would be expected to decrease the crash rate (as long as the effects are consistent across different drivers). However, some drivers may respond to increased demands with undesirable behaviour such as speeding up, or ignoring potential hazards. Therefore the overall net effect of visual clutter may be to increase crash rate (Elliot et al., 2003).

Visual clutter in the form of highly conspicuous objects may distract the driver by temporarily capturing their attentional resources (Theeuwes, Kramer, Hahn, & Irwin, 1998). Drivers may also need to focus their attention on reading a particular sign, for example, which will have a similar effect to concentrating on an in-vehicle task. Such tasks are known to affect speed control. Drivers have been found to reduce their speed when distracted by an in-vehicle visual task (Engstrom, Johansson, & Ostlund, 2005), while distractions from auditory, manual or visual tasks have been shown to result in greater speed variability (Merat, Anttila, & Luoma, 2005; Parkes, Luke, Burns, & Lansdown, 2007).

Visual clutter may affect speed choice, but vehicle speed will also moderate the effect of visual clutter. At higher speeds, the effects of clutter will be greater because the driver has less time to process visual information from an object such as a sign. So in high-speed areas, simple and well-spaced signs are needed to avoid driver distraction.

3.6 SIMULATOR EXPERIMENTS ON THE ROADSIDE ENVIRONMENT

Godley et al (1999) included roadside features such as trees on the road edge and novel reflector post positioning in their studies of perceptual countermeasures to speeding. A particular pattern of post spacing and height reduced speed on curves; however, trees were not found to be effective in reducing speeds.

Van der Horst and de Ridder (2007) examined the effect of roadside trees, barriers/guard rails and different colour schemes for the barriers on driver speed choice on straight and curved sections of road. Drivers slowed down in the presence of roadside barriers; however, trees only affected speeds when they were closer than 2m to the road.

Manser and Hancock (2007) examined whether visual patterns on the walls of a tunnel affected driver speed choice in a simulator. They found that the presence of texture or vertical segments that gradually decreased in width resulted in slower speeds, while vertical segments that increased in width were associated with increased speed.

Previous MUARC research using the driving simulator has shown that drivers drive more slowly when they are in a more complex environment with many buildings, highway furniture and oncoming vehicles (Horberry et al., 2006). Drivers also drive more slowly when approaching and passing simple billboards, either because they are compensating for increased workload/distraction, or because they are paying less attention to their speed (Edquist 2008).

4 EXPLICIT INFORMATION

Implicit information from the road environment may act on the driver subconsciously, by activating a mental representation of a particular situation and the appropriate behaviour. Explicit information requires the driver to consciously perceive the information and choose whether, and in what way, to act on it.

Explicit information about the speed at which a driver should be travelling may be gained from speed limits painted on the road or on signs, curve warning signs with accompanying advisory speeds, and hazard warning signs. Vehicle activated signs can be used to remind the driver of the speed limit, or to measure the vehicle's speed and display whether it is above the limit. Other signs may also have an effect on the driver's speed: for example, signs with the message that speed cameras are used in that area may remind drivers to check their speed, and reconsider the costs and benefits of speeding along a particular section of road.

4.1 SIGNS

Hawkins (1993) tested the effects of signs with flashing lights that informed drivers of a lowered speed limit for school zones when the lights were flashing. Average speeds at the test sites were lower during morning and afternoon operating periods. Although the effect was largest in the first month, after a year there was still a 2.2mph reduction. This was however not below the school zone speed limit of 25mph.

Lajunen et al (1996) performed an on-road test of three signage combinations: the European 'built-up area' sign (which contains a silhouette of a built-up area and signifies a speed limit of 50 km/h) by itself, with a symbolic 'danger' sign, and with a '50' km/h speed limit sign. Speed was significantly lower only when the explicit information of the required speed limit was posted. This is unlikely to be due to driver unfamiliarity with the 'built-up area' sign, as this sign had been in place for several years before the experiment. A second study showed that the presence of a police car after the sign reduced speeds somewhat when only the 'built-up area' sign was present, but not to a level where drivers would not be prosecuted for speeding, which the authors interpreted as evidence that drivers either did not notice the sign or did not know its speed-limiting purpose.

