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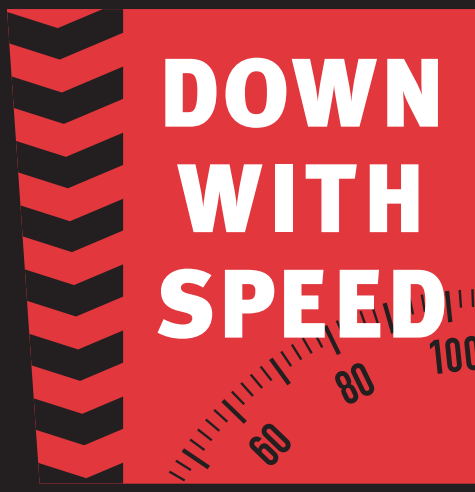



Down with Speed: A Review of the Literature, and the Impact of Speed on New Zealanders.

## We can't afford to ignore speeding on our roads

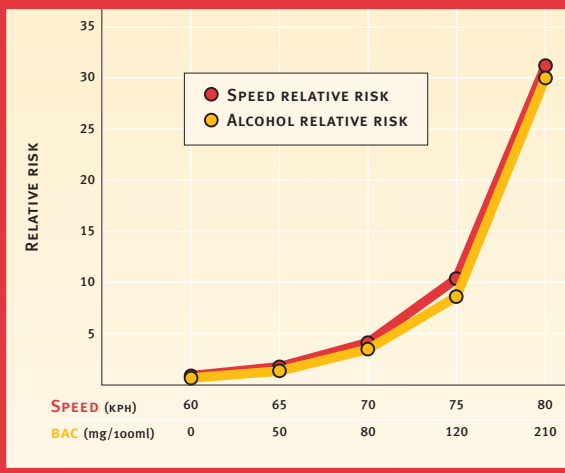
Excess and inappropriate speed on our roads is the single biggest road safety issue in New Zealand today. And yet the seriousness of speeding is still lost on many people. Hundreds of New Zealanders are killed or injured each year, but many people openly admit to enjoying driving fast on the open road; a view which sadly seems to reflect a widespread tolerance of speeding as an acceptable social behaviour. ACC is concerned about the deadly attitude to speeding that New Zealanders are taking to our roads. With research assistance from the Land Transport Safety Authority, ACC wants to dispel some myths, and provide new information about speeding which New Zealanders simply can't afford to ignore.

## 1 Higher speeds result in more crashes

The faster a driver travels on a road, the more likely the driver is to crash. A driver travelling on a road at 90 kph, for example, is more likely to be involved in a crash resulting in an injury than if the driver were travelling at 80 kph. As speed increases, the stopping distance increases, there is greater probability of exceeding the critical speed on a curve, and there is greater chance other road users will misjudge how fast the speeding driver is travelling.

## 2 Higher speeds result in more severe injuries

The severity of injuries resulting from a crash is directly related to the pre-crash speed of the vehicle, whether or not speeding was a factor in the crash. When a vehicle crashes, it undergoes a rapid change of speed. But the occupants keep moving at the vehicle's previous speed until stopped, either having been thrown from the vehicle and hitting an external object, having smashed into the vehicle interior, or having been restrained by a safety belt or airbag. The faster the speed at which the human body must absorb the energy released in the crash, the greater the severity of the resulting injury.




Relative risks of involvement in a casualty crash for speed and alcohol

## 3 Speeding is just as dangerous as drink-driving

New research from Australia shows there is a comparable relative risk for drink-driving crashes and for speeding crashes. A 5-kph increase in speed above 60 kph in a 60-kph zone increases the risk of a crash resulting in a casualty by about the same amount as an increase in blood alcohol concentration (BAC) of 50 mg/100 ml.

There are large differences between penalties for speeding and drink-driving, despite the similarity in a driver's risk of crashing, and injuring or killing themselves or someone else.

| | Base Offence | Relative Risk for Offence | Penalty |
|---|---|---|---|
| Drink-driving | Exceeding 80 mg/100 ml blood alcohol concentration | 3.2 | ▸ maximum 3 months prison or $4,500 fine (maximum 6 months prison or $6,000 fine for third or subsequent offence) and<br>▸ 6 months licence disqualification (12 months for third or subsequent offence), except in special circumstances |
| Speeding | Travelling 70 kph in a 60-kph zone (speed limit exceeded by not more than 10 kph) | 4.2 | ▸ fine of $30 and<br>▸ 10 demerit points (unless a speed camera offence)<br>▸ 100 demerit points in 2 years results in 3 month licence suspension |

Comparison of penalties for similar drink-driving and speeding offences in New Zealand, for a similar relative risk of involvement in a casualty crash

## 4 Fewer New Zealanders would be killed and injured if we all slowed down

The speed we drive on our roads is a major public safety and health issue in New Zealand. 162 deaths, 539 reported serious injuries, and 1,896 reported minor injuries on the road were attributed to speeding in 1998. This is likely to be an underestimate of the impact of speed-related crashes and injuries.

If we reduced average speed on New Zealand's rural roads by just 4 kph – that is, from 102 to 98 kph – it is estimated that 52 fatalities, 133 serious injuries, and 257 minor injuries would be saved.

## 5 New Zealand's rural roads aren't generally built for speeds over 100 kph

A significant part of New Zealand's rural road network was constructed under an 80-kph open-road speed-limit regime. Where roads have been rebuilt, these design speeds have generally been increased to 100 kph. Similar road networks in other developed countries often have speed limits of 80 or 90 kph.

The roading system in New Zealand is not built to safely sustain vehicle speeds over 100 kph. We are consistently driving too fast on our rural roads.

**National Winter Rural Speed Survey, 1999**

| | |
|---|---|
| Rural speed, average | 102.1kph |
| Rural speed, 85th percentile | 113kph |
| Percentage of vehicles exceeding 100kph | 55.6% |

Note: The 85th percentile speed indicates that 15% of vehicles travelled above this speed.

## 6 Vehicle design can affect how fast we drive

Modern vehicle design has created less noise, less vibration, less tilting when taking corners, and more comfort. These design features insulate drivers from the perception of danger when speeding and influences speeding behaviour. Vehicle safety initiatives have focused on reducing the severity of injuries arising from road crashes (secondary prevention) rather than on reducing the incidence of crashes (primary prevention) through measures aimed at reducing vehicle speed, such as speed limiters.

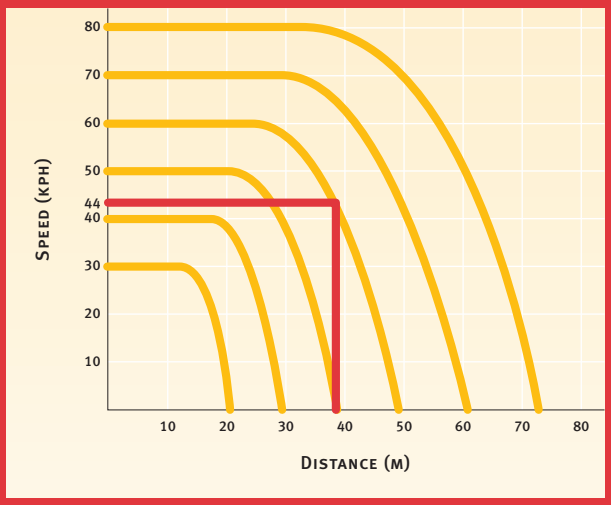
## 7 The roading environment can be altered to slow us down

How drivers perceive the road is a critical factor in speed reduction. Roadside development tends to slow traffic down, so drivers will tend to travel faster on open rural roads and slower on built-up urban roads. Speed humps, road narrowing, and chicanes, as well as road markings, can help reduce speed. To be effective, speed limits should be consistent with the design speed of the road and be backed up by enforcement.

## 8 People can't beat the laws of physics

The faster a driver travels on the road, the greater the risk the driver has of missing critical hazard cues. Upon recognising the hazard at the faster speed, the driver will travel further before applying brakes, and will travel further once the brakes are applied.

**Speed versus distance for emergency braking from time=0**




An example: Two cars travelling side by side, one car travelling at 50 kph and the other overtaking at 60 kph. A child runs onto the road at a point just beyond that at which the car travelling at 50 kph can stop. The other car will still be travelling at 44 kph at that point, a collision speed at which a pedestrian has more than a 50% probability of being killed or severely injured.

**National Winter Urban Speed Survey, 1999**

| | |
|---|---|
| Urban speed, average | 55.8 kph |
| Urban speed, 85th percentile | 62.5 kph |
| Percentage of vehicles exceeding 50 kph | 80.3% |

Note: The 85th percentile speed indicates that 15% of vehicles travelled above this speed.

## 9 Slowing down loses very little time, it saves money, and it is good for the environment

Reducing average speed from 90 to 85 kph on a 10-km trip adds just another 23 seconds to travel time. Fuel efficiency starts to reduce noticeably at speeds above 90 kph. At high speeds and acceleration, the emission of several major pollutants rise due to increased power demands on the engine.

## 10 Enforcement protects New Zealanders from speeding drivers

Rigorous enforcement of speed limits not only leads to speeding drivers being apprehended and punished, but it also increases their perceived risk of being caught and deters them from speeding. Speed cameras can increase the certainty of apprehension and in New Zealand have reduced speeds and crashes in areas where they are deployed.

# Introduction


The Accident Compensation Corporation (ACC) is committed to reducing both the number and severity of injuries on the road. With research assistance from the Land Transport Safety Authority (LTSA), ACC wants to dispel some myths about the impact of speed on New Zealanders' health and well-being.

This document provides a substantial research base to New Zealand's consideration of speeding as a safety issue, and the sorts of strategies that can be employed to reduce speed. It draws conclusions based on research and on injury prevention principles, and is the key resource for ACC's Down With Speed Programme.

The ten points outlined at the front of this document are being used as the basis for a series of presentations, and a supporting leaflet, promoted by ACC to a range of organisations within the community. Through the Down With Speed Programme, ACC hopes to increase understanding of the harmful impact that speeding has on our lives, and to encourage New Zealanders to do more to reduce that impact.

We need first to recognise that motor vehicles have provided individuals and communities with very high levels of mobility, by increasing the distance that is able to be travelled during any given period and decreasing the time it takes to get from one place to another. The increasing mobility that the world has seen over the last hundred years has, however, brought with it a terrific loss of life on the road. Tragically for those who survive road crashes, one of the greatest losses is often physical mobility itself. The mobility that motor vehicles provide comes at a very high cost to personal and community safety.

Speed is the central factor in any consideration of the trade-off between safety and mobility within the road transport system. This is because speed affects every part of the system. Roads are generally designed to safely facilitate travel at a specific speed. Vehicles are designed to allow people and goods to move at a range of different speeds depending on the circumstance. And people constantly make choices about the speed they drive a vehicle on a road.

In this document, speed is considered in terms of "excess speed and inappropriate speed". "Excess speed" refers to instances when vehicles travel in excess of the legally declared speed limit. "Inappropriate speed" refers to instances when vehicles travel at a speed that is unsuitable for the road and traffic conditions. As the European Transport Safety Council noted in its 1995 report, *"the distinction is important because a speed limit… declares [only] higher speeds to be illegal, and it remains for each driver to decide what speed, within the limit, is appropriate"* (p10).

Speed lies at the very heart of the road toll in New Zealand, and indeed in every other motorised country in the world. It is a core contributing factor to road crashes and the resulting death and injury toll. Even when speed is not necessarily a contributing factor in a road crash, however, it is a very important factor in determining the severity of the injuries, fatal or otherwise, resulting from the crash.

Reductions in the road toll over the last decade in New Zealand and around the motorised world have come from an increasingly scientific approach to road safety. This document is based explicitly on the quantitative research that has developed over the last thirty to forty years on the impact of vehicle speed on the safety of our road transport system. The primary reason for concentrating on quantitative research is to extract the essential elements from the area in such a way that leaves little room for argument that is not based on fact. This is because, unfortunately, we do not appear to adequately understand the nature of the problem, and discussion on speeding gets sidetracked away from the core safety problem.

The core safety problem is that we are simply driving too fast on our roads. Without the research information in front of us, we can explain our speeding by referring to the long, flat, straight piece of road that we were driving on. Without the research information, we can explain our speeding by referring to our above-average capacity to detect and respond to hazards. Without the research information, we can explain our speeding by referring to the superior occupant safety features in our car. Without the research information, we can explain our speeding by referring to our need to get from A to B "as soon as possible".

This document has been developed to put our research understanding at the front of our thinking about speeding. With the research information in front of us, we can start to recognise the limitations that New Zealand's roading network places on how fast we can safely drive. With the research information, we can start to recognise the limitations that our mental and physical functions place on the speed that we drive. We can also start to recognise the incongruity within the road transport system of motor vehicles that can drive twice as fast as the maximum speed limit. While based on scientific principles, therefore, this is not intended as an abstract document. It is intended to provide New Zealanders with the capacity to think again about how fast we drive on our roads, and about what we can do to reduce deaths and injuries on the road associated with speeding.

To prompt that rethink, we must first consider speeding as a safety issue, beginning with the basic principles of risk as they apply to speed. Part A of this document outlines the relationship between the speed we drive and the risk of crashing, before discussing the most beneficial means of managing the speed-crash risk. Part A also investigates the risk relationship between the speed we drive and the severity of the injury that will occur in a crash. We then examine the essential elements within the system that impact on our speeding behaviour – vehicles, roads, and people.

Part B focuses on design and engineering issues as they relate to vehicles and to roads. Our discussion on vehicle safety reviews improvements in occupant protection, which is relevant in terms of injury severity, and also considers safety benefits from reducing speed through engineering initiatives. This is followed by a discussion on road and traffic design and engineering. Relevant research issues here involve the application of speed limits and, particularly on rural roads, the design speed of the roading network. Some roadway treatments that have been shown to reduce speed are outlined.

After having examined basic issues associated with risk, and how the built environment of the vehicle and the road impacts upon speeding, Part C turns to how people respond in motor vehicles on roads. This discussion begins by looking at driver capability in identifying and responding to hazards

at different vehicle speeds, and then moves on to examining the use of enforcement as a response to drivers exceeding speed limits. The remaining sections in Part C address means of improving the effectiveness of enforcement activity.

Given the central role of speed within the road transport system, it is necessary to look beyond the central safety issue to develop a more complete understanding of speed. Part D addresses time considerations, fuel efficiency, and environmental impacts of speeding. Finally, Part E addresses speeding within a specifically New Zealand context. The breadth of research addressed in this literature review attests to the international recognition of speeding as a safety issue. It should also be acknowledged that New Zealand's roading environment presents a very particular set of issues regarding how fast we drive on our roads. The document concludes by laying these issues bare and providing a national overview of the trauma that speeding imposes on New Zealanders and of our attitudes towards this behaviour.

# Part A

## Risk, Speed, Crashes, and Injuries

Vehicle speed has a twofold effect on the safety of New Zealanders on our roads – it affects the risk of involvement in an injury crash and it affects the severity of the consequences of a crash.

To aid our understanding of the role speeding plays in the continuing toll of injury and death on our roads, it is useful to relate it to the role played by alcohol. Most New Zealanders have a basic understanding of the fact that a driver who is affected by alcohol is more likely to be involved in an injury crash than a driver not affected by alcohol. Similarly, at any point in time, a driver travelling at an excess or inappropriate speed is more likely to be involved in an injury crash than a driver travelling below the speed limit or at a speed that is more appropriate for the conditions.

The purpose of Part A of this review is to explain the scientific research and understanding that has built up over the years to inform us about the effects of increased speed on crash risk. As we shall see, there have been a number of approaches to studying this topic, and a number of different, sometimes conflicting, conclusions have been reached over the years. With the value of hindsight, re-examination of old studies, and introduction of new research findings, we explain the increased risk to road users that comes with increased traffic speed.

Speeding is directly linked to the severity of injuries that arise from crashes, regardless of whether speed was a reported cause in the crash. This opening discussion on risk therefore concludes with an examination of the direct link between the speed of vehicles involved in crashes and the severity of injuries resulting from those crashes.

The research findings discussed in this Part allow us to develop a clearer perspective on how to reduce the risk that vehicle speed contributes to New Zealanders being killed and injured on our roads. Ways to reduce this risk will be taken up in later Parts of this document.

# 1: The Relationship between Vehicle Speed and Crash Risk

The relationship between vehicle speed and the risk of involvement in a crash has been a topic of interest for some time in the road safety literature[1]. One useful explanatory research approach has been to compare the speeds of vehicles involved in crashes with the speeds of control vehicles (those not involved in a crash). Another approach has been to investigate the relationship between crash risk and variations in the speeds of vehicles on stretches of road. The findings from these approaches are set out below, along with the findings of two further approaches, evaluating the relationship between driver speed and crash history and discussing the principles of physics in relation to speed.

An important point to bear in mind when considering the data that follow is the distinction between urban roads, rural roads, and motorways/highways. The urban roads in these international studies are those in cities and residential areas and tend to have speed limits of around 50 to 60 kph. The rural roads referred to are those between cities and towns, with open-road speed limits (generally 80 kph and above). Motorways and highways have speed limits that range from 100 to 130 kph. German autobahns are not subject to a national speed limit, but some have a local speed limit, some sections are subject to variable speed limits (such as speed limits in bad weather), and there is an advisory speed limit of 130 kph. The distinction between data from these road types is important because different patterns are sometimes found.