Gitelman and Hakkert (2002) note that ignorance of the speed limit is often used as an excuse for speeding. They examined the effectiveness of speed limit 'reminder' signs on two dual-carriageway and two single-carriageway roads. Compared to control sites, there was no improvement in average speed, 85th percentile speed, or rate of speed limit violation.

Elliot et al (2003) cited a number of studies showing that vehicle activated signs that light up only when vehicles exceed a pre-set speed are highly effective, and suggest that this is because they provide drivers with a better explicit knowledge of the speed limit. It is also possible that the effect of the signs is to provide drivers with knowledge that their own speed is too fast, thus simplifying the chain of events required to reduce speeds to an appropriate level.

Elvik & Vaa (Elvik & Vaa, 2004) combined data from two studies on the effects of providing recommended curve speed warning signs. Although data on speed changes were not available, the signs reduced property damage only accidents by 29% and injury accidents by 20%.

Ray et al (2008) summarised on-road studies of signage in five U.S. states. They noted that dynamic signs (activated by approaching vehicles) resulted in small but sustained reductions in speed, and that these signs can be particularly useful in warning of hazards such as curves or roadworks.

4.2 ROAD MARKINGS

Road markings primarily give implicit information about the road (see section 2.6); however, in some circumstances they can also provide explicit information. For example, the speed limit or the words ‘slow’ may be painted on the road to emphasise transition points from a rural highway to a town. Such markings have been found to be effective in reducing speeds in a driving simulator (Taylor et al 2002, cited in Elliot et al., 2003).

4.3 SIMULATOR EXPERIMENTS ON EXPLICIT INFORMATION

Charlton (2004) studied the effects of chevrons, an advisory speed on a sign, and an advisory speed painted on the road on drivers’ curve approach and transition speed. He found that the chevrons were most effective at reducing vehicle speeds, a result that he attributed to implicit perceptual cues. However, it is possible that this could have occurred because chevron signs are usually located only at sharp curves. While this experiment found the strongest effect for chevrons placed at wider curves, drivers may have assumed that the wide curves were sharper than they appeared and adjusted their speed for a sharp curve. It should also be noted that all three warning types resulted in speed reductions compared to no warnings.

Horberry (1998) studied the effect of signs and markings on drivers’ abilities to judge the height of a low bridge. Drivers approached a low bridge in the virtual environment and were instructed to stop if they believed that they would hit the bridge. Signs with a warning height limit placed before the bridge did not assist drivers to make this decision. However, a marking system which used wide bands painted on the bridge itself improved judgement accuracy.

5 SELF-EXPLAINING ROADS

Road geometry and other characteristics will influence drivers' expectations of the appropriate speed for a road (Weller, Schlag, Friedel, & Rammin, 2008). Therefore, it should be possible to manipulate driver speed choice through changes in road design, rather than merely relying on signage. The concept of 'self-explaining roads' involves designing a road system in which the driver's expectations created by the road environment are implicitly in line with the safe, appropriate behaviour for the road (Theeuwes & Godthelp, 1995).

5.1 ROAD CATEGORISATION AND SPEED

Road categorisation may refer to either the official road categories used by road authorities, or to the implicit subjective categories that road users develop as they become familiar with a particular road system. Because of inconsistencies in the characteristics of roads that share an official category, and similar characteristics of roads in different official categories, the subjective and official categories may not always match. Matching official categories with road users' subjective categories should increase the probability of road user behaviour matching the desired behaviour for a particular road and thereby ensure appropriate speed selection. Drivers are more likely to adhere to the speed limit if they perceive it as being realistic and appropriate for the road concerned (Allsop & European Transport Safety Council, 1995).

Riemersma (1988) asked participants to judge the similarities and differences between a set of photographs of Dutch roads. This process produced a set of 'constructs' that contributed to subjective categorisations of roads, and a second set of participants rated each of the photographs on each construct. These latter participants were also asked to estimate what speed they considered safe for each section, and which official road category the section belonged to. Roads that received similar ratings on the set of constructs tended to have similar perceived safe speeds. However, these clusters did not match the official road categories particularly well. The author concludes that official road categories should make better use of those physical features of roads that people use to judge road categories, and consequently, safe speeds.

Kaptein et al (2002) showed that manipulating road characteristics could lead to subjective categorisations of roads that are more in line with the official categories. This had corresponding effects on speeds in a driving simulator, in that participants showed progressively higher speeds for progressively faster categories of road (i.e. speeds were highest for freeway-type roads, then for highways with intersections designed for a 100km/hr limit, then for highways designed for an 80km/hr limit, etc). The variability in speeds also decreased for some road categories.

Weller et al (2008) performed a similar study to that of Riermersma (1988), using photographs of German roads. They edited some of the pictures so that one element in each was different to the original. Participants were asked to rate pictures on the constructs in the previously developed Road Environment Construct List. The analysis resulted in three factors, and the roads were clustered into three groups depending on their scores on these factors. Road characteristics that influenced the clustering included road surface, width, markings, sight distance, and curvature change rate (whether the sharpness of consecutive horizontal curves was consistent or inconsistent).

Matena et al (2006) reviewed road categorisations used by road authorities across Europe, and determined that official road categories do not necessarily correlate with the design features of the road or the speed limit. They note that some countries (the Netherlands, Denmark, Germany) are moving towards a self-explaining road approach in which these factors are more closely related.

5.2 TREATMENTS BASED ON THE SELF-EXPLAINING ROAD CONCEPT

Drivers' mental categories of roads may be a particular problem where the road changes from one category to another. The self-explaining road concept suggests that such transitions should be marked by changes in the road environment to let drivers know that the appropriate behaviour for the road has changed. An example of this type of treatment is the use of 'gateway' schemes in the UK, which mark where rural highways enter villages. Gateways have been successful in reducing speeds, although the exact reduction achieved depends on the exact treatments used. A series of UK studies found that simple signing and road markings reduced speeds by 1-2 miles per hour; more conspicuous treatments such as coloured road surfacing and markings which create the appearance of narrowing reduced speeds by 5-7 miles ph; and adding physical narrowing or other engineering treatments such as speeds humps or horizontal deflections resulted in a reduction of 10 miles ph in average speeds (Elliot et al., 2003).

5.3 SIMULATOR EXPERIMENTS ON SELF-EXPLAINING ROADS

An early simulator study examined the effects of village gateway treatments. Yellow poles to give the impression of road narrowing, a 50km/h sign, different coloured pavement and a central island in advance of the gateway together resulted in a decrease of 11km/hr in mean driving speeds, although this mean speed was still higher than the indicated speed limit (Riemersma, van der Horst, Hoekstra, Alink, & Otten, 1990).

Kaptein et al (2002) examined the effects of manipulating aspects of the road geometry for four different Dutch road categories on speeds chosen in a driving simulator. Speed variability across drivers was lower in some road categories when they were part of the self-explaining set of roads. Questionnaires revealed that participants took into account many of the features that had been manipulated in judging the appropriate speed at which to drive. However, they also took into account various other features besides road geometry (e.g. the presence of trees and houses, bike paths, and lights), which implies that the self-explaining road concept could viably be extended to other aspects of the road environment.

6 TEMPORARY FACTORS

6.1 NIGHT VS DAY

Less visual information is available at night, which may influence drivers' perception of how fast they are travelling, as well as their perceptions of the appropriate speed for the environment. For example, the presence of roadside trees has less effect on speed selection at night (Fildes & Lee, 1993). Consequently, speeds may be either faster (if the lack of visual information removes perceptual cues to speed), or slower (if the lack of visual information makes drivers feel less safe) at night than during the day.

Fildes and colleagues (1989) performed a laboratory experiment in which participants viewed film clips taken from the driver's perspective and had to estimate the travel speed and rate whether it was slower or faster than the speed they would consider safe. For clips taken at night, speed estimates were significantly slower than during the day, however the speed chosen was rated as appropriate for night clips and too slow for day clips.

Reflective delineators and guide posts have been used to increase the amount of visual information available to drivers at night, and to create the missing peripheral optical flow patterns that assist drivers in judging their own speed (Fildes & Lee, 1993).