## 1a: Comparing Speeds of Vehicles Involved in Crashes and Control Vehicles

The earliest research approach to examining the relationship between vehicle speed and crash involvement was to obtain data on the speeds of crash-involved vehicles prior to the crash (for example, from police reports or by interviewing the driver). These data were then compared with data on the speeds of control vehicles that were not involved in a crash but were in similar circumstances to the crash-involved vehicles (for example, they were on the same

road at the same time of day). Although Kloeden, McLean, Moore, and Ponte (1997) considered this approach to be the strongest theoretically, there are practical problems inherent in the approach – particularly, in accurately determining the pre-crash speeds of vehicles and in finding an appropriate control group – that have limited its usage. Furthermore, once the results are obtained, careful interpretation is needed that takes into account the complexities of the road and traffic environment[2].

### Solomon and the U-Shaped Curve

The first significant study using an approach that allowed an examination of the relationship between vehicle speed and crash risk was conducted in the USA in the 1950s (Solomon, 1964). Solomon examined the reports of 10,000 crashes that occurred on 35 sections of rural highway (a total of 600 miles) from 1955 to 1958. In most cases, the crash reports contained an estimate of the pre-crash speed of the crash-involved vehicle[3], as obtained from the driver, the police, or witnesses (in 20% of cases, vehicle speed was estimated based on details in the report). To obtain the control vehicle speed, the speeds of 290,000 vehicles not involved in crashes were measured (in 1957 and 1958) at one location on each of the 35 sections of highway, and the mean speed for each section was calculated. Solomon then calculated the degree to which the estimated pre-crash speed of each crash-involved vehicle deviated from the mean speed of the control vehicles[4] on the section of highway where the crash occurred. When deviation from mean speed was plotted against crash involvement rate per hundred million vehicle-miles of travel[5], a U-shaped curve was found. That is, where speeds deviated greatly from the mean speed – either faster or slower than the mean speed – crash involvement rates were high, whereas speeds close to the mean speed had low crash involvement rates[6].

The highways on which the crashes occurred had a number of access points (including intersections and driveways) and were likely at times to experience congestion. The crashes at low speeds were generally due to these factors. For example, of the low-speed daytime crashes (at 22 mph (35 kph) or less), 47% were rear-end crashes (which are typical of congested conditions) and 38% were angle crashes (which typically occur at intersections). In these crashes, the drivers were not travelling at free speeds – that is, the driver's speed was impeded by the congestion or the controls at the intersection and was not necessarily the driver's chosen speed of travel on the rural highway. Hence, the high crash involvement rate found at slow speeds cannot be interpreted as indicating there is a high chance of crashing when a driver chooses a slow travel speed along a rural highway. Instead, it may be interpreted as indicating that a high number of crashes occur when travel speed is slowed by congestion or a high number of access points.

This problem with the interpretation of these data does not occur with the high-speed data. Solomon found, for example, that, as the speed of the crash-involved vehicles increased, particularly above 50 mph (80 kph), the number of single-vehicle crashes increased. As will be discussed later, single-vehicle crashes typically occur at high speeds, when the driver loses control of the vehicle. Unlike many of the drivers travelling at low speeds, those travelling at high speeds are able to choose their speed of travel, as their choice of speed is not restricted by the traffic conditions. Thus, the high crash rate at speeds above the mean can be more appropriately interpreted as indicating there is a high crash rate when drivers choose to travel at high speeds.

### Injury Risk

As well as a high crash risk when drivers choose to travel at a high speed, there is also a high risk of injury if involved in a crash. For example, when Solomon analysed the number of people injured per 100 crash-involved vehicles by the speed of the vehicle, the left side of the previously U-shaped curve was eliminated, leaving only the right side

1 The following summary is based primarily on reviews conducted by Kloeden, McLean, Moore, and Ponte (1997), Fildes and Lee (1992), and the Transportation Research Board (1998). Generally, these reviews cited and discussed the same research papers and reached the same conclusions. In cases where a paper was cited in only one of these reviews, attempts were made to obtain that paper. In some cases, the paper concerned could not be obtained in time for inclusion in the present review.

2 For example, Maycock, Brocklebank, and Hall (1998) found that 77% of the variation in observed speeds on different trunk roads in Great Britain was due to road type, road geometry, and weather and road surface conditions. In the following studies, it is not always clear whether different road factors have been controlled for when comparing crash-involved and control vehicles.

3 The pre-crash speed of the crash-involved vehicle is the speed at which the vehicle was travelling before the driver became aware of the impending crash.

4 The deviation from the mean (or average) speed for each section of highway included vehicles travelling slower than, as well as faster than, the mean speed. A crash-involved vehicle travelling at the mean speed had a deviation score of zero, those travelling faster than the mean speed had positive scores, and those travelling slower than the mean speed had negative scores.

5 The crash involvement rate per hundred million vehicle-miles of travel took into account the measured traffic volume on each section of highway.

6 The way Solomon calculated the mean speed (and hence each crash-involved vehicle's variation from the mean) is an important point to note as it indicates a methodological flaw in his study. This is discussed in more detail later in this sub-section.

of the curve, or a consistently increasing slope (see Figure A1). That is, the number of people injured per 100 crash-involved vehicles increased with increasing speed.

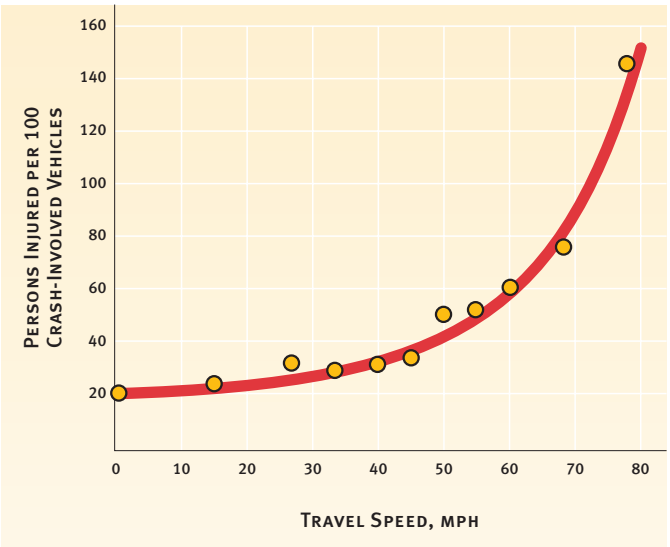



**Figure A1 – Number of people injured per 100 crash-involved vehicles**

Source: Solomon (1964, p11).

### Further Research on the U-Shaped Curve

The U-shaped relationship between deviation from mean traffic speed and crash involvement was also found by Cirillo (1968). Cirillo examined speeds and multiple-vehicle crashes on rural and urban interstate highways in the USA. Cirillo used Solomon's method of measuring the speeds of control vehicles at one location on each highway, calculating the mean speeds, and calculating speed variation as the deviation of the speed of each crash-involved vehicle from the mean for that section of highway. As with Solomon's study, Cirillo's data showed a very high crash rate at speeds much slower than the mean (as well as above it). Cirillo also found, however, that crash rates were highest for sections of the highways closest to interchanges. This finding was taken to (at least partly) explain the high number of crashes at low actual speeds.

There are a number of flaws in Solomon's and Cirillo's studies that limit the conclusions that can be drawn from them. For example, because the pre-crash speeds were often estimated by the drivers or the police, the accuracy of the estimates of vehicle speeds is doubtful, and the estimates used are likely to be underestimates of actual crash speeds[7].

The Research Triangle Institute (RTI, 1970) attempted to reduce the weaknesses in Solomon and Cirillo's approach. They obtained more reliable speed estimates of the crash-involved vehicles on state highways and county roads in Indiana[8]. Also, because turning vehicles tend to have to slow down or stop in order to turn (and hence their crash rates are not representative of drivers choosing to travel at a slow speed[9]), crashes involving turning manoeuvres were excluded from the analysis. Although a U-shaped pattern was found, crash involvement rates at speeds lower than the mean speed were not as high as those of Solomon's study.

West and Dunn (1971) analysed the data from the RTI (1970) study further, by including only the crash-involved vehicles for which there was a measurement of speed prior to the crash. For purposes of comparison with the RTI study, all crashes involving turning vehicles were also removed from the analysis. With the less accurate speed data and data on turning vehicles removed, a weakened U-shaped curve was found and the elevated crash risk at speeds much lower than the mean disappeared.

In addition to the criticisms of the Solomon and Cirillo studies referred to above, a number of other reviewers (Fildes and Lee, 1992; Kloeden et al, 1997; Transportation Research Board, 1998) have identified other biases and methodological flaws in these studies. Some of the flaws arose because they did not use a matched control group[10]. Matched control group data would comprise the measured mean traffic speed

7 Furthermore, in Solomon's study, in 20% of the crash reports there was no estimate of vehicle speeds, and the speeds had to be deduced from the information given.

8 For the first eight months of the study, speed estimates for crash-involved vehicles were obtained from experts' on-site assessment of the crash. At that time, however, a new computer-sensor system was developed that enabled the measurement of the speed of traffic and of individual vehicles. The sensors were embedded at 16 points along the main highway in Indiana. So, during the last few months of the study, it was possible for the researchers to use this computer system to identify crash-involved vehicles or the platoon in which they had been travelling and obtain their respective pre-crash speeds.

9 Crashes involving turning vehicles may occur, not as a result of the turning vehicle's (slow) speed, but instead because the driver misjudged the gap required to turn across the path of an approaching vehicle that was travelling at excess speed. In this scenario, the crash is due to driver misjudgement and the excess speed of the other vehicle. Hence, including vehicles turning at low speeds in an analysis of crash involvement by speed may falsely give the impression that vehicles travelling at low speeds have a high risk of crashing due to their speed.

10 Research designs that included matched control groups were not in common use in the 1950s when Solomon undertook his study. Given that his study included data from 10,000 crashes, obtaining a matched control would have been a huge undertaking.

at each location where each crash included in the crash data had occurred. Where possible, the mean speeds would be measured at the same time of day and day of week as the crashes had occurred (and under the same road and weather conditions). Deviation from the mean speed would then be calculated individually for each crash-involved vehicle and aggregated to show the risk of crash involvement at each degree of variation from mean traffic speed. West and Dunn's (1971) attempt to remove the bias towards crashes at speeds greatly below the mean by removing the data on turning vehicles did not fully address the issue[11] but did highlight the extent to which these crashes are over-represented in the data.

Overall, the weaknesses in the early research gave the impression that drivers travelling at low speeds have a high risk of crashing **because** of this low speed. As discussed, the relatively high crash-involvement rate of these drivers is often due to other factors, such as congestion and inter-section points. However, the weaknesses in the studies did not diminish the finding that the risk of crash involvement on rural highways increases with increased speed above the mean traffic speed. Another unchallenged finding of the early research was that the number of injuries from a road crash increases with the increasing speed of the crash-involved vehicles.

### Recent Australian Research

A more recent study examined the relationship between speed and crash risk on urban roads in Australia. Kloeden, McLean, Moore, and Ponte (1997) conducted a study in Adelaide's 60-kph metropolitan area, using crash data and matched control data. The main criterion for inclusion of crash-involved vehicles in the data was involvement in a crash where at least one vehicle occupant was transported from the crash scene by ambulance. Crashes involving illegal manoeuvres and those in which alcohol was a factor were excluded from the study, as were crash-involved vehicles not travelling at free speeds[12]. The control vehicles were four vehicles travelling at free speeds in the same direction as the crash-involved vehicle, at the same location, at the same time of day, on the same day of week, and under the same weather conditions as the crash. The speeds of the crash-involved vehicles were estimated using crash reconstruction techniques[13] and compared to the control vehicle speeds[14]. Only vehicles in crashes in which there was sufficient information to carry out the computer-aided crash reconstruction could be included.

Kloeden et al (1997) found that, in general, the crash-involved vehicles were travelling faster than the control vehicles. Figure A2 shows how travelling speed affects the risk of involvement in a crash in which casualties occurred, relative to a speed of 60 kph (the speed limit). Significantly, Kloeden et al found that above 60 kph the risk of involvement in a casualty crash increases exponentially; that is, with each 5 kph increase in travelling speed, the risk of involvement in a casualty crash approximately doubles. The researchers estimated that a large proportion of the crashes in the study could have been avoided had the crash-involved vehicle been travelling at a slower speed.

Kloeden et al's (1997) study represents a new under-standing of the relationship between speed and crashes on urban roads[15]. It is important to note, however, that the relationship relates only to crashes in which there was an injury severe enough to require hospitalisation; hence the study is biased towards high-speed crashes and the crash rates at low speeds may be understated. Another weakness, acknowledged by Kloeden et al, was that the pre-crash speeds were estimated rather than measured. Hence, despite the high reliability of the crash reconstruction technique, there may be an unknown bias. Overall, though, the study by Kloeden et al demonstrated that the higher the speeds in urban areas, the higher the risk of crashing.

11 To fully address this issue, it would be necessary to select control vehicles that were performing the same turning manoeuvre as the crash-involved vehicle, measure the speeds of those vehicles, and compare the speed of the crash-involved vehicle with the mean speed of the control vehicles.

12 That is, vehicles slowed by traffic, vehicles slowing to execute a manoeuvre, and vehicles accelerating away were not included. These exclusions "*aimed to ensure that the association between travelling speed and crash involvement was not confused by the inclusion of vehicles executing (necessarily slow) manoeuvres or [giving way]*" (Kloeden et al, 1997, p27). Vehicles involved in rear-end crashes were also not included in the study; these crashes are usually due to drivers misjudging safe following distances for the speed travelled rather than to speed per se. Further, physical conditions were controlled for as far as possible by not including crashes that occurred while it was raining, and not including crashes on sections of road with advisory speed signs (advising motorists to travel at less than 60 kph).

13 The crash reconstruction technique used was "SMAC" (Simulation Model of Automobile Collisions). SMAC is a computer reconstruction program developed on the basis of physical testing and studies of vehicle dynamics.

14 The control vehicle speeds were measured with a laser speed gun. Checks were made to ensure motorists were not warning others about the presence of the laser gun.

15 The study specifically relates to 60-kph speed limit areas. A more extensive study involving a variety of speed limits would be needed to enable generalisation of the results to all speed limit areas.

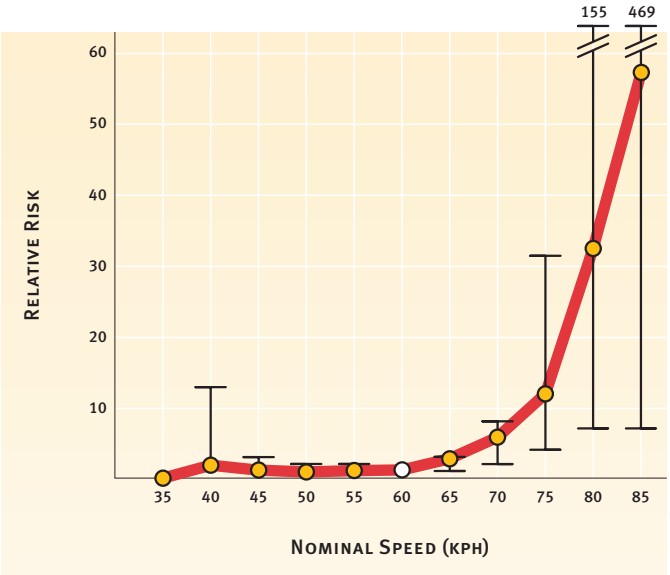



**Figure A2: Travelling speed and the risk of involvement in a casualty crash relative to travelling at 60 kph in a 60-kph speed-limit zone**

Source: Data for figure generated from Kloeden et al (1997, Table 4.3, p37).
Notes: Relative risk at 60 kph set at 1.00. 95% confidence intervals are shown by the vertical lines.

### Explaining Travel Speed and Crash Risk

Kloeden et al (1997) went on to analyse why increased travel speed increases crash risk. The most common crash types they observed were an oncoming vehicle turning right across the path of vehicles travelling at free speeds and a vehicle turning right from a side street across the path of vehicles travelling at free speeds. Kloeden et al hypothesised that these crashes occurred because the approaching vehicle was travelling at excess speed and the turning driver misjudged the gap because he or she mistakenly assumed the approaching vehicle was travelling at about the same speed as the other free-flowing traffic on the road.

Kloeden et al stated that related vehicle speed factors *"often have a cumulative… effect on the risk of involvement in a casualty crash. For example, a speeding vehicle is likely to have its speed misjudged by another driver, thereby creating a crash situation, in which the speeding vehicle will travel further during the reaction time of its driver, will lose less speed under emergency braking, and will crash at a comparatively greater speed with much greater crash energy"* (p48).

Another finding by Kloeden et al (1997) was that drivers travelling at very high speeds (above 90 kph in a 60-kph zone) had an extremely high risk of losing control of the vehicle and of subsequent crashes and injuries. In New Zealand, loss of control is the most common type of crash in which speed is identified as a contributing factor, in both urban and rural environments (see Part E).