A recent Cochrane meta-analysis of fifteen before-after trials of street lighting concluded that crash rates were reduced in areas with street lighting (Beyer & Ker, 2009). Although they did not test effects on speed, the authors attributed this to the effect of increased visibility outweighing the effects of drivers feeling safer.

6.2 OTHER ROAD USERS

The presence of other road users would be expected to affect driver speed choice in that they now need to take into account the behaviour of other moving objects, rather than just stationary elements of the road environment. In particular, it might be expected that drivers would slow down in the presence of vulnerable road users such as pedestrians and cyclists.

In fact, Fildes and Lee (1993) note that studies available at the time of their literature review showed surprisingly little effect of pedestrians on speeds. However, in a later review Elliot et al (2003) conclude that the presence of pedestrians is associated with reduced speeds, citing research by the Scottish Executive Development Department. .

The amount of ambient traffic affects speed choice in that speeds reduce as roads become more congested. In free-flowing traffic, the speed that each driver chooses may be influenced by the speed at which other vehicles are travelling – many drivers will choose to drive 'with the other traffic' rather than at the posted speed limit of the road (Harrison, Fitzgerald, Pronk, & Fildes, 1998; Organisation for Economic Co-operation and Development, 2006).

Fildes and Lee (1993) note that the Australian Road Design Handbook suggests that the traffic mix (the variety of vehicle types on the road) may affect speed choice. They cited Duncan (1974) as showing no effect on free speed measurements related to the volume of heavy vehicles. A more recent study of German autobahn speeds shows that on Sundays and holidays when heavy vehicle traffic is banned and traffic is primarily leisure travel, speeds are lower (Brilon & Ponzlet, 1996).

6.3 PARKED CARS

Parked cars reduce the effective pavement width, which can cause drivers to slow down (as discussed in section 2.2). They also increase the unpredictability of the road environment. The presence of parked cars implies the nearby presence of pedestrians, who could walk out from behind the parked vehicle at any time. Parked vehicles may also start moving and rejoin the through traffic. While reductions in speed have been found on roads that allow parallel parking, it is not clear whether the observed reductions in speed are due to the reduced width of the road or the increased potential danger (Elliot et al., 2003). The average speed may also be reduced by vehicles slowing down to look for or enter parking spaces.

6.4 ROADWORKS

Roadworks are associated with rougher and more slippery road surfaces, sudden lane blockages, and the presence of pedestrian workers and slow vehicles. It would therefore be expected that drivers should slow down for these conditions. However, it is difficult to tell how drivers would react to such a situation given a free speed choice in roadwork zones, as these zones are accompanied by lowered posted legal speed limits.

Gardner and Rockwell’s (1983) survey of 284 highway drivers found that 46.5% of drivers said that they reduced speed in roadwork zones on seeing signage, 21% said that they slowed on seeing construction work, 17.3% said that they watch the behaviour of other drivers, and 2.5% admitted they did not reduce speeds. However this study did not include any speed measurements to compare with the drivers’ self-reported behaviour.

6.5 WEATHER CONDITIONS

There is mixed evidence as to whether drivers compensate sufficiently for bad weather by slowing down. Of the studies reviewed by Fildes and Lee (1993) some studies found lowered speeds during bad weather, while others found no differences between wet and dry days. More recently, Brilon and Ponzlet (1996) found that speeds on German autobahns reduced by about 10km/hr in wet weather, and Holdener (1998) found that speeds on a Texas roadway were 5 to 14 km/h lower (depending on traffic volume) in wet conditions than in dry. Kilpelainen and Summala (2007) studied drivers on Finnish rural roads in winter and found that drivers reported slowing down by 6km/hr in very poor weather conditions (i.e. snow) compared to fair weather, while their actual speeds dropped by 5km/hr. None of these papers reported whether the speed reductions would likely be sufficient to compensate for the increased road slipperiness and reduced visibility.

Finland has speed limit reductions of 20km/hr for roads that are normally 100km/hr during the winter months (November to February). This seasonal speed limit reduction has been found to result in a decrease in mean speeds of 3.8km/hr, with a concomitant 21% decrease in the rate of accidents, and a 40% decrease in fatal accidents (Elvik & Vaa, 2004).