### Comparing Speed Risks and Alcohol Risks

A further significant element that Kloeden et al (1997) explored was the crash risk of speeding in a 60-kph speed limit zone compared with the crash risk of driving after consuming alcohol. They reported a previous study conducted in Adelaide by McLean, Holubowycz, and Sandow (1980, cited in Kloeden et al, 1997) that related the risk of crash involvement to a driver's blood alcohol concentration (BAC)[16]. Kloeden et al concluded that quite small increases in speed result in an increase in the relative risk of crash involvement that is comparable to illegal blood alcohol levels. A 5-kph increase in speed above 60 kph (in a 60-kph zone) increases the risk of a casualty crash by roughly the same amount as an increase in blood alcohol concentration from 0 to 50 mg/100 ml. The results are summarised in Table A1 and Figure A3 below. An example of comparable relative risk is the risk of involvement in a casualty crash when travelling at 70 kph in a 60-kph zone or when driving with a BAC of 80 mg/100 ml.

| Speed (kph) | Speed Relative risk | BAC (mg/100ml) | BAC relative risk |
|---|---|---|---|
| 60 | 1.0 | 0 | 1.0 |
| 65 | 2.0 | 50 | 1.8 |
| 70 | 4.2 | 80 | 3.2 |
| 75 | 10.6 | 120 | 7.1 |
| 80 | 31.8 | 210 | 30.4 |

**Table A1 – Comparing relative risks of involvement in a casualty crash for speed and alcohol**

Source: Adapted from data in Kloeden et al (1997, p54).
Notes: BAC = blood alcohol concentration. The relative risk for speed is relative to 60 kph in a 60-kph zone; the relative risk for BAC is relative to zero mg/100 ml. Blood alcohol concentration is converted to New Zealand units (milligrams of alcohol per 100 millilitres of blood, mg/100 ml). 80 mg/100 ml is the legal limit in New Zealand.

16 In the speed data, the researchers excluded the crash data of alcohol-affected drivers (in fact, they recorded the data during the day and found few such cases). It is not known whether speed was controlled for in the alcohol data.

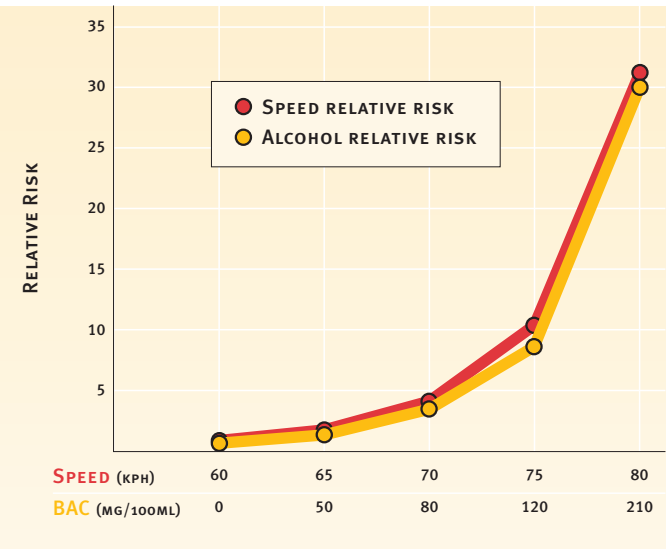



**Figure A3 – Relative risks of involvement in a casualty crash for certain speeds and with certain levels of blood alcohol concentration (BAC)**

Source: Data for figure generated from Kloeden et al (1997, Table 5.2, p54).
Notes: The relative risk for speed is relative to 60 kph in a 60-kph zone; the relative risk for BAC is relative to zero mg/100 ml.

Although there are useful parallels to be drawn in the relationship between driver consumption of alcohol and crash risk and the relationship between vehicle speed and crash risk, it is important to bear in mind that alcohol and speed increase crash risk for quite different reasons.

Alcohol increases crash risk through a combination of factors. For example, alcohol-affected drivers are unable to perform multiple tasks; therefore, they have difficulty responding to hazards that appear in their path. The crash risk for alcohol-affected drivers is also increased because they are less risk-adverse and less able to withstand peer pressure. Furthermore, alcohol-affected drivers have slower reaction times, which affects both their risk of crashing and the consequences of a crash.

Speed also increases crash risk through a combination of factors – such as the reduced time available to detect and respond to hazards in the driving environment and the increased stopping distance. Furthermore, if there is a small deviation in the direction of travel, then the risk of leaving the road and crashing increases with increased speed. As will be discussed later, the consequences of a crash also increase with increasing speed.

A further difference between alcohol and speed in terms of crash risk is the length of time that the increased risk exists. After a person drinks alcohol, the blood alcohol concentration remains elevated until the body is able to process the alcohol and remove it from the blood (this process can take several hours). Thus, an alcohol-affected driver will present a higher crash risk over a sustained period of time – generally for the entire journey. By contrast, a speeding driver can increase the crash risk in a more transient manner. Through changing his or her speed over a journey, a driver can increase the crash risk significantly over short periods of time and can maintain a relatively low level of risk at other times during the journey.

## 1b: Comparing Crash Rates after Changes in Mean Speed and Speed Variation

Another approach to understanding and explaining the relationship between speed and crash risk is to examine crash rates before and after a change in speed limit. One of the criticisms levelled at this approach is that the studies have often not taken into account other factors (aside from the speed limit change) that may affect crash rates, particularly the level of enforcement of and compliance with the new speed limits (Kloeden et al, 1997), and this may weaken the findings to a degree. In spite of any weaknesses in the studies, however, this approach adds to our overall understanding of the speed-crash relationship through use of actual crash data and formulae to show the expected effects of a traffic speed change on crash rates.

### The New Zealand Experience

During December 1973, New Zealand imposed an open-road speed limit of 50 miles per hour (mph) (80 kph) as a fuel-saving measure. Before this time, the speed limit was set at either 55 or 60 mph (88 or 97 kph). Due to concern over the fuel shortages, compliance with the new speed limit was high; hence there was an 8- to 10-mph reduction in rural mean speeds when the limit was imposed. The drop in speeds led to a significant reduction in injuries compared to roads unaffected by the speed limit change (that is, urban roads) (Frith and Toomath, 1982). The drop in mean speeds was also associated with a sharp contraction in the distribution of speeds.

Following the oil crisis, mean speeds on the open road began to increase again to pre-1973 levels. On 1 July 1985, the open-road speed limit was increased to 100 kph. Since speeds prior to the increase had been high, the change in

speed limit did not result in a subsequent increase in crashes (Jones, Derby, and Frith, 1986). These findings suggest that speed limit increases or decreases are only likely to change crash rates if they are accompanied by mean speed changes.

### International Experiences

Interstate highways in the USA have been the largest area of study of changes in speed limits. In 1974, again in response to the oil crisis, the National Maximum Speed Limit (NMSL) for highways was introduced and set at 55 mph (88 kph). Before the introduction of the NMSL, states set their own speed limits, and these were generally higher than 55 mph. Several studies examined the effect of the new speed limit on road safety. The Transportation Research Board (TRB, 1984) reviewed these studies and found that the lower speed limit reduced both travel speeds and fatalities, but that compliance with the speed limit decreased over time.

The NMSL was raised to 65 mph (105 kph) in 1987. Following the change, 40 states raised their speed limits to the new maximum. The effect of the change was examined by a large number of studies at both the national and state level. A review of these studies by the TRB (1998) concluded that *"raising the speed limit led to an increase in both rural interstate fatalities and fatal crashes"* (p118). For example, one study conducted by Garber and Graham (1989, cited in TRB, 1998) that controlled for many other variables that affected highway safety found that, across the 40 states that raised their speed limits, there was a 15% increase in fatalities on interstate highways.

Finch et al (1994) also reviewed the NMSL change from 55 to 65 mph. They concluded that *"the immediate effect [of] raising the limit has been to increase average car speeds by about 3 mph; the effect is not constant, but varies from state to state"* (p12). They found that this mean speed change increased fatalities by about 20% to 25%, which was estimated to correspond to an extra 500 lives lost per year.

In 1995, the NMSL was repealed, again allowing states to set their own speed limits. Several states raised their speed limits almost immediately. An evaluation by the National Highway Traffic Safety Administration (NHTSA, 1998) reported that *"it is estimated that… the 32 states that increased [interstate] speed limits experienced approximately 350 more fatalities than would have been expected based on historical trends, about nine percent above expectations"* (p56).

Other countries have conducted similar studies on speed limit changes. A review of the studies from several countries (South Africa, Belgium, Finland, France, Great Britain, Germany, USA, and New Zealand) where a speed limit was reduced or established prior to 1981 found a reduction in road crashes ranging from eight percent to 40% (Fieldwick, 1981, cited in Fildes and Lee, 1994).

One of the most recent evaluations of changes in speed limits examined the change from 100 to 110 kph on Melbourne's rural and outer freeway network in 1987 and the change back to 100 kph in 1989. Sliogeris (1992) found that, compared to a control group of all other roads in Victoria that remained at 100 kph between 1987 and 1989, the injury crash rate per kilometre travelled increased by 24.6% following the change from 100 to 110 kph, and decreased by 19.3% following the change back to 100 kph.

There is a consistent finding from the studies referred to above that shows that increasing the speed limit increases crash, injury, and fatality rates and that decreasing the speed limit can reduce these rates.

### Nilsson and the Fourth Power of Speed

One highly reported piece of research comparing speeds and the risks of crash involvement before and after a speed limit change was undertaken by Nilsson (1982).Nilsson combined a number of evaluations of increases and decreases in speed limits in Sweden between 1968 and 1972 to validate a model for estimating the effect of changes in traffic speed on road safety. The model was further validated by applying it to data from other studies of speed limit changes in Sweden, Denmark, and the USA.

The model used the physics law[17] relating to kinetic energy (the energy that something has by virtue of being in motion) – that is:

$$\text{kinetic energy} = \tfrac{1}{2} \times \text{mass} \times (\text{speed})^2.$$

17 The physics law is based on the following probabilities:
(a) The probability of a personal injury accident in the road system reported by the police is proportional to the square of the speed ($v^2$), which is a shortened formula for the kinetic energy.
(b) The probability of a fatal accident resulting from a personal injury accident is also proportional to the square of the speed ($v^2$), which means that the number of fatal accidents is proportional to the fourth power of the speed ($v^4$) (cited in Andersson and Nilsson, 1997, p6).

Nilsson's model was that, if $v_a$ = mean or median traffic speed before the change of speed limit and $v_b$ = mean or median traffic speed after the speed limit change, then:

- the number of all injury crashes after the change = $(v_b/v_a)^2$ x the number of all injury crashes before;
- the number of fatal and severe crashes after the change = $(v_b/v_a)^3$ x the number of fatal and severe crashes before;
- the number of fatal crashes after the change = $(v_b/v_a)^4$ x the number of fatal crashes before.

Figure A4 below, which plots Nilsson's formula, demonstrates that there will be twice as many fatal crashes when the mean speed is 120 kph than when it is 100 kph.

More information about the effects of crashes, including their impact on the human body, will be discussed in Section 3 of this Part of the present review.

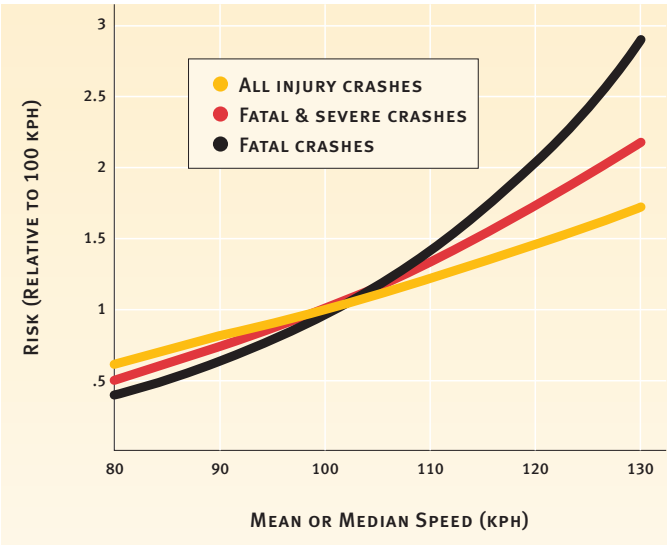



**Figure A4 – Risk of crashing relative to a mean or median speed of 100 kph**

Source: The figure was generated using Nilsson's (1982) formula.

Another statistical relationship between mean speed and crash risk was reported by Finch et al (1994). They examined studies from Finland, Germany, Switzerland, and the USA in which there was a change in mean traffic speed. Using multivariate linear and non-linear regression techniques on the data in the studies, they found that *"for every 1 mph rise in the mean traffic speed, the percentage change in [crashes] rises by about five percent"* (p18). This relationship applied to both urban and rural roads.

More recently, the Transport Research Laboratory (TRL) conducted extensive research into the statistical relationship between speed and crash frequency (Lynam, Baruya, Taylor, and Finch, 1999, cited in Silcock, Smith, Knox, and Beuret, 1999). They demonstrated that a 1 kph reduction in mean speed can produce up to a three-percent reduction in crashes. This finding was consistent with many studies of speed changes. They reported, however, that the risk of crashing varies depending on the road type (see Figure A5). For example, the elevated crash risk occurs at higher speeds on semi-rural link roads than it typically does on inner city link roads. This finding very much reflects the design speeds of the different road types and, therefore, the safe travel speeds on those roads.

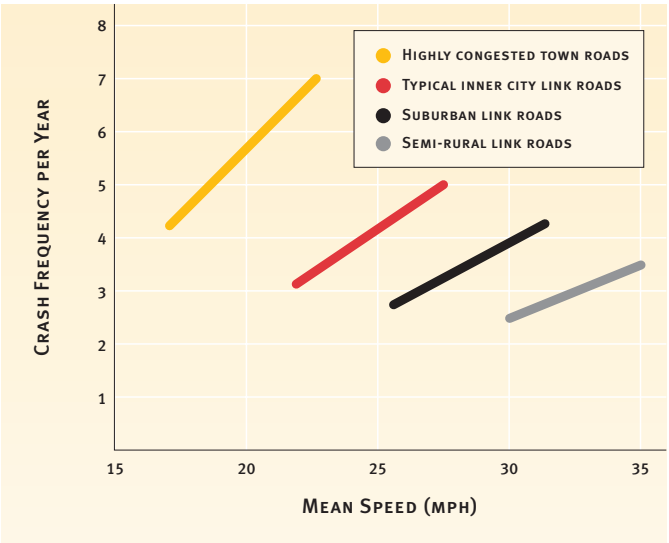



**Figure A5 – Speed-crash relationship on UK urban roads**

Source: Lynam et al (1999, cited in Silcock et al, 1999, p3).
Note: The speeds in the figure, when converted to kilometres per hour, are approximately as follows: 15 mph = 24 kph, 20 mph = 32 kph, 25 mph = 40 kph, 30 mph = 48 kph, 35 mph = 56 kph.

The evaluations of speed limit changes have indicated that increasing a speed limit can increase crash rates, while decreasing a speed limit may decrease crash rates. The effect is, however, very much dependent on the mean speeds before and after the speed limit change. Formulae have been developed by Nilsson, Finch et al, and Lynam et al to show the relationship between the change in the mean or median speed and crash data. Although the formulae are not exactly the same, they all indicate that an increase in the mean speed of traffic produces an increase in crash rates. Nilsson's formula also indicates that a decrease in the mean speed will produce a reduction in crash rates.

### Mean Speed and Traffic Speed Variation as Crash Factors

In Section 1a, we discussed how some researchers have investigated the relationship between crash risk and the degree to which the speed of the crash-involved vehicle deviated from the speed of surrounding traffic. Other researchers have looked at speed variation in a different way; that is, they have looked at the distribution of speeds at a point on a stretch of road.

It is important to understand that speed variation in this context refers to variability in a stream of traffic. Therefore, it can only be a factor in crash risk if there are at least two vehicles interacting (and travelling in the same direction) on a stretch of road. When there is only one vehicle on the stretch of road, there is no speed variation. On New Zealand's rural roads, for example, it is not unusual for there to be only one vehicle using a particular stretch of road. However, a large number of crashes still occur when the crash-involved vehicle is the only vehicle on the road, but these single-vehicle crashes are not due to variations in the speeds of vehicles on the road. Hence, traffic speed variation can never account for 100% of the crash risk in a stream of traffic. Andersson and Nilsson (1997) point out that, when using statistical measures of mean speed and speed variation to explain or predict crash risk, it is very difficult to isolate the relative effects of these two factors. They go on to state: *"The speed variance can be attributed to a limited part of the road [crash] problem, while the [mean] speed level affects every [crash], particularly [in terms of] injury consequences"* (p9).

Early research on speed variation found that crashes were more likely to occur on roads with skewed speed distributions than on roads with normal speed distributions[18] (for example, Taylor, 1965, and Krzeminski, 1976, both cited in Kloeden et al, 1997). However, these findings have been criticised for the absence of important information that may have influenced the crash pattern, such as the causes of the skewed distribution or whether the skewness was positive or negative (Kloeden et al, 1997).

More recently, Garber and Gadirau (1988, cited in Kloeden et al, 1997) measured crash rates, speed variation, and mean speed on 36 sections of interstate highways in Virginia. Each section of highway had a posted speed limit of 55 mph, but the design speeds[19] across the sections ranged from 40 to 70 mph. Garber and Gadirau found overall that, as mean speed increased, crash rates decreased. That is, the sections of highway with the highest mean speeds were safer than the sections with lower mean speeds. This finding is explained by the observation that the sections of highway with the highest mean speeds were those with the higher design speeds (that is, these sections were designed to accommodate higher speeds). They also found that crash rates increased with increasing speed variation. However, Kloeden et al suggest this relationship may also be related to the design features of the road. That is, better designed roads have low crash rates because provision is made for overtaking and turning vehicles, therefore lessening the situations that lead to large speed variation. A further criticism of the study made by Kloeden et al was that the measure of speed variation appeared to be dependent on a small number of slow vehicles at a site. At one location, the slowest two percent of vehicles accounted for 47% of the speed variance.

In his analysis of speed variation effects across a range of road classes in 48 states of the USA, Lave (1985, cited in TRB, 1998) defined speed variation as the difference between the mean speed and the 85th percentile speed (the speed at or below which 85% of vehicles were travelling). Using multiple regression, Lave found that speed variation was significantly related to fatality rates for rural interstate highways and rural and urban arterial routes; that is, the greater the speed variation, the higher the fatality rate. This finding is not surprising given that speed variation was measured as the difference between the 85th percentile speed and the mean speed. That is, when this difference was large, it meant that the fastest vehicles were travelling at very high speeds compared to when the difference was small, and, as we have seen, with higher travel speeds, the fatality rate is higher. Kloeden et al (1997) criticised Lave's study because the regression model did not fit these data very well. Furthermore, the regression approach may have given more weight to speed variation than to mean speed for purely mathematical reasons, which leaves some doubt as to which of the two variables is the primary causal variable.

Baruya and Finch (1994, cited in Kloeden et al, 1997) studied crash rates on Britain's rural roads and looked at whether mean speed or speed variation was the stronger contributing factor to crashes. In investigating this relationship, they found that the coefficient of variation (the standard deviation of the distribution divided by the mean speed) and mean speed had a counterbalancing effect – that is, on roads where mean speed was relatively high, the coefficient

18 Normal distributions are symmetric, single-peaked, bell-shaped density curves (Moore and McCabe, 1993). The mean is located at the centre of the symmetric curve and is the same as the median. A skewed distribution, however, is asymmetric so that it peaks at one end of the graph and has a tail that trails off at the other end. The mean is pulled towards the long tail of a skewed distribution more than is the median because of the influence of values far out in the tail.

19 Design speed is the speed judged to be the maximum safe travel speed under favourable conditions. It was used in the study to reflect the geometric characteristics of a section of highway.

of variation tended to be comparatively low. This finding is not surprising given that there are natural and mechanical limits on the speed at which people can travel on a road. Significantly, however, Baruya and Finch found that the effect of mean speed on crash rates was stronger than the effect of speed variation. This was particularly true when the distribution on the road was non-normal, as it often is in low-speed urban environments because of situational factors such as junctions, crossings, or congestion.

One methodological problem with Baruya and Finch's study, identified by the Transportation Research Board (TRB, 1998), may limit their hypothesis of the relationship between mean speed and speed variation – the speed data were collected in 1992 and 1993, but the crash data were collected from 1983 to 1988. A more recent study does, however, provide some support for their hypothesis. Schmidt (1996, cited in Kloeden et al, 1997) used statistical modelling to examine crash rates on two-lane rural roads in Germany. The alignment and width of the carriageway[20] and the median traffic speed explained approximately half the variance in crash rates on the different roads. Speed variation (the standard deviation of the speed distribution) did not contribute any additional predictive capacity to the model.

### Changes in Mean Speed and Speed Variation

The above studies focused on the importance of speed variance over mean speed on crash rates. A more meaningful approach is to discuss the combined effects of mean speed and speed variance on crash rates, since they are inter-related. Although approaches to managing mean speed and speed variation will be discussed further in Section 2, it is useful here to illustrate graphically the effect on the speed distribution of reducing mean speed and/or speed variance.

Figure A6 demonstrates graphically the effect of a reduction in mean speed on a speed distribution, when the speed variance remains constant. As discussed in detail in Section 1b, a reduction in mean speed, such as that indicated in Figure A6, will reduce crash rates.

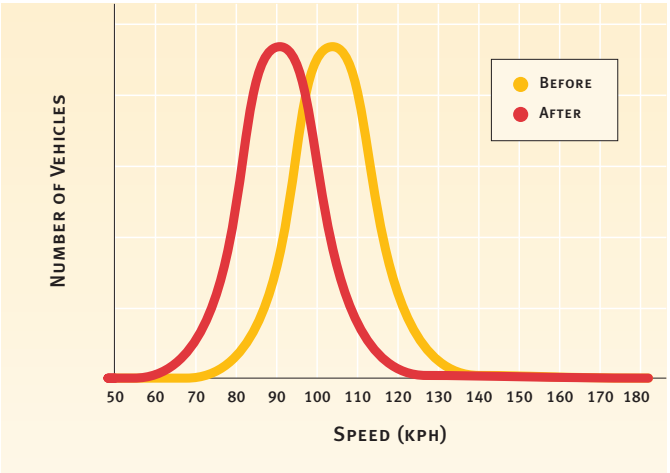



**Figure A6 – A change in mean speed from a high mean speed (before) to a lower mean speed (after)**

Note: The figure has been produced for illustrative purposes and does not represent any real data.

Another approach is to reduce the variability of the speed distribution without changing the mean speed (see Figure A7). This approach means there are fewer drivers travelling excessively above the mean speed, which reduces the crash risk, particularly for those drivers.

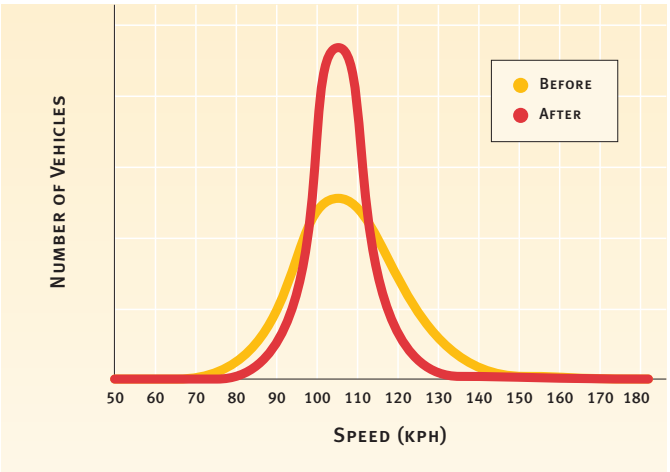



**Figure A7 – A change in speed distribution from a wide speed distribution (before) to a slimmer speed distribution (after)**

Note: The figure has been produced for illustrative purposes and does not represent any real data.

20 The carriageway is the part of the road (or lane) on which vehicles travel. The carriageway does not include the shoulders of the road (the edges) or any median strip (space in the centre of a two-way road).

Instead of reducing only the mean speed or only the speed variance, it is possible to reduce both at once. Figure A8 demonstrates graphically the effect of a reduction in both mean speed and speed variance. As can be seen from the figure, when mean speed and speed variance are reduced, there are even fewer drivers travelling at speeds excessively above the rest of the distribution.

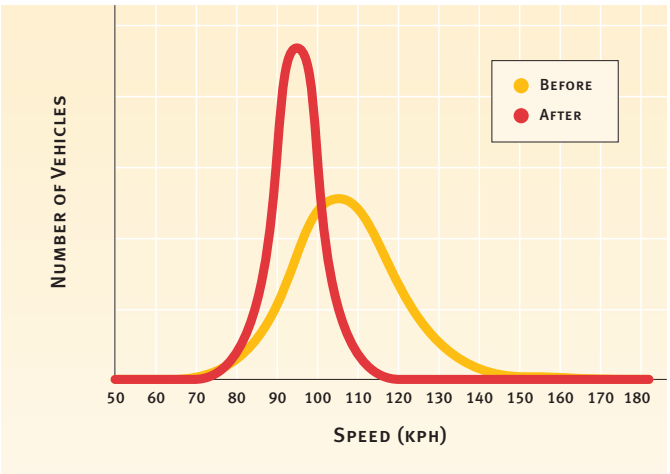



**Figure A8 – Changes in both mean speed and speed distribution from a high mean speed and wide speed distribution (before) to a lower mean speed and a slimmer distribution (after)**

Note: The figure has been produced for illustrative purposes and does not represent any real data.

## 1c: The Relationship between a Driver's Speed and Crash History

A third approach to examining the speed-crash relationship has seen researchers measuring a driver's speed in a specific setting and then examining the driver's crash history (both injury and non-injury crashes were studied). Generally, these studies indicate that the higher the driver's speed, the greater the likelihood that the driver had been involved in a previous crash. The largest problem with this approach is the potential bias in the sample due to the exclusion of drivers who were killed in past crashes (Kloeden et al, 1997) or who are no longer able to drive because of injury. In addition, a driver's speeding behaviour may change after a crash. A further bias is that the crash history of drivers is often obtained by self-report.

The first study of this kind was conducted by Munden (1967), who measured the speeds and recorded the registration numbers of vehicles during evening peak traffic flow on rural main roads in England during 1962. The registration numbers of the vehicles were matched to crash records for crashes that occurred in 1961 or 1962. When graphed, a U-shaped curve was found; that is, owners of vehicles travelling one standard deviation above or below the mean speed had an inflated crash rate[21]. The results should be interpreted with caution, however, particularly as there was large variability in the speed ratio (see footnote) and the study relied on small numbers. Also, there is no guarantee that the driver of the car at the time of the study was either the currently registered owner or the same driver as in an earlier crash[22]. Furthermore, Munden cautioned that other factors, such as driver traits, may have caused the elevated crash risk at low and high speeds.

Hauer (1971) provided an interpretation of Munden's findings in terms of the rate of overtaking, although the interpretation can apply only to two-lane, two-way roads. Drivers travelling at slow speeds are overtaken most, hence these drivers may have an inflated crash risk because of |their proximity to the overtaking vehicle (which is travelling at a higher speed). These findings have been interpreted as meaning it is unsafe to travel at slow speeds, but this interpretation ignores the fact that drivers involved in crashes at higher speeds are at greater risk of injury than those driving at lower speeds (see Section 2 for a discussion of the safety implications in requiring slow drivers to speed up and Section 3 for a discussion of the increased injury risk at high speeds). Furthermore, in New Zealand, overtaking crashes represent a small proportion of all speeding crashes, and the vehicle being overtaken is involved in the crash in only approximately half of the cases.

Wilson and Greensmith (1983) used a similar approach to Munden's study; however, driver speeds were measured using a "drivometer", a mechanical device fitted to a car to record speed information. From data on drivers who had had moderate driving experience, the researchers found that those who reported previous crashes recorded higher speeds than those who reported no previous crashes. A similar result was found by West, French, Kemp, and Elander (1993).

21 Owners whose speeds were recorded at least twice were included in the data. Each vehicle's speed was compared to the speed of traffic around it at the same time to give a "speed ratio" for each vehicle (a matched control). The crashes on record were not necessarily on the roads on which the speeds were measured.

22 The car may have been driven by someone other than the registered owner, or the car may have been sold between the time of the earlier crash(es) and the time of the study.

Fildes, Rumbold, and Leening (1991) unobtrusively measured the speeds of vehicles on two urban arterial roads and two rural undivided highways in Melbourne. The vehicles whose speeds were measured were subsequently stopped and their drivers interviewed about, among other things, their crash history over the past five years. Fildes et al found that the self-reported crash involvement rate rose as a function of the measured vehicle speed (see Figure A9). They also found that young drivers tended to be the fastest drivers and to have a high self-reported crash history.

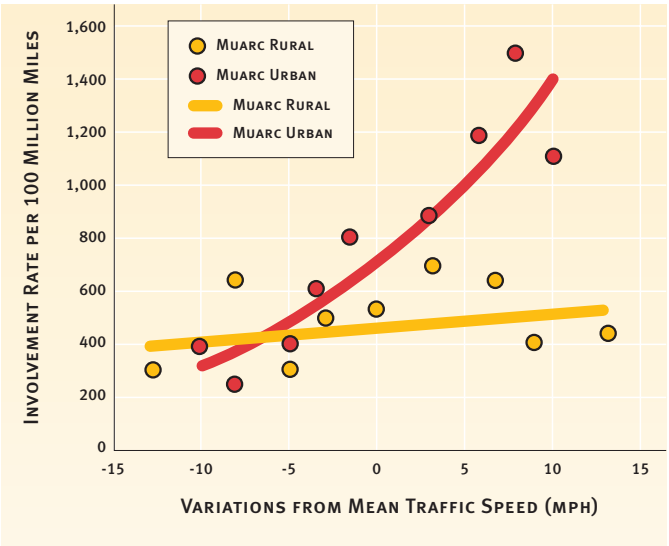



**Figure A9 – Involvement rate by variation from the mean traffic speed**

Source: Adapted from Fildes et al (1991), with permission.
Note: 15 mph is approximately 24 kph.

Recently, Maycock, Brocklebank, and Hall (1998) measured the speeds of vehicles on 43 sections of single and dual carriageways and motorways in Great Britain, and a questionnaire was sent to the drivers[23]. The measured speeds for individual drivers were compared to their self-reported crash frequencies. In general, drivers with high measured speeds had high crash liabilities.

When crash frequencies for individual drivers were modelled against speed for the drivers, they found that a *"one-percent change in an individual driver's choice of speed is associated with a 13.1% change in that individual's [crash] liability"* (Maycock et al, 1998, p14). They caution, however, that the result does not necessarily mean there is a causal link between speed and crashes. It could be due to *"the fact that both speed and [crashes] are related in similar ways to the same variables – particularly age, experience, and exposure"* (p14).

## 1d: Principles of Physics

Applying the principles of physics can also demonstrate the relationship between vehicle speed and crash rates. For example, a central factor in the relationship is stopping distance. Stopping distance is affected by vehicle speed, and influences whether or not a crash occurs. There are two components to stopping distance – (1) the distance travelled by the vehicle during the reaction time of the driver and (2) the distance travelled once the brakes are applied. The reaction time of the driver is generally the same regardless of travelling speed; therefore, the greater the speed, the greater the distance travelled during the driver's reaction time. The stopping distance of a vehicle once the brakes are applied is roughly proportional to the square of the pre-braking speed (TRB, 1998), although in reality the formula is much more complicated.

Therefore, because both components of stopping distance increase as vehicle speed increases (and because distance travelled while braking is proportional to the square of the speed, rather than proportional to the absolute speed), total stopping distance increases disproportionately[24] with vehicle speed. The probability of a collision increases similarly, although it also depends on the distance between the vehicle and the hazard when the hazard is first detected. In general, though, the faster the vehicle is travelling when a hazard presents itself, the greater the stopping distance, and the higher the likelihood that the vehicle will collide with the hazard (or another object in attempting to avoid the hazard) before coming to a stop.

Another situation that is affected by speed is the driver's ability to recover from running off the road or to manoeuvre

23 Forty-six percent of the 14,050 questionnaires sent were completed and returned. Seventy-seven percent of the variation in absolute (measured) speeds was due to the site features such as road type. When site-to-site variation was reduced by looking at each site separately (that is, comparing a driver's absolute speed with all other drivers at the same site), they found that the faster drivers were more likely to be young and to drive a high number of miles annually. The number of self-reported crashes during the past three years for drivers who had at least three years' driving experience were also examined. They found that crash frequencies were higher for young drivers and that crash frequencies fell rapidly with more experienced drivers.

24 That is, the relationship is not linear, but follows an upward sloping curve.

to avoid a hazard. Donald and Cairney (1997) provide an example of the distance travelled during the reaction time and recovery time of a driver in a situation where the driver's vehicle runs off the road at one degree (1°) (see Figure A10). If a road has a sealed shoulder 500 mm wide, a vehicle running off the road at this angle would travel 28.5 metres before leaving the sealed surface. A vehicle travelling at 105 kph (29.2 metres per second (m/s)) would cover this distance in just under one second (0.98 s); however, a vehicle travelling at 120 kph (33.3 m/s) would cover the distance in only 0.85 seconds. Research has shown the fastest reaction time of unalerted drivers to be about one second (Triggs, 1981, cited in Donald and Cairney, 1997). Therefore, the driver travelling at 120 kph is unlikely to be able to recover before running off the road. Donald and Cairney note that recovery is much more difficult once vehicles have left the sealed surface, leading to a higher crash risk.

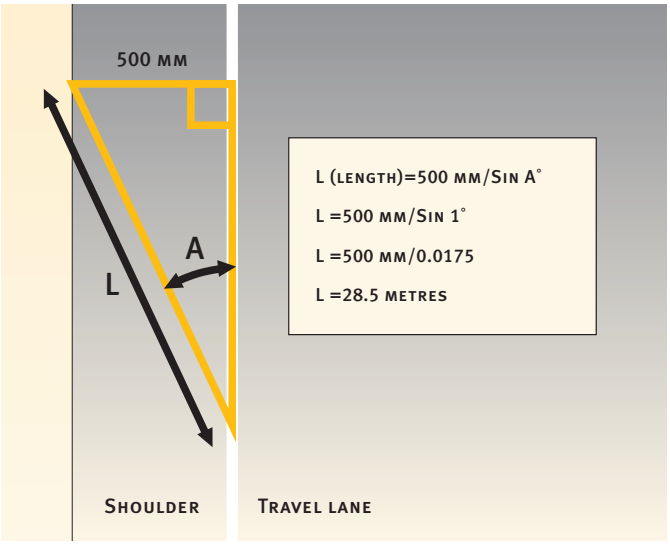



**Figure A10 – Run-off-the-road crashes**

Source: Donald and Cairney (1997, p24).

Another factor in the relationship between vehicle speed and crash rates is following distance. Because stopping distance increases as speed increases, drivers require a greater distance between their vehicle and the vehicle in front of them when they are travelling at higher speeds. The crash risk for vehicles travelling at high speeds is increased because drivers do not always compensate for their high speed by reducing their following distances (O'Flaherty, 1974). This means that, if the vehicle in front is required to suddenly slow down or stop, there is a high chance of a rear-end crash.

Another factor that increases with vehicle speed is the probability of exceeding the critical speed on a curve. This, combined with the increased braking distance at high speeds, also increases the risk of a crash.