Fog and glare reduce visibility even more than rain (unless the rain is very heavy), but do not affect road slipperiness. No on-road studies were found which had examined whether drivers compensate by slowing down under these conditions. One simulator study found that drivers adopted longer headways when car-following under simulated foggy conditions (Van der Hulst, Rothengatter, & Meijman, 1998). Conditions that reduce visibility may also impair speed perception (as they will reduce the peripheral optic flow and therefore remove cues as to how fast the vehicle is travelling).

6.6 EVENTS

Events such as the start or end of the school day, business hours for shopping centres, or occasions such as special events can change the level and type of traffic using a particular road. Increased congestion, numbers of parked cars, slowly moving vehicles and pedestrians would all lower the average vehicle speed on such occasions (see sections above). No studies were found which had specifically examined the effect of such events on speed separately from the associated features such as congestion.

7 INTERACTIONS

There are several factors that may interact with the road environment to affect driver speed choice. The context and characteristics of the driver, as well as the speed limit and the road design/environment, will all affect how reasonable the speed limit for a particular road at a particular time is perceived to be by a particular driver (Organisation for Economic Co-operation and Development, 2006). Level of experience, enforcement and education can change drivers' perceptions of the likely negative consequences of speeding, while time pressure, personality and vehicle factors may affect the perceived positive consequences of speeding. Some aspects of a driver's current state (e.g. being distracted by a non-driving-related task) can affect the driver's ability to perceive information from the road environment, which may have effects on speed.

7.1 WORKLOAD, DISTRACTION, STRESS AND FATIGUE

Workload from roadside visual clutter interacts with the workload caused by current tasks that the driver is performing; there is a difference in the workload required by the tasks of driving on an open road, maintaining safe following distance in heavy traffic, changing lanes, or merging in a safe manner etc. Where there is a great deal of other information, or the driver is likely to have a high workload due to tasks like merging or lane changing or dealing with heavy traffic, drivers may not be able to pay sufficient attention to speed control.

Engstrom et al (2005) showed that visual demand in particular can affect speeds. They report a study in which drivers in a fixed-base simulator, a moving base simulator and an instrumented vehicle in real traffic performed the same visual in-vehicle task; all three groups drove significantly slower during the task. Drivers who are distracted by mental tasks (such as conversing on mobile phones) are also likely to pay less attention to speed, which may result in driving faster (Recarte & Nunes, 2002) or slower (Parkes et al., 2007). It should also be noted that distracted drivers will show other effects, such as longer response times to road signs and hazards, that may interact with the effects of changed speeds to affect the crash rate (Edquist, 2008).

Stress is likely to reduce drivers' attentional capacity and ability to process information (Hancock & Warm, 1989). As stated above, where the ability to process information is impaired, drivers are less able to adapt speed to the environment. Stress may be due to the demands of the driving task itself, or to other factors within the driver. Responses to stress will vary depending on the individual – some people may adopt riskier behaviours (such as driving faster), while others may attempt to reduce stress by slowing down or attempting to improve hazard monitoring (Elliot et al., 2003).

One particular form of stress is time pressure. Fildes et al (1991) found that drivers who were on business trips and/or behind schedule were more likely to exceed speed limits than drivers who were travelling for recreational purposes and/or not on a particular travel schedule. Time pressure may change driver motivations so that they discount the potential safety consequences of travelling faster in a particular road environment.

Other factors that will reduce attentional capacity and the ability to perceive important aspects of the road environment are fatigue (Williamson, 2005) and vigilance decrements after long periods of low stimulation (Young & Stanton, 2007). Drivers affected by these temporary states may fail to adjust their speed appropriately.

Drivers' lowered capacity to monitor and adjust speed may be of special concern in areas where the speed limits change (for example strip shopping centres located along major roads). Signage may need to be made simpler so that drivers can understand the information on the sign and respond appropriately and quickly. Alternatively, the road environment could be manipulated to implicitly give the information about the change in appropriate speed limits without drivers having to detect and process a sign (see section on self-explaining roads).