## Conclusions

- The research comparing the reported (or measured) pre-crash speeds of vehicles with mean traffic speeds has shown that, in both urban and rural environments, the risk of crashing increases as the pre-crash speed increases above the mean.
- Studies of changes in speed limits have shown that increasing the speed limit leads to increases in crash rates when the speed limit change is accompanied by a mean speed increase. Similarly, decreasing a speed limit can reduce crash rates when the speed limit change is accompanied by a mean speed decrease.
- Researchers have postulated the following relationships:
  - there will be twice as many fatal crashes when the mean speed is 120 kph than when it is 100 kph;
  - for every 1 mph rise in the mean traffic speed, the percentage change in crashes rises by about five percent;
  - a 1-kph reduction in mean speed can produce up to a three percent reduction in crashes.
- Crash risk increases with increasing mean traffic speed. Speed variation also has some effect on crash risk. A slower mean speed is safer than a faster one.
- There is a comparable relative risk for drink-driving crashes and for speeding crashes. A 5 kph increase in speed above 60 kph in a 60-kph zone increases the risk of a casualty crash by about the same amount as an increase in blood alcohol concentration from 0 to 50 mg/100 ml.
- As speed increases, there is an increase in the following factors and, in turn, an associated increase in the risk of crash involvement:
  - stopping distance – both distance travelled during reaction time and distance travelled after brakes are applied;
  - the probability of exceeding the critical speed on a curve;
  - the chance of other road users misjudging how fast the speeding driver is travelling;
  - the probability of a rear-end crash if the driver has not accounted for their increased speed by increasing their following distance.

# 2: Managing Mean Speed and Variations in Vehicle Speed

The focus of road safety campaigns and enforcement strategies on reducing the mean speed of traffic on our roads is supported by the research findings discussed. However, despite the greater importance to road safety of mean traffic speed, there is some suggestion in the literature that speed variation should also be targeted through enforcement strategies (for example, Lave, 1985, cited in Zaal, 1994). The strategies available for controlling mean traffic speed are discussed at some length in subsequent Parts of this report. In this section, we continue our discussion of how mean speed and speed variation are related, taking up later in more detail some of the matters discussed in relation to enforcement.

### Approaches to Managing Variations in Vehicle Speed

If we accept that it is desirable to reduce speed variation, there are two obvious approaches to doing so – encouraging drivers who travel at the slowest end of the speed distribution to increase their speed or encouraging drivers who travel at the fastest end of the speed distribution to decrease their speed. (Another approach is to use both strategies at once.)

It has been argued that some ways of targeting speed variance would not be beneficial for road safety (Zaal, 1994) – encouraging the slowest drivers to speed up is clearly in that category. Such a strategy may actually increase the crash risk of the slow drivers. Slow drivers may choose to travel at a slower speed in the face of probable peer pressure to go faster because they feel less comfortable with travelling faster (Evans, 1991). This in turn is likely to be related to driver or vehicle capabilities or the driver's confidence level. For example, older drivers may slow down to compensate for their reduced vision and visual acuity or to allow for their slower reactions.

Encouraging or forcing slow drivers to speed up beyond their comfort level is contrary to road safety wisdom. Not only is this strategy likely to increase the crash risk of the slowest drivers, but, if these drivers subsequently became involved in a crash, any injuries would be much more severe than if they had travelled at slower speeds (Fildes and Lee, 1993). (This matter will be explored further in Section 3.) Thus, rather than encouraging slow drivers to increase their speed and expose themselves to greater risk, a more beneficial road safety measure would be to encourage them to pull over periodically at safe locations if they hold up traffic.

It is fast drivers, rather than slow drivers, however, who comprise the core safety problem, and encouraging all speeding drivers to slow down would have great benefits for overall road safety. There are no increased risks associated with this approach. One strategy for achieving this aim is to place more emphasis on the drivers who travel at speeds that are excessively above the speed limit than on those who travel at speeds that are moderately above the speed limit. This strategy is already being used worldwide through targeting all speeding drivers and having an increasing penalty rate for increasing speeds – that is, excessive speeders receive higher penalties than moderate speeders.

The overall aim of targeting speeders is to reduce the number of drivers travelling at excess or inappropriate speeds. If successful, this strategy reduces both the mean traffic speed and the degree of variations from the mean speed – that is, the slow drivers do not speed up, but the fast drivers slow down, giving a reduction in the overall distribution of speeds.

### Mean Speed and Speed Variation

In contrast to some of the findings discussed in the previous section, studies in New Zealand have demonstrated that, when mean speed is reduced, speed variation also reduces. For example, Frith and Toomath (1982) found that, when the New Zealand open-road speed limit was reduced to 50 mph in December 1973, there was a sharp drop in mean speeds. This drop in mean speeds was accompanied by a sharp contraction in the distribution of these speeds.

Similarly, Keall and Frith (1997) found a significant decrease in the New Zealand national mean speed in urban areas from 1995 to 1996. This reduction was associated with a significant decrease in the spread of speeds at the top end of the distribution; that is, a decrease in the 85th, 90th, and 95th percentiles[25]. In other words, the spread of speeds reduced at the high end of the speed distribution, hence contracting the overall speed distribution (see Figure A11). A similar result was found when mean speeds reduced in the police's Midland region of New Zealand following the introduction of hidden cameras in the area (Keall, Povey, and Frith, 1999 – see Part C for details of the study).

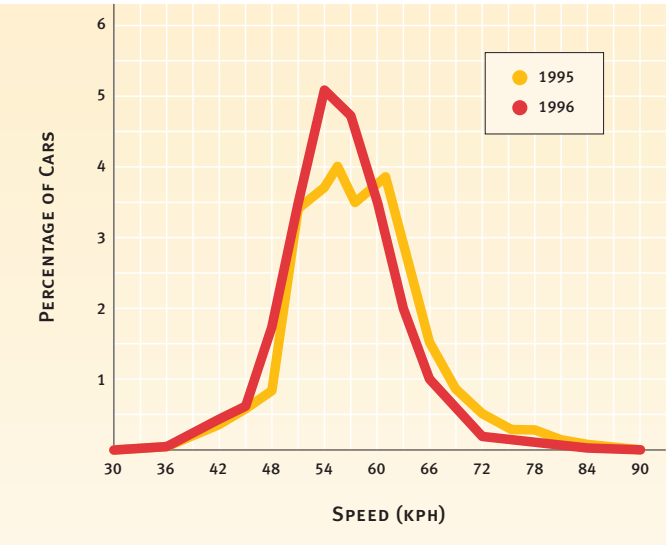



**Figure A11 – Estimated distribution of urban speeds, 1995 and 1996**

Source: Keall and Frith (1997, p12).

Conversely, increases in mean speed may be associated with increases in speed variation. For example, the National Highway Traffic Safety Administration (NHTSA, 1992, cited in TRB, 1998) examined the speed distribution between 1986 and 1990 on rural interstate highways in the 18 USA states that raised their speed limit when the National Maximum Speed Limit (NMSL) increased from 55 to 65 mph. They found that, following the speed limit change, there was an increase in mean speeds. This increase in mean speeds was accompanied by a wider speed distribution. This came about because some of the fastest drivers increased their travel speeds, hence extending the top end of the distribution, while many of the drivers at the slow end of the distribution did not change their speeds (see Figure A12 below).

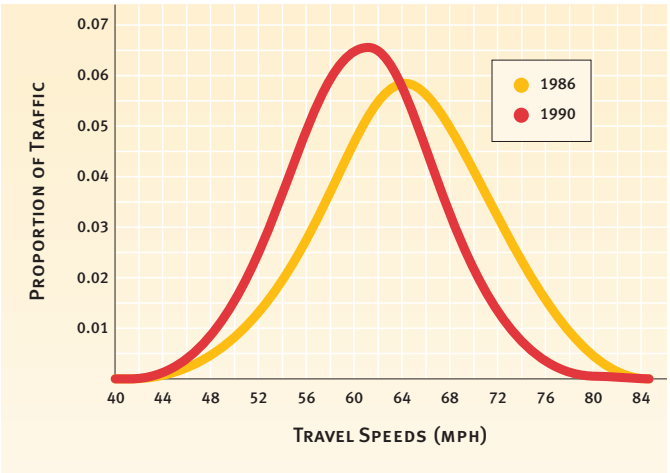



**Figure A12 – Estimated changes in the distribution of rural interstate highway travel speeds between the fourth quarter of 1986 and the fourth quarter of 1990 in the 18 states that raised speed limits in 1987**

Source: NHTSA (1992, cited from TRB, 1998, p117).

These studies demonstrate that mean speed and speed variation are highly correlated. Therefore, care needs to be taken when considering which is of greater importance in improving road safety.

It should be noted that the results above all relate to normal speed distributions. When the distribution is not normal, a different result may emerge. Urban areas often have non-normal distributions, especially at peak times, because of congestion; therefore, reducing the mean speed in such situations may have quite a different effect on the speed variation (Lynam et al, 1999).

25 The 85th percentile decreased from 65.5 to 63.5 kph, the 90th from 67.5 to 65.5 kph, and the 95th from 71 to 69 kph.

### Conclusions

- Slowing the speed of drivers travelling at excess or inappropriate speeds will tend to reduce the mean speed of traffic as well as reduce the number of drivers at the top end of the speed distribution.
- Encouraging slow drivers to speed up would lead to more crashes and injuries. Slow drivers could instead be encouraged to pull over at safe locations if they hold up traffic.
- Fast drivers rather than slow drivers comprise the core safety problem, and encouraging all speeding drivers to slow down would have greater benefits for overall road safety than targeting the speed of slower drivers.

# 3: The Impact on the Human Body of Different Crash Speeds

In the discussions so far in this Part, we have seen that increased speed increases crash risk. Crashes place intense physical pressure on the human body, whether that body is an occupant in a crashed vehicle or is another road user such as a pedestrian. The human body usually has no capacity to cushion the effects of a crash once it occurs, and so is left to the mercy of the physical forces that are at play to determine the severity of the resulting injury.

As we shall see later on, excess and inappropriate speed is recorded as contributing to a large number of road crashes in New Zealand. This has been assessed in terms of reduced stopping distances, the driver exceeding the critical speed on a curve, the loss of friction between the vehicle's tyres and the road, and the reduced capacity of the driver to detect and respond to hazards. But this is only one part of the speed story.

For every crash where speed is an identifiable factor in contributing to the crash, there are many other crashes where speed may not be identified as a direct crash factor, but where it is a direct injury factor. This distinction between speed as a crash factor and speed as an injury factor is fundamental to our understanding of the critical role that speed plays in the toll of injury and death on our roads.

In general, as driving speed increases, so does the impact speed of a vehicle in a collision (TRB, 1998). Similarly, the higher the speed at which a vehicle crashes, the more severe the injuries for the vehicle occupants and for other persons affected by the collision. For example, the Peugeot-Renault biomechanics laboratory conducted a study of injuries sustained in crashes by 100,000 occupants of small cars fitted with seatbelts. They found that at speeds up to 35 kph there were practically no fatalities. However, at speeds of 70 kph almost 50% of the occupants were killed (European Conference of Ministers of Transport (ECMT), 1996).

### The Severity of Injuries to Vehicle Occupants

Evans (1991) provides a detailed description of what happens to vehicle occupants during a collision:

*"When a vehicle crashes, it undergoes a rapid change in speed. Occupants continue to move at the vehicle's previous speed until stopped, either by impact with objects external to the vehicle if ejected, by striking the interior of the vehicle, or by being restrained in some other way (through, for example, airbags or seatbelts)"* (p247).

The rapid change in speed that a vehicle undergoes in a crash is known as "Delta-V" and is an important measure of crash severity (TRB, 1998).

The injury severity to occupants in a crash increases non-linearly with impact speed, because of the relationship between the energy released in the crash and the speed of the vehicle. In the first section to this Part, we referred to the formula for kinetic energy – that is, $\frac{1}{2} \times \text{mass} \times (\text{speed})^2$. Fildes and Lee (1994) illustrate how this formula relates to the crash situation – *"a 20% increase in speed will, for example, result in a 44% increase in kinetic energy to be dissipated"* (p10).

Also, as the TRB (1998) stated, *"The greater the speed at which occupants must absorb the energy released by the vehicle at impact, the greater the probability and severity of injury"* (p63).

Several studies have been conducted on injury severity with differing Delta-V or impact speed[26]. For example, O'Day and Flora (1982, cited in TRB, 1998) conducted an intensive investigation of approximately 10,000 crashes that occurred between 1977 and 1979. The probability of a fatality increased dramatically with impact speed. For example, a driver crashing with an impact speed of 80 kph was twice as likely to be killed as one crashing with an impact speed of 64 kph. *"At impact speeds above 50 mph [80 kph], the probability of death exceeded 50%"* (TRB, 1998, p64).

Joksch (1993) examined crashes of all severity levels between 1980 and 1986 from the National Analysis Sampling System (NASS) database[27] in the USA. He found that the probability of a fatality is related (approximately) to the fourth power of Delta-V (see Figure A13).

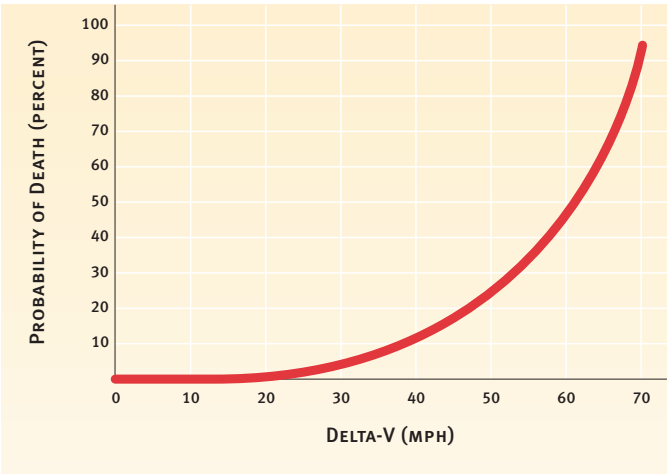



**Figure A13 – Fatality risk for car drivers in relation to Delta-V**

Source: Data for figure generated using Joksch's (1993) formula: $(\text{Delta-V}/71)^4$.

Bowie and Walz (1994, cited in TRB, 1998) also used the NASS data, this time from 1982 to 1989, as well as the Abbreviated Injury Scale (AIS), which rates injury severity levels from 1 (minor injury) to 6 (injury not currently survivable). They found a dramatic increase in injury severity as Delta-V increased.

The risk of injury for older people involved in collisions is generally a lot higher than the risk for younger people, because of their greater frailty. For example, analyses by Wouters (1989, cited in Maycock, 1997) and Evans (1991) on the vulnerability of vehicle occupants indicate that a male driver aged between 70 and 80 would be three times more likely to be killed in a crash than would a 20-year-old male (for women in this age group, the risk is approximately 20% higher than for the men). Evans obtained this relationship by examining fatal injuries of drivers from crashes of similar severity – that is, he examined crashes with the same physical impact and determined the fatality risk for all driver ages relative to age 20.

Evans (1991) also examined the fatality risk for all male car occupants and motorcycle riders relative to age 20. From his analysis, he generated a formula of the fatality risk from similar physical (crash-related) assaults relative to age 20 (see Figure A14).

26 Note that the results of these studies depend on the use of restraints (particularly seatbelts). Since these studies were conducted in the USA where the rate of restraint use is low, the risk may be over-estimated for New Zealand, which has a relatively high restraint wearing rate.

27 The NASS database contains data on inspections of crashed vehicles in the USA.

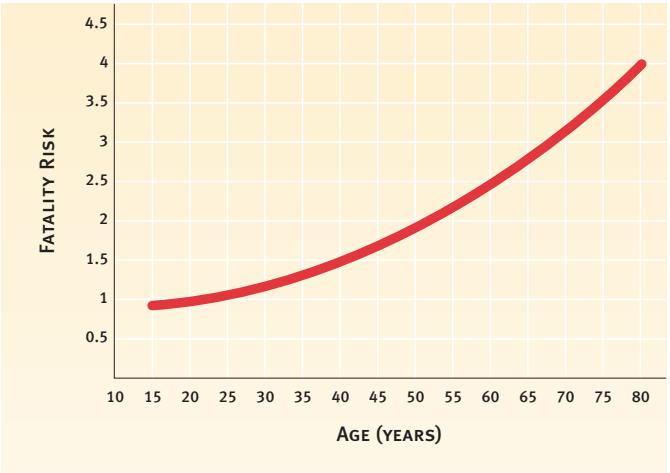



**Figure A14 – Fatality risk for similar physical (crash-related) assaults for males of different ages relative to the risk for 20-year-old males**

Source: Data for figure generated from formula in Evans (1991, p26).

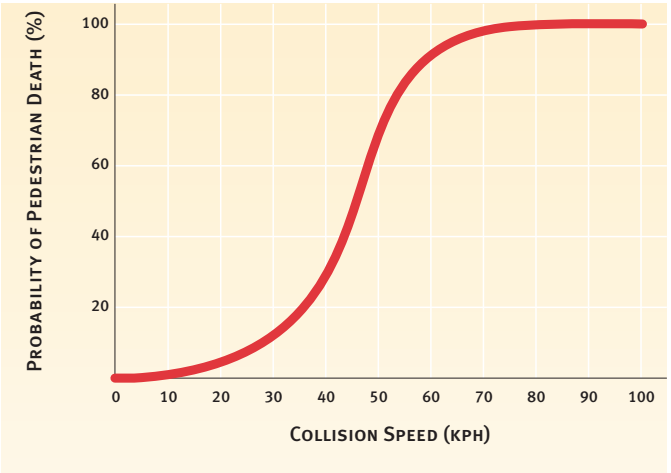



**Figure A15 – The influence of the collision speed on the probability of death of a pedestrian**

Source: Data for the figure generated using Ashton's 1982 formula (cited in Pasanen and Salmivaara, 1993).