7.2 DRIVER AGE, EXPERIENCE, GENDER AND PERSONALITY

Older drivers are impaired in several facets of attention, which will affect their ability to extract relevant information from the road environment and adjust speed accordingly (see McDowd & Shaw, 2000, for a review). For example, older drivers have more difficulty dividing attention between two tasks or information sources; processing of peripheral information is more affected by demands in the central visual field; and overall cognitive processing is slower.

Fildes et al (1987) found that driver experience did not affect speed perception in their laboratory studies, and concluded that differences in speeds were likely due to attitudes, motivations or driving skills. Novice or inexperienced drivers scan the road less, have lower awareness of other vehicles and potential hazards, and may therefore fail to adjust their speed to the conditions (McKnight & McKnight, 2003). Young inexperienced drivers may be more distractible and/or more willing to engage in distracting activities while driving (McEvoy, Stevenson, & Woodward, 2007), which will affect their speed control and consequently their crash risk.

Driver gender may affect speed perception. Fildes et al (1987) found that females tended to underestimate speeds in rural environments, while males were more likely to underestimate speeds in walled, urban environments. The authors did not offer an explanation for this difference. Gender may also affect personality factors and social norms which can affect speed selection (see below).

Young males in particular are more likely to exceed the speed limit (Harrison, Triggs, & Pronk, 1999). This may be due to personality factors such as a higher propensity to risk-taking behaviour, or higher confidence in their own ability. Comfort in exceeding the speed limit is a major predictor of actual driving speed (Harrison et al., 1998). Drivers who are more confident in their own ability and who feel that they are safer than other drivers may be more likely to discount the danger posed by particular aspects of the road environment. This is particularly a concern for younger/inexperienced drivers, who are more likely to overestimate their driving skill (Deery, 1999).

Drivers have two main motivations for exceeding the speed limit: reducing travel time, and experiencing the 'thrill' of driving fast (Organisation for Economic Co-operation and Development, 2006). Differences in drivers' personalities will affect how important each of these motivations is to an individual.

The personality trait of 'sensation seeking' affects how likely an individual is to seek out stimulation and thrills from their environment. Drivers who score highly on sensation seeking prefer higher speeds, and perceive high speed limits as safer than other drivers (Goldenbeld & van Schagen, 2007). The same study found that high sensation seekers take into account less information than low sensation seekers when deciding on preferred speed for a particular road environment.

Social norms may also affect individual attitudes and speeding behaviour. Drivers who perceive other drivers as driving fast, and drivers who are tolerant of a range of illegal behaviours, were both more likely to speed (Haglund & Aberg, 2000; Harrison et al., 1998). Social norms can be affected by enforcement and education campaigns.

7.3 ENFORCEMENT AND EDUCATION

Enforcement and education campaigns are often used with the introduction of new speed limits, sometimes accompanied by engineering treatments. In these situations it is difficult to disentangle the effects of the different interventions. However, it would be expected that education would increase public acceptance of new engineering treatments aimed at lowering speeds. When engineering treatments result in the road becoming safer, drivers may adapt their behaviour by driving faster; enforcement may be a restraining influence on this tendency (Summala, 2002).

Drivers may perceive a different level of risk for being detected speeding in different environments; for example residential back streets or rural roads may be perceived as being less likely locations for speed enforcement than urban arterial roads (Harrison et al., 1999).

Mannering (2009) found that drivers' perception of the speed above the speed limit at which they will receive a speeding ticket affects the speed they believe is safe for the road; however this survey did not examine road environment effects and interactions.

Elvik (1997) found that automatic speed enforcement (photo radar) reduced injury accidents by 20%, but that the effect was much smaller on roads that did not comply with official warrants for the use of automatic speed enforcement based on the rate and density of accidents. This result may reflect lower speeds induced by environmental variables on the low-accident roads; however it was not possible to examine this as actual speed data was not available.

Readers who are interested in the effects of enforcement on speed are directed to MUARC report 200 (Delaney, Diamantopoulou, & Cameron, 2003). Readers who are interested in the effects of education/publicity campaigns on speed and crash rates are directed to MUARC report 220 (Delaney, Lough, Whelan, & Cameron, 2004). Readers who are interested in the interactions between these two interventions that both act on driver motivations are directed to MUARC report 201 (Cameron, Newstead, Diamantopoulou, & Oxley, 2003).