### The Severity of Injuries to Pedestrians

The severity of injuries to vehicle occupants is clearly related to the impact speed of the vehicle, although the injuries are lessened by vehicle factors, such as energy-absorbing characteristics and mass and also by the restraints on the vehicle occupants. The severity of the injury sustained by a pedestrian hit by a vehicle is also related to the impact speed. However, pedestrians do not have any protection factors to absorb the energy of the collision. Therefore, an impact speed that may injure a vehicle occupant will kill a pedestrian. For example, a formula was developed from a case study by Ashton (1982, cited in Pasanen and Salmivaara, 1993, p308) on the risk of death to pedestrians hit by a vehicle. Figure A15 plots the formula for speeds between 0 and 100 kph.

As can be seen from Figure A15, the risk of death for a pedestrian hit by a vehicle increases dramatically at collision speeds from 40 to 60 kph. Similar findings have been reported elsewhere in the literature. For example, the European Transport Safety Council (ETSC, 1995) reviewed several studies of pedestrian-vehicle crashes. They concluded that the probability of death for a pedestrian is five percent if hit by a vehicle travelling at 32 kph, 45% if hit by a vehicle travelling at 48 kph, and 85% if hit by a vehicle travelling at 64 kph.

The risks of killing weaker members of the population, such as the elderly, are even higher. Similarly, young children are particularly vulnerable to injury in a pedestrian-car collision because of their small stature – that is, their heads are more likely to be hit directly by the rigid front of the car. Once children are tall enough that their heads are clear of the landing edge of the bonnet, the risk is much reduced.

Evidence of the increased risk for the elderly was demonstrated by Glaeser (1993, cited in McLean, Anderson, Farmer, Lee, and Brooks, 1994). Glaeser examined 522 cases in which a pedestrian was struck by the front of a passenger car. The pedestrian's head injuries were given an Abbreviated Injury Score (AIS) rating[28]. Glaeser found that high AIS ratings for head injuries occurred at impact speeds above

28 AIS assesses severity of injury in relation to probability of death: 1 = minor, 2 = moderate, 3 = serious, 4 = severe, 5 critical, and 6 = maximum.

30 kph, and that these high ratings are very frequent at speeds over 50 kph, especially among elderly pedestrians.

Further evidence of the effect of speed on all pedestrian injuries has been demonstrated in a study by Walz et al (1983, cited in McLean et al, 1994). They investigated the reduction in the Zurich urban speed limit, from 60 to 50 kph, and found that the number of pedestrian-vehicle collisions in the first year after the change fell by 16%, resulting in a 25% decrease in pedestrian fatalities. The Injury Severity Score (ISS)[29] of the pedestrians involved in the collisions also decreased. Furthermore, fractures to the pelvis and ribs of the pedestrians were reduced by 50%.

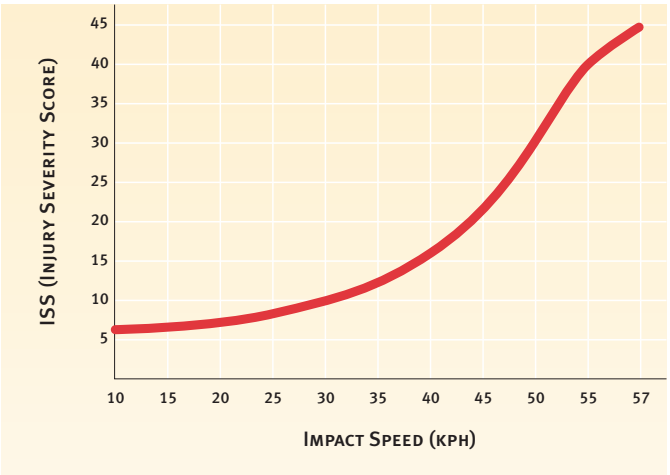



**Figure A16 – Impact speed and injury severity (ISS)**

Source: Walz et al (1993, cited in McLean et al, 1994, p8).

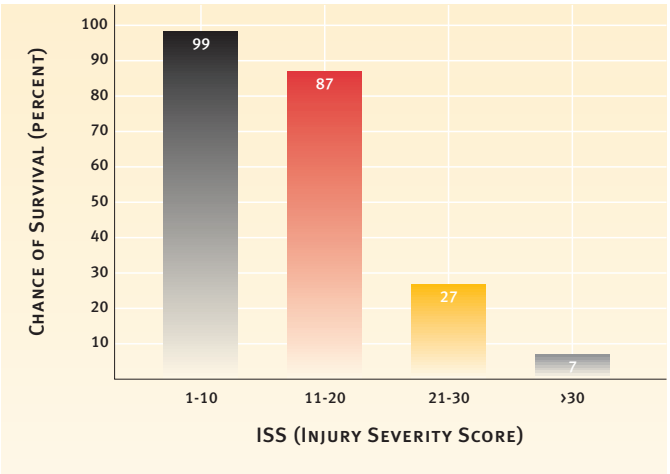



**Figure A17 – Probability of survival as a function of ISS**

Source: Walz et al (1993, cited in McLean et al, 1994, p9).

Walz et al (1993, cited in McLean et al, 1994) also compared the distribution of impact speeds in their data with the distributions from five other studies. The potential pedestrian injury severity was then related to the impact speed of the vehicle (see Figure A16). The probability of survival for a given ISS was then estimated from 952 cases (see Figure A17).

### The Combination of Collision Risk and Injury Severity to Pedestrians

It is important to note that reducing the travel speed of vehicles in an area, through such measures as reducing a speed limit with associated enforcement, can have two effects for pedestrians. It can reduce the chances of a collision between a vehicle and a pedestrian and it can reduce the severity of injuries to the pedestrian should such a collision occur. That is, at a slower speed, a driver has a greater chance of being able to stop under emergency braking and avoid colliding with a pedestrian in his or her view. Furthermore, if the vehicle is travelling at a slower speed, the pedestrian has a greater chance of seeing the approaching vehicle in time to move to avoid the collision. Even if the driver and pedestrian are unable to avoid the impending collision, at a slower speed the impact is less; hence the pedestrian receives less severe injuries than if hit at a higher speed.

McLean et al (1994) determined the relationship between initial speed and stopping distance from an examination of 176 fatal pedestrian collisions in the Adelaide area between 1983 and 1991. (This study is discussed in more detail in Part C.) Using the analysis of these fatal collisions, the researchers determined what effect a reduction in vehicle travelling speeds would have on the incidence of fatal pedestrian-vehicle collisions in the Adelaide area. Several speed reduction scenarios were considered. For example, in the scenario of a uniform speed reduction of 10 kph in 60-kph speed limit zones, McLean et al predicted that the incidence of fatal pedestrian-vehicle collisions would reduce by 48%. Furthermore, in this scenario, 22% of the pedestrian-vehicle collision cases would have been avoided altogether. Hence, small reductions in speed can lead to large safety benefits for pedestrians as well as for other road users.

29 ISS is the sum of the square of the highest AIS score for each of the three most severely injured body regions.

## Conclusions

- The research into the relationship between vehicle speed and injury severity has consistently shown that, as a vehicle's speed increases, its impact speed in a crash increases, which in turn dramatically increases the severity of the resulting injury.
- If the crash involves a pedestrian, the probability of death for the pedestrian also increases dramatically with impact speed. However, the risk of death for pedestrians involved in a collision is greater at lower speeds than the risk for vehicle occupants. Also young and older pedestrians are at greatest risk of injury if involved in a pedestrian-vehicle crash.
- The probability of death for a vehicle occupant is related to the fourth power of Delta-V (the rapid change in speed that a vehicle undergoes in a crash).
- The severity of an injury for vehicle occupants increases dramatically as Delta-V increases.
- The risk of death to a pedestrian increases dramatically from an impact speed of 40 to 60 kph.

# Part B

## Countermeasures: Vehicle and Road Design

We know that increased vehicle speed increases the risk of crashing and the severity of injuries arising from those crashes – we discussed these issues in Part A. We know also that increased mean traffic speed increases the number of minor, serious, and fatal injuries on the road. With this information, we need to begin assessing how we can control – and reduce – speed. A significant barrier to reducing speed is the increasing performance and speed capacity that is being built into the traffic system. This Part addresses design and engineering matters that are relevant to the speed problem, in relation to both the roads that provide the foundation of the traffic system and the vehicles that drive on those roads.

Design and engineering play a fundamental role in the safety of our traffic system, in terms of both the physical and performance characteristics of roads and vehicles and drivers' responses to these characteristics in terms of their perceptions of danger. New vehicle design, for example, often seeks increased mechanical performance in terms of both power and speed, and increased consumer comfort, even though some "enhancements" may negatively impact on the safety of road users. (For example, if a driver chooses to travel at a higher speed due to the increased comfort at high speeds in new vehicles, then his or her crash risk is increased and the severity of injuries sustained in a crash is increased.) And yet, vehicle safety standards have been instrumental over the last 20 years in saving lives and in reducing the severity of injuries suffered by vehicle occupants when crashes occur.

New road design can have a similar effect. In terms of physical capacity, new road building generally allows for increased capacity and mobility. This can reduce driver perceptions of danger in the roading environment and increase speed. However, improved roading design and traffic engineering provide a significant means to reduce speed (particularly in urban areas), reducing crashes, deaths, and injuries.

Better road design can also reduce the chances of a crash at any speed. However, this may be outweighed if the better road design increases the number of vehicles travelling at high speeds. That is, despite the better road design, vehicles travelling at high speeds have a high crash risk. Furthermore, if a vehicle travelling at high speeds is involved in a collision, the occupants are likely to receive more severe injuries than occupants involved in crashes at lower speeds.

In the context of a safety discussion about the impact of speed, therefore, design and engineering are seen as a two-edged sword – a pivotal part of the speed equation. On one side, improved mechanical or physical properties improve the ease with which road users move on the roading network. On the other side, increasing the ease of use might reduce the perceptions of real danger in the use of the network. This discussion of design and engineering issues focuses on the role that vehicles and roads play in driver speed behaviour and on measures to improve that behaviour.

# 1: Vehicle Design

Motor vehicles provide an exceptionally high level of mobility, primarily because of the speed at which they can move at any one time. That development and that mobility has, of course, also come at an exceptionally high cost in human life, and a primary factor in the human cost is the speed at which these vehicles travel.

### Vehicle Design and the Risk of Injury

It is important to recognise firstly the considerable progress that has been made in reducing the risk of injury through vehicle design. This is illustrated by Figure B1 below, which shows the increasing crashworthiness[30] of the Australian vehicle fleet over the last 30 years, and maps this against the introduction of Australian Design Rules (ADR).

New vehicle design is continuing to decrease the number and/or degree of injuries sustained in a crash (through secondary prevention measures). However, new vehicle design has not focused a great deal on decreasing the chances of a crash (that is, through primary prevention measures) and, even when it has, the measure has not been shown to be completely effective. For example, the anti-lock braking system (ABS) was designed to decrease the chances of a crash through more effective braking (Evans, 1991). Unfortunately, ABS does not appear to have been effective at reducing the incidence of crashes as much as its advantages over vehicles fitted with non-ABS brakes would predict (Evans, 1991; Highway Loss Data Institute in the USA, 1994, cited in Várhelyi, 1996). Behavioural changes by drivers with ABS brakes are the suggested reason for their weakened effectiveness. For example, drivers driving on ice and snow in vehicles equipped with ABS took risks that were greater than the advantages ABS gave (Biehl, Aschenbrenner, and Wurm, 1987, cited in Evans, 1991). Similarly, Aschenbrenner et al (1992, 1993, cited in Várhelyi, 1996) found that drivers with ABS-equipped cars drove with smaller safety margins than drivers of cars without ABS. Furthermore, the effectiveness of ABS brakes differs depending on whether or not the road is sealed. On an unsealed road, ABS brakes lead to a longer stopping distance than other types of brakes. Despite the less than expected benefit of ABS brakes for vehicle occupants, ABS brakes are likely to provide safety benefits for road users outside the vehicle, such as pedestrians and cyclists. For example, a driver with ABS brakes may be able to stop the vehicle sooner than a driver without ABS brakes when encountering a pedestrian in his or her path.

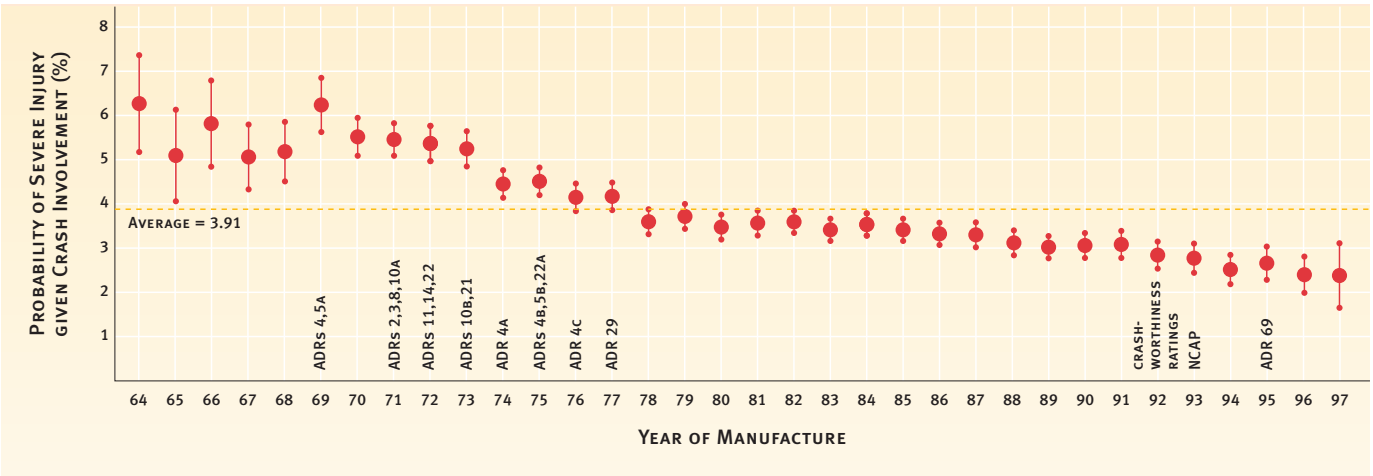



**Figure B1 – Crashworthiness of vehicles by year of manufacture**

Source: Newstead and Cameron (1999). Graph courtesy of Monash University Accident Research Centre.

30 A vehicle's crashworthiness is its ability to protect its occupants from serious injury given crash involvement.

In terms of secondary prevention, there are two types of occupant protection devices designed to prevent injury should a crash occur – active devices, which require the user to perform a specific act (such as put on their safety belt), and passive devices (such as airbags), which protect the user without requiring the user to perform an action. As discussed in Part A, during a collision a vehicle undergoes a rapid change in speed, known as Delta-V, and unrestrained vehicle occupants will continue to travel at the speed the vehicle was travelling before the collision. Safety belts, used in tandem with airbags, decelerate the occupant to either avoid or minimise the occupant's impact with the vehicle's interior. As well as reducing the likelihood and severity of injuries to users, safety belts have the major benefit of reducing the chance that the occupants will be thrown from the vehicle (where they would travel close to the pre-crash speed until striking something in the environment).

Passive occupant protection devices in use that continue to be improved include side impact protection, frontal crash protection, offset front crash protection, padded head impact areas, improved safety belt systems, and "intelligent" airbags that adjust deployment rate to crash severity and restraint status of occupants. All of these are designed to reduce the injury severity of occupants involved in crashes by reducing the immediate impact on the occupant.

Design attention has also turned to vehicles that are "pedestrian friendly". Pedestrian-friendly vehicles are designed – with sloping fronts, for instance – to reduce the injuries to a pedestrian involved in a pedestrian-vehicle collision. Once a collision occurs, the main aggravator of pedestrian injuries is the impact on the human body by parts of the vehicle that are too stiff. In some cases, the skin of the vehicle may be soft enough in itself, but to protect the pedestrian there also needs to be a crush space underneath the skin of the vehicle; for example, between the bonnet and stiff engine components. Pedestrian-friendly vehicles are also designed to be free of sharp and protruding objects.

### Vehicle Design and its Impact on Speed

Despite such improvements to vehicle design, particularly in relation to the protection and comfort of vehicle occupants, vehicle speed will always be the central factor in injury risk to road users, whether they are motor vehicle occupants, pedestrians, cyclists, or motorcyclists.

It has been argued that recent developments in vehicle design are insulating vehicle drivers from the perception of danger when speeding, and influencing speeding behaviour. For example, physical cues about speed such as the noise and vibration of the road and the tilting motion on sharp curves that were more obvious in older vehicles are muted by improved vehicle handling, high-performance tyres, and air-conditioning systems in modern vehicles (Comte et al, 1997, cited in TRB, 1998). The sound of the air stream passing over and around the moving vehicle is also reduced by improved seals on windows and doors, while improvements in the quality and performance of car stereo systems can also effectively mask auditory cues about speed. As well, drivers report that, with more comfort, the sensation of speeding is reduced, leading to subconscious speeding (Nilsson, 1986, cited in Várhelyi, 1996). Evidence for this was provided more recently by Horswill and McKenna (1996). They found that drivers on a driving simulator drove faster when the volume control regulating engine and traffic noise on the simulator was turned down than when the volume was set at its normal level; however, the drivers were unaware that the simulator volume was lowered.

While driver perception of speed may be affected by these comfort factors, the European Conference of Ministers of Transport (ECMT) concluded that performance remained the main objective of new design for vehicle manufacturers (ECMT, 1996). Vehicles are designed to travel much faster than the speed limit, and the newer the vehicle, the greater the performance. Fildes, Rumbold, and Leening (1991) found that drivers of newer vehicles travel faster than drivers of older vehicles. In both urban and rural environments, drivers of vehicles less than four years old were more likely to exceed the speed limit and travel at excessive speeds than drivers of older vehicles. More recently, Fitzgerald, Harrison, Pronk, and Fildes (1998) found that large, relatively new vehicles not owned by the driver tended to be driven at high speeds. Furthermore, the greater the performance of the vehicle in terms of engine size, the higher the speed. Quimby, Maycock, Palmer, and Butress (1999) found that drivers of a car with an engine size of 2,000 cc (cubic centimetres) drove four percent faster than drivers of a car with an engine size of less than 1,000 cc.

### Future Vehicle Design

In terms of primary prevention, new perception-based technologies can help to reduce the speed at which drivers choose to travel. For example, devices such as "heads-up display speedometers", which display the vehicle's current speed in the driver's normal field of vision rather than on the dashboard, are designed to make it easier for drivers to monitor their speed, although their safety value is questionable, as it is unknown whether the devices negatively affect the driving task (Comte et al, 1997, cited in TRB, 1998). Other devices are designed to detect hazardous situations and warn drivers to adjust their speed. For example, systems have been designed that warn drivers when they get too close to the vehicle in front given their current speed or when a sharp curve is approaching and a reduction in speed is needed (TRB, 1998). Recent global positioning technology can help drivers who unintentionally exceed the speed limit by telling drivers where they are and what the speed limit is in that area.

More sophisticated technology is also addressing physical separation of vehicles in order to reduce crashes. These new technologies include advanced cruise-control systems, which maintain safe following distances, and "smart cards", which determine maximum driving speeds based on the user of the car (TRB, 1998). Such technologies do not address the more fundamental problem of how fast vehicles are designed to travel.

The most direct means of reducing vehicle speed and crash risk appears to be speed limiters, which limit the top speed of the vehicle to a predefined value regardless of the user. Several field and simulation studies have been conducted to examine the effectiveness and acceptability of speed limiters in Europe. For example, Várhelyi and Mäkinen (1998) conducted a study in which drivers drove a car equipped with a speed limiter around a pre-defined route in one of three European cities[31]. Driving behaviour in the vehicle fitted with the speed limiter was compared to driving behaviour over the same route in a vehicle without a speed limiter. Várhelyi and Mäkinen found that the speed limiter reduced speeds, particularly in free driving conditions (that is, when unimpeded by other vehicles). The speed limiter also decreased individual speed variation and led to smoother approach speeds at roundabouts, intersections, and curves. Hence, as well as reducing speeds, speed limiters have the potential to make traffic flow smoother. The drivers were also asked their opinions on speed limiters before and after the two test drives. The drivers tended to show increased acceptance towards using a speed limiter after having driven with one. A frequent comment from the drivers was that the speed limiter would be "useful" or "ideal" if all vehicles were equipped with one, presumably because there would be less pressure from other traffic to travel above the speed limit. The results of this study and others on speed limiters indicate that they are likely to be effective in built-up areas. However, further research is needed in rural conditions.

These mechanical limitations on speed are in use on heavy vehicles in Australia. However, the use of speed limiters within a national vehicle fleet has not yet been implemented anywhere. This seems to be because car manufacturers are not generally supplying speed limiters as a safety feature, new car consumers are not demanding speed limiters as a safety feature, and governments are not regulating their use except in relation to heavy vehicles. Speed reduction mechanisms in themselves do not appear to be a desirable safety feature in new vehicles.

### Conclusions

- Significant progress has been made in vehicle design to reduce the injury impact on vehicle occupants.
- In terms of reducing the effect of vehicle speed, vehicle safety design has concentrated on secondary rather than primary injury prevention. That is, greater emphasis has been placed on design features that reduce the severity of the injury, rather than on features that reduce the incidence of crashes that lead to the injury.
- Specifically, recent vehicle design has:
  - tended to insulate the driver of the vehicle from the perception of danger when speeding, thereby facilitating an increase in driving speeds;
  - improved vehicle performance, thereby facilitating increased driving speed.
- European studies have shown that direct speed reduction, through mechanisms such as speed limiters, is likely to be effective in reducing speeds.

31 The speed limiter was automatically triggered by transmitters attached to speed-limit signs. Thus, the speed the vehicle was limited to depended on the speed limit.

# 2: Roading Factors and their Impact on Speed

Vehicle safety improvements take time to work through vehicle fleets and impact in a significant way on the level of injury and death on the road, often taking between 10 and 20 years to have an effect. Changes in public attitudes can take even longer to produce a substantial gain in road safety. By comparison, safety improvements to the roading environment can take place in a matter of weeks and months, rather than years. Indeed, the most crucial factors appear to lie in diagnosing the road or traffic factor that may be affecting safety on a piece of road, and developing an appropriate solution that improves safety and does not simply shift the safety problem from one point to another or replace one safety problem with another. This section outlines the roading techniques that can be used to improve safety, and reports on evaluations of those techniques[32].

## 2a: The Impact of the Environment on Speed and Perceptions of Safety

As we shall see, psychology plays a part in much of the following discussion on the use of road and traffic design to reduce speed. Before progressing further, therefore, we should recognise that a driver's choice of travel speed is dependent on both sensory perception and cognitive processing. Sensory perception determines what information is available to the driver, while cognitive processing determines what the driver will do with the incoming information. Therefore, the environment the driver travels in is a very important factor in determining his or her choice of speed. In particular, as we shall see, a driver makes a judgement about the relative "safety" of a stretch of road based on his or her perception of the roading environment. Generally, where drivers perceive a stretch of road to be "safe", travel speeds tend to be higher. Below, we discuss environment and road factors that influence perception and, hence, speed choice.

### Roadside Developments

In general, more extensive roadside development tends to reduce speed, and drivers travelling on roads through open farmland could be expected to drive faster than they would through a built-up urban area. Roadside development is a critical factor in the development of speed limits, and speed limits tend to be lower on urban than on rural roads, a factor that in itself influences (or even reinforces) drivers' speed choice. Overall, rural roads tend to have higher speeds, lower traffic volumes, and higher crash severity than urban roads (Hungerford and Rockwell, 1980; Jennings and Demetsky, 1983). The design of the two different road types also has a major effect on speed perception.

Fildes and Lee (1993) define roadside development as *"any aspect of the environment close enough to the roadway to influence driving"* (p59), whether on four-lane highways or on urban roads. Houses set close to the road in urban environments have been found to reduce speed, and trees on the side of rural roads have been found to influence the perception of speed and safety. For example, Fildes, Fletcher, and Corrigan (1987) found that roads without roadside trees were perceived to be safer and travel speeds were underestimated much more than was the case for roads that had a large number of roadside trees. However, this perceptual effect disappeared in semi-rural environments.

Two studies have analysed the perception of safety on curves with different roadside developments. Fildes, Leening, and Corrigan (1989) reported that speeds for curves that had a small radius, that were walled, or that had a gravel surface were judged to be more unsafe than the same speeds on curves without these features. Vaniotou (1990) found that bends with immediate surroundings that contained any or a combination of safety rails, fences and walls, vegetation, poles, overhead cables, or reflective posts gave different perceptions of safety to bends with essentially similar bend geometry but without the immediate surroundings material or with a different combination of surroundings material (although which combinations gave the greatest perceptions of safety was not reported in Fildes and Lee, 1993). These differences in

32 Fildes and Lee (1993, chapter 5) provide an excellent summary of the influence of the environment and road on speed perception and related speeding behaviour. The following is an outline of their review with, wherever available, the inclusion of more recent literature. Unless otherwise indicated, all references prior to 1993 are cited from Fildes and Lee (1993).

perceptions of safety are broadly in line with the real levels of safety in the different environments.

### Physical Attributes of the Road

The physical attributes of the road have also been shown to have an effect on speed. These attributes are outlined below, but they all relate to the overall standard of the road, and ultimately to design speed. In general, the higher the road standard, the greater the proportion of drivers who exceed the speed limit. For example, Grime (1987, cited in Várhelyi, 1996) found that the proportion of drivers exceeding the speed limit was five percent on two-lane roads with a speed limit of 60 mph (97 kph), 12% on dual carriageways with a speed limit of 70 mph (113 kph), and 40% on motorways with a speed limit of 70 mph (113 kph) (see also O'Cinnéide and Murphy, 1994, cited in Várhelyi, 1996). A driver's perception of safe speeds is also influenced by the category of the road. For example, Fildes et al (1989) found that high speeds on median-divided roads were judged safer than high speeds on two-lane, undivided, two-way roads.

Several studies have found a relationship between vehicle speed and road width. For example, Vey and Ferrari (1968) found that speeds on 3.4 metre lanes on a bridge in Philadelphia were higher than speeds on 3.0 metre lanes on a comparable bridge. Nilsson (1989, cited in Várhelyi, 1996) reported that, for each metre increase of paved road width, speeds increased by 0.4 kph.

Although road markings are generally used to define lane width, several studies have examined the effects of different variations of markings on vehicle speed. Edge lines on curves have been shown to keep vehicle speeds on curves appropriate. For example, Witt and Hoyos (1976) found that drivers in a simulator adopted a more suitable speed profile while negotiating a curve where edge lines were varied, rather than being in a uniform configuration. Varying edge lines on straight sections of road do not appear to affect vehicle speeds, however (Lum, 1984; Cottrell, 1985); edge lines on straight sections of road are more useful for guidance within the lane (Triggs and Wisom, 1979; Triggs, 1986). In terms of guiding vehicles along the road, a study in Finland discovered that reflector posts designed to assist guidance during darkness increased vehicle speeds on two-lane rural roads (Kallberg, 1993, cited in Várhelyi, 1996). For example, *"reflector posts on roads with an 80-kph speed limit and relatively low geometric standard increased driving speeds in darkness by up to 10 kph"* (Várhelyi, 1996, p10).

Also relevant in this context is road geometry. Road geometry refers to the bends and curves ("horizontal curvature") and the hills and raised sections ("vertical curvature") of a road. Speeds on curves appear to be dependent on how the driver perceives a curve before entering it. For example, Milosevic and Milic (1990) found that drivers underestimated their speeds on curves. However, drivers' estimations were more accurate if they had seen warning and speed limit signs. Matthews and Barnes (1988, cited in Matthews, 1988) found that a high proportion of night-time crashes in New Zealand occur on curves on rural roads, particularly on curves with a short radius (that is, sharp corners) in isolated areas. Matthews (1988) suggested these crashes were due to drivers failing *"to perceive the curve or the particular demands of the curve"* (p276) and not adjusting their speed accordingly. Matthews (1988) conducted a study that examined the effect of placing a red flashing chevron before a curve to alert the driver to the presence of the curve. He found that *"the speeds of vehicles entering curves were substantially reduced by supplementing the standard advisory signs and chevrons with a red flashing chevron"* (p286).

Regarding "vertical curvature", researchers have found an over-representation of crashes on graded sections of road compared to flat sections (Agent and Deen, 1975; Cooper, 1980). However, there is an under-representation of crashes at curve crests. Cooper (1980) suggested the result is due to vehicle speeds increasing on the downgrade, which may lead to the driver losing control. Wright and Zador (1981) and Hall and Zador (1981) reported an increased risk of single-vehicle fatal roll-over crashes on downhill slopes than on level or uphill sections. Speeds are likely to be less on curve crests because of a restricted sight distance (that is, the driver does not know what is over the curve crest).

Several studies have examined the relationship between sight distance and vehicle speed. Some have shown no relationship (for example, Yagar and van Aerde, 1983, cited in Várhelyi, 1996), while others have found that sight distance restrictions induce a small reduction in speeds, although only for the faster travelling drivers. However, a recent study by Hogema and van der Horst (1994, cited in Várhelyi, 1996) on a two-lane motorway in the Netherlands has shown clear reductions in vehicle speed depending on visibility range (that is, depending on whether fog or bad weather was present). Compared to clear visibility (defined as visibility of over 1,000 metres), when the visibility range was 300 metres, free-driving speeds reduced by about five

percent in the left lane of the motorway and by eight percent in the right lane. Speeds remained relatively constant when visibility was between 140 and 300 metres. When visibility reduced to less than 100 metres, speeds dropped drastically. However, the researchers reported that, when visibility ranged from 40 to 120 metres, *"even in an extreme case of hard braking…, the speeds of the free driving vehicles… were too high to avoid a collision if suddenly confronted with a stationary obstacle"* (p13). Fildes and Lee (1993) reported that *"it is difficult to separate the effects of gradient [or curvature] alone from sight distance in the speed literature"* (p65), as the horizontal and vertical curvature of a road are primary causes of sight distance restrictions.

Finally, the smoothness of the road surface also appears to be directly related to vehicle speed (for example, Oppenlander, 1966; McLean, 1982). Anund (1992, cited in Várhelyi, 1996) measured the roughness of the road surface using the International Roughness Index (IRI). As IRI increased for a road, the mean speed of passenger cars travelling on the road decreased, although no difference in speed was detected for trucks. These findings are likely to be partly due to the higher noise level (caused by friction between the tyres and the road) as roughness increases.

All of the above physical attributes affect the standard of the road, and the overall standard of the road is itself related to the design speed of the road (that is, the travel speed that the road has been designed for). The design speed is based on factors such as curvature and sight distance.

#### Traffic Factors

Beyond the physical attributes of the road, other traffic related factors can also influence vehicle speed. In general, as traffic volume and density increases, travel speed decreases (Oppenlander, 1973; Rankin and Hill, 1974; Armour, 1983). Crash rates also tend to increase with increasing traffic volume, although there is a threshold effect at high volumes (for example, Raff, 1953; Peter Casey and Associates, 1979), presumably because traffic flow becomes severely restricted. This has been demonstrated on multi-lane highways, where flow rates over 1,400 passenger cars per hour per lane have been shown to result in speed decreases (Highway Capacity Manual, 1985, cited in Várhelyi, 1996).

Encountering an intersection affects a driver's speed. A Hungarian study showed that drivers approaching a minor road intersection regulated by a give-way sign began to slow down on average 30 to 50 metres before the intersection (Bank and Draskóczy, 1982, cited in Várhelyi, 1996). When visibility at the intersection was good, drivers slowed down much earlier and passed through at higher speeds (when there was no traffic on the major road) than at intersections with poor sight. That is, with good sight distance, drivers could travel at higher speeds through an intersection than they could with poor sight distance.

A study in the Netherlands (van der Horst, 1990, cited in Várhelyi, 1996) observed that drivers approaching the give-way sign on the minor road, in an encounter with another road user on the main road, started braking about three seconds before the intersection, regardless of their approach speed, the type of intended manoeuvre, and the type of road user on the main road. Car drivers on the main road generally did not reduce their speed when encountering a car on the minor road.

At least two studies have been conducted on the effect of parked vehicles on speed. Research on the effect of parked vehicles has produced mixed results. For example, Smith and Appleyard (1981) found that vehicle speeds increased as the width of the road increased. Road width was affected by the presence of parked vehicles; therefore, when parked vehicles were present, speeds decreased. Joscelyn et al (1970) found that speeds were affected by the presence of objects, such as vehicles, on the road shoulder when lanes were up to 6.2 metres wide (speeds were unaffected at or above this lane width).

The presence of pedestrians on the roadside has been found in some studies to have little effect on driver speed. For example, the presence of children on the roadside had no effect on vehicle speed in the UK, although speed was reduced slightly when large groups of pedestrians were present (Thompson, Fraser, and Howarth, 1985). Even when a neighbourhood road safety campaign was conducted in New South Wales, there were only minor speed reductions on residential streets, and these reductions could have been due to factors other than the campaign (for example, weather). Várhelyi (1996) also conducted a review of vehicle speeds at zebra crossings when pedestrians were present (but not crossing) and found that the presence of pedestrians on the roadside had little or no influence on the speed of approaching vehicles. Unfortunately, the presence of pedestrians does lead to a high number of collisions in which a pedestrian is injured (see Part E). Hence, keeping speeds low in the presence of pedestrians is very important.

### Time of Day and Weather

In spite of the road environment, speeds tend to be higher at night than during the day in Sweden (for example, Norrish, 1991; Nilsson et al, 1992, cited in Várhelyi, 1996). This may be because higher traffic congestion during the day may restrict a driver's choice of speeds. Perceptions of speed also differ between daylight and darkness. For example, more accurate judgements of rural road speeds are made at night than during the day (Triggs and Berenyi, 1982). This was attributed to *"the increased angular speed of elements visible to the driver which, under headlights, [appear]… much closer than normal and form streaming patterns produced by reflectorised road delineators"* (Fildes and Lee, 1993, p66). However, rural roads were perceived as less "safe" at night than during the day (Fildes et al, 1989), although perceptions of safety during the day and at night were similar when the roadside environment had a "walled" surrounding (such as trees close to the road). This is presumably because driving in a walled environment is similar to driving at night because of the restricted peripheral vision. The findings relating to perceptions of safe speeds and speed travelled during the day versus at night may seem contradictory, but if traffic congestion during the day was similar to congestion levels at night, it is likely that speeds would be higher during the day when drivers feel safer and are less accurate at estimating their speed.