7.4 VEHICLE FACTORS

The capability of the vehicle to travel at high speeds influences driver speed choice; Fildes et al (1991) found that observed speeds were higher for drivers of more recently manufactured vehicles, while Harrison et al (1998) found that observed speeds were higher for those driving larger cars.

Vehicle safety features may also influence drivers' behaviour. For example, drivers of cars equipped with ABS (automatic braking systems) and who are aware of the increased control provided by the system may feel more able to respond to emergencies and therefore may drive faster (Grant & Smiley, 1993).

These factors are likely to be more of a problem in high-speed environments such as urban freeways and rural highways than in suburban areas or central business districts.

New technologies may have effects on speed that interact with the environment. Intelligent Speed Adaptation (ISA) is a system that informs drivers of the speed limit, provides feedback when the limit is exceeded or actually limits vehicle speed. Systems may be based on general speed limits for a particular road, may have additional limits built in (for example lower limits at school zones and curves), or may dynamically adapt to road conditions.

Van Nes et al (2008) conducted a driving simulator experiment on the interaction between road environment factors and warning ISA technology. The road environment factors manipulated were road width, vegetation near the road, and separation between driving directions; narrow roads with trees and no median strips were assumed to have high speed limit credibility, while wide roads without trees and with medians were assumed to have low speed limit credibility. All participants drove high and low credibility roads, and half of the participants were assisted by ISA. Results showed that drivers with ISA drove more slowly overall, while drivers without ISA reduced their speed more in response to the environmental variables.

Vehicle factors may also influence speed *perception*. For example, drivers of tall vehicles whose eye height is further away from the road may perceive their travel speed as lower than drivers in low, road-hugging vehicles such as sports cars (Rudin-Brown, 2006). Drivers of large vehicles tend to receive less auditory feedback from road-tyre noise than drivers of smaller vehicles, which results in underestimation of speed (Matthews & Cousins, 1980). Drivers of more highly soundproofed vehicles also receive less auditory feedback, which may make them more likely to drive faster and less likely to notice engineering treatments that create noise when traversed at a certain speed such as rumble strips (Organisation for Economic Co-operation and Development, 2006). Because small cars provide more auditory feedback, drivers adapt to high speeds to a greater extent, which leads to speeding when transitioning from a high speed road to a slower speed road – although drivers in large cars are still likely to drive faster overall (Matthews, 1978).

8 CONCLUSIONS

Road environment features can have significant effects on driver speed choice, by influencing drivers' perceptions of their own speed and their perceptions of the appropriate speed for a road. Perceptual countermeasures, which aim to implicitly affect drivers' perceptions of how fast they are travelling, are a well-established research area. Engineering treatments to force drivers to slow down are in common use. There is less information on how road environment factors affect drivers' perceptions of the appropriate travel speed for a particular road, without physically slowing traffic.

Studies using driving simulators have examined many facets of driver speed choice. As they allow discrete manipulations of drivers' perceptions they are ideal for studying how fast drivers perceive themselves to be travelling in various situations. They can also be used to assess the effects of different treatments on the speed the driver feels is appropriate for a given road. Simulation offers a naturalistic, non-intrusive alternative to typical research designs that request explicit judgements of speed from participants.

The next component of the Baseline Road Design and Speed program, in conjunction with data gathering for modelling factors that affect crash risk, is to conduct a pilot study in the MUARC driving simulator to assess driver behaviour in response to variable speed limit signs around strip shopping centres. The effect of variable speed limits on crash rates has been examined and found to be positive overall (Scully, Newstead, & Corben, 2008). However there was a wide range of effects across the 18 shopping strips studied, with some even showing higher crash rates after the introduction of variable speed limits. Examining the environmental factors that differ across the strips and the resulting effects on speed may elucidate why the effects were not more consistent and allow better targeting of this countermeasure in future. The choice of which variables to examine will depend on which factors vary across the sites showing widely different effects. However, road width and setback in urban environments, and the level of visual information close to the road, are areas with little prior research that may be good candidates for investigation.

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