Both road conditions and visibility are affected by weather, and speeds tend to reduce as weather deteriorates. For example, Kolstrud (1984, cited in Várhelyi, 1996) found that the mean speeds of passenger cars on straight and horizontal stretches of different types of roads in Sweden decreased on average by 2 kph when the roads were wet and by 8 kph when the roads were icy or snowy, compared to when they were dry. A review by Öberg (1994, cited in Várhelyi, 1996) of studies in Sweden of the mean speeds on icy or snowy roads compared to dry roads showed a 10-kph decrease in mean speeds on the icy or snowy roads. When the road is icy or snowy and there is also snowfall or snow-drift present, the mean speeds reduced by up to 20-25 kph compared to dry roads. Recently, Edwards (1999) found that traffic on the M4 motorway in south Wales travelled at a lower speed both in wet weather and in misty conditions than it did in dry conditions. However, the size of the speed reduction was not large enough to make up for the increased hazard from the weather, when considering required braking distance and loss of grip on the road surface.

## 2b: Controlling Traffic Speed

To a certain extent, road safety relies on the driver's willingness and ability to monitor and regulate his or her own driving behaviour. A number of speed control measures have been developed to assist drivers to monitor and regulate their speed.

### Speed Limits

The primary method of managing travel speed is by imposing speed limits. To be effective, speed limits should be compatible with the design speed of the road, although the design speed tends to have a greater effect on a driver's choice of speed than does the speed limit (Várhelyi, 1996). For example, if the speed limit is lower than the design speed, this can lead to a general disregard for the limit. The effectiveness of speed limits in improving road safety was discussed in Part A. In general, a speed limit increase results in slightly increased speeds, which in turn increases fatalities, although the magnitude of these increases depends on the mean speeds before the speed limit change[33] (TRB, 1998). The opposite effect generally occurs following a decrease in speed limits.

It is important to recognise that speed limits alone do not tend to control driver speed effectively. They need to be supported with enforcement and engineering measures to keep drivers at a safe speed (TRB, 1998). Engineering measures are discussed in the following subsections, and enforcement issues are covered in Part C.

### Advisory Speed Signs

To provide speed related information to drivers beyond the speed limit itself, advisory speed signs are sometimes posted at hazards, such as narrow curves, to slow drivers from their travel speed, without changing the speed limit at the location. However, recent research has indicated that the

33 That is, if the mean speed is already close to the new speed limit, mean speeds may change only slightly or not at all.

presence or absence of these signs has little effect on driver speeds, particularly for drivers who are familiar with the road, and that the signs are no more effective at slowing speeds than a curve warning sign on its own (Graham-Migletz Enterprises Inc, 1996, cited in TRB, 1998; Zwahlen, 1987, cited in Várhelyi, 1996). The poor compliance with advisory speed signs may arise because they are set unrealistically low (Chowdhury et al, 1998, cited in TRB, 1998) or based on engineering criteria rather than on human factors. Evidence for this has been provided in a recent survey by Transit NZ, which indicated that a large proportion of the New Zealand drivers surveyed believed that advisory speed signs were set at a speed much lower than the curve could be safely travelled (McCormick, 1998). This survey was conducted when there was a shortage in New Zealand of side thrust gauges (devices used to measure the sideways force as a car is driven along a road). However, when advisory speeds signs on curves were first set in New Zealand, using a side thrust gauge, they were found to reduce crashes on curves (Palmer, 1962). Thus, if advisory speeds are set using side thrust gauges, they may be more effective.

#### New Technology

Drivers' speeds in certain situations in the USA have recently been affected by new road-based technologies such as variable message signs. These electronic signs allow roading authorities to inform and warn drivers of crashes, adverse road and weather conditions, and other factors that require drivers to adjust their speed, as these conditions occur (Dudek, 1997, cited in TRB, 1998). Unfortunately, the effectiveness of the latest versions of these signs on speed reduction has not been studied. One use is as variable speed-limit signs, which inform the driver of the appropriate speed limit for the given conditions. Preliminary evaluations of the use of variable speed limits on autobahns in Germany have indicated they have reduced crash rates (Coleman et al, 1996, cited in TRB, 1998).

Mobile roadside speedometers are another new road-based technology. These devices measure a vehicle's speed and display the speed to the driver on a changeable message sign as the vehicle passes. Traffic speed in the vicinity of a mobile speedometer and a short distance downstream tends to reduce, compared to traffic speed without a speedometer present (Casey and Lund, 1993, cited in TRB, 1998). The device is particularly effective at reducing the speed of those exceeding the speed limit by at least 10 mph (16 kph) and reducing traffic speed in school zones. However, both enforcement and supporting publicity are needed for this speed reduction to occur (Comte et al, 1997, cited in TRB, 1998).

Devices similar to mobile speedometers, known as automatic speed warning signs, have proven effective in Norfolk, England (Farmer, Barker, and Mayhew, 1998). These signs display the speed limit to drivers who have exceeded a pre-set speed threshold. The aim is to warn drivers that the limit has been exceeded and to encourage them to slow down. A trial of the signs placed at entrances to rural villages in Norfolk found that the signs substantially reduced the mean speeds of vehicles travelling into the villages (the mean speed reduction over all sites was 4.3 mph). Furthermore, these speed reductions were maintained over a period of 12 months.

## 2c: Environmental Speed Control Devices

Measures to control traffic speed tend to rely on enforcement to be effective at maintaining safe driving speeds. Since it is not practical for enforcement authorities to oversee every section of road, engineering methods that keep speeds down have been developed. These engineering methods need to be designed according to the type of traffic on the roadway. For example, treatments used on local (urban) roads to reduce speeds are not necessarily useful for arterial routes that carry large volumes of traffic (Fildes and Lee, 1993).

Recently, the Dutch government has adopted a policy and implementation programme known as "sustainable" road safety, in which roads are clearly distinguished by their primary function, such as traffic flow, traffic distribution, and access (TRB, 1998). Speed design measures are used to reflect these primary functions. For example, residential environments are designed for the safety of vulnerable road users, such as pedestrians, whereas rural environments are designed for the safety of vehicles travelling long distances, taking into account travel time. Travel time is considered further in Part D. Whatever the function of the road, its design separates different road users, thereby reducing the risk of contact between vehicles travelling at different speeds.

Measures used to control the speeds of through traffic on residential roads are known as Local Area Traffic Management (LATM) measures. One of the earliest LATM devices, developed in the Netherlands, was the "Woonerf design" (Fildes and Lee, 1993). The "Woonerf design" involves pedestrians and vehicles moving in the same space, but with pedestrians having the right of way. Vehicle speeds

are reduced to walking pace through different engineering methods. Some shopping areas in New Zealand cities use a similar concept. The following are some types of engineering methods for reducing speeds, with an emphasis on LATM devices. These devices are normally used in area-wide schemes.

### Speed Humps

Speed humps are designed to *"give the driver a clear physical feedback to keep a low speed"* (Várhelyi, 1996, p116). They are used on residential streets. They differ from bumps, which are designed for use in carparks and the like. Humps have *"dimensions in the order of a 4 metre radius and 10 cm height"*, whereas bumps have *"a radius [of] between 0.1 and 1.0 metre and height variations from 5 cm to 15 cm"* (Stephens, 1986, cited in Fildes and Lee, 1993, p70).

A review of studies on the effectiveness of speed humps found them to be very effective in reducing speeds, particularly at sites where speeds prior to hump installation were high (Stephens, 1986, cited in Fildes and Lee, 1993). Speeds tended to reduce by 40-45 kph when pre-installation speeds were 65-70 kph, and tended to reduce by 10 kph when pre-installation speeds were 30-40 kph. Engel and Thomsen (1992, cited in Fildes and Lee, 1993) concluded that speed humps were responsible for speed reductions of 1 kph for every 1 cm of height of the hump, although, presumably, there was a minimum and maximum height beyond which this was not true. Overall, speed humps have been shown to be an efficient speed-reducing physical measure (Várhelyi, 1996).

### Road Narrowing, Chicanes, and Gateway Treatments

Another effective means of reducing speed is use of "diagonal slow points" or chicanes, which narrow the road and force the driver to change direction in order to manoeuvre through traffic islands on either side of the road. The optimal configuration of chicanes, suggested by Bowers (1986, cited in Fildes and Lee, 1993, p71), is that they *"should create 45 [degree] changes in direction of the carriageway approximately every 50 metres, with an offset of the full width of the carriageway"* (p61). A study of chicanes by Taylor and Rutherford (1986, cited in Fildes and Lee, 1993) showed that they reduced speed from above 50 kph to under 30 kph, although speeds were reduced for only about 40 metres on either side of the chicane. A Swedish study produced a similar finding; however, the chicanes were found to have caused some contact or potential contact between passing vehicles and to have generated some irritation from the public (TSV, 1985, cited in Várhelyi, 1996).

Similarly, gateway treatments produce the effect of passing through a constricted "gateway" opening by road narrowing combined with vertical elements such as trees and lamps (Fildes and Lee, 1993). A gateway treatment on rural roads at entrances to villages in Germany reduced the mean speed on the roads from 77 to 66 kph, although speeds were still well above the 50-kph speed limit (Alink and Otten, 1990, cited in Várhelyi, 1996).

Road narrowing alone, whether implemented along the whole road (or large sections of it) or at certain points through the use of traffic islands on either side of the road, can also reduce speeds. However, a Swedish study found that road narrowing had the smallest effect on speed reduction compared to humps and chicanes (Hydén et al, 1983, cited in Várhelyi, 1996). In Hydén et al's study, mean speeds reduced from 38-45 kph to 32-40 kph following road narrowing in Sweden. Similarly, in Denmark, road narrowing on residential streets produced a speed reduction of 4.7 kph (Engel and Thomsen, 1990, cited in Várhelyi, 1996).

### Roundabouts

Studies have indicated that roundabouts are effective at keeping vehicle speeds down on straight roads (for example, Lynam, 1987, Schnull and Lange, 1990, Davies, 1988, all cited in Fildes and Lee, 1993). However, their effectiveness depends on the extent to which drivers are forced into a roundabout manoeuvre. For example, a large roundabout at the entrance to a town was more effective at slowing traffic than a mini-roundabout (Herrstedt, 1992, cited in Fildes and Lee, 1993). However, if properly designed, mini-roundabouts can also be effective at reducing speeds. For example, mini-roundabouts on arterial routes in a Swedish town reduced mean speeds through the intersections to 30-35 kph and reduced the risk of injury crashes by 40% (Hydén et al, 1995, cited in Várhelyi, 1996). Mini-roundabouts are often part of LATM measures.

### System-Wide Effects

A through road in a built-up area can be environmentally adapted by using combinations of devices (for example, a gateway, chicanes, and general road narrowing) to reduce traffic speed. Elvik et al (1996, cited in Várhelyi, 1996) reviewed the findings of several studies that examined the effects of environmentally adapted through roads. The technique reduced the number of injury crashes by between 30% and 50% and, on average, mean speeds decreased from 53.7 to 44.4 kph. Herrstedt (1992, cited in Fildes and Lee, 1993) also reported speed reductions of 10 kph in 40-kph and 50-kph zones when a combination of devices was used.

In general, the overall benefits of LATM measures in reducing speeds and crashes in urban areas are clear and exceed the costs[34]. Fildes and Lee (1993) caution, however, that research has not explained the effects of the treatments on the entire roading system. One such effect is traffic migration, evidence for which was found by Vis, Dijkstra, and Slop (1990, cited in Fildes and Lee, 1993). They measured traffic volumes before and after the introduction of LATM devices in 15 areas in the Netherlands and observed reductions of five percent to 30% in traffic volumes using the adapted roads. If the speeding drivers use alternative routes, then there can be crash migration to these areas.

There are some other suggested problems with LATM measures (Fildes and Lee, 1993). For example, McKee and Mattingly (1977) found that environmental traffic schemes can disadvantage the elderly by increasing journey times and distances to shopping and recreational destinations. They also disadvantage older drivers by increasing the complexity of the driving task in their local area. They may also disadvantage the entire road user population by increasing the number of crashes because of their physical obstruction of the roadway. Furthermore, they may restrict the mobility and ease of access of emergency services such as ambulances. Unsafe driving behaviour due to frustration at the devices is another suggested problem. However, it appears that no research has been conducted to demonstrate the full extent of these problems.

## 2d: Perceptual Countermeasures to Speeding

Because drivers tend to choose their travel speed based on their perceptions of relative "safety" of a stretch of road, some roading measures have attempted to reduce drivers' perceptions of safety without actually reducing the safety of the road. The effectiveness of these "perceptual" countermeasures in reducing speeds is variable. Fildes, Leening, and Corrigan (1989) argued that these countermeasures are more likely to be successful in environments perceived as unsafe (for example, narrow walled environments) than in environments perceived as safe. In "safe" environments, speed choice is more dependent on social and enforcement factors, whereas in "unsafe" environments it is more dependent on perceptual factors. Some of the measures that have been shown to be effective are outlined below, but generally more research appears necessary in this area.

Transverse road markings are lines painted or adhered across the road surface. One use of this perceptual countermeasure is to place these markings (usually with decreasing spacing between the lines) to give the illusion that vehicle speed is increasing (Várhelyi, 1996). They are suggested for use at locations where drivers have been travelling at high speeds for some time and are then required to slow down, such as at motorway exits. Researchers have found transverse road markings to be effective at reducing speeds in the long term in both the UK (Helliar-Symons, 1981, cited in Fildes and Lee, 1993) and Australia (Jarvis, 1989, cited in Fildes and Lee, 1993). However, in a study by Rutley (1975, cited in Várhelyi, 1996), they lost some effectiveness after one year (possibly as drivers became aware of the illusion). Initially, these markings reduced mean speeds by 23%, but one year later the speeds were reduced by only eight percent from the initial mean. As well as producing the illusion of increasing vehicle speed, the markings may be effective because drivers are reacting to them as a warning device.

Another perceptual countermeasure is a narrowing of the width of the vehicle lane. A narrowing of the lane to a width of 3.0 metres or less is required to produce the perceptual effects needed for speed reductions (Fildes and Lee,

34 Several studies other than those already cited have shown crash reduction benefits and/or speed benefits from treatments on residential streets (for example, Kraay et al, 1984, Engel and Thomsen, 1990, Hydén et al, 1983, all cited in Várhelyi, 1996; Fisher and Van den Dool, 1989, Chua and Fisher, 1991, Kjemtrup and Herrstedt, 1992, Engel, Krosgaard, and Thomsen, 1989, Engel and Thomsen, 1992, Bowers, 1986, Engel, 1990, all cited in Fildes and Lee, 1993).

1993), although there is a minimum possible lane width through which vehicles can travel safely. Similarly, intensive road treatments are used in some locations to severely restrict the number and size of travel lanes though the use of wide white gravel medians with edge-line markings. These treatments have been shown to reduce travel speed in some locations.

A device that allows drivers to monitor their own driving behaviour through auditory rather than visual cues is an audible edge line. This is a strip along the edge of the road with evenly spaced, raised ridges that cause vibration and associated rumbling within the vehicle if the vehicle drives along or across it. Thus, speeding (or distracted) drivers will be alerted that they are leaving the carriageway and that they must lower their speed and/or correct their vehicle direction. Trial stretches of audible edge lines have been laid in New Zealand, but no research is available on their effectiveness. Queensland Transport in Australia found that fatal crashes on two sections of highway in Queensland fell by 39% over 12 months as a result of the introduction of audible edge lines (Queensland Government, 1997).

## Conclusions

- Generally, drivers travel faster on stretches of road they perceive to be "safe" for higher travel speeds, regardless of whether this perception is accurate.
- Roadside development, such as trees in rural environments or houses in urban environments, play a significant role in the speed drivers perceive to be safe, and hence how fast they drive. There are a range of other environmental factors – such as the width, surface, and marking of the road, sight distance, traffic volume, time of day, and weather – that affect how fast vehicles travel on the road.
- Many of these factors themselves are dependent, particularly for new road developments, on the speed that the road was designed to be driven on.
- Speed limits alone are not effective in reducing vehicle speed. They need to be reinforced either through engineering (or environmental) measures or through enforcement activity.
- A range of perceptual and physical road and traffic measures are available to reduce speeds on the road. The use of these measures needs to be assessed on a case-by-case basis to minimise the risk that the devices become hazards in their own right, and to ensure that speed management problems do not simply migrate to other parts of the roading network.
- Most is known about Local Area Traffic Management (LATM) devices that place physical barriers in front of vehicles to slow their speed in urban areas.

# Part C

## Countermeasures: Enforcement, Publicity, and Penalties

The focus of Part C is on reducing speed by targeting those who drive at excess and inappropriate speeds. The more common, traditional approach to controlling vehicle speeds – that is, by focusing on changing the attitudes and behaviours of speeding drivers through enforcement, publicity, and a system of penalties – is discussed.

The first point of discussion addresses the continuing but misguided view among some individual drivers that they have superior driving skills such that they are able to drive at increased and inappropriate speeds on public roads without endangering themselves or other road users. Consistent with this view is a lack of support for strict police enforcement of laws relating to speeding. Such attitudes are in sharp contrast to our demands as a society for further police enforcement presence to protect our interests in almost any other area, whether that be in relation to burglary, rape, murder, fraud, domestic violence, or drink-driving. In many ways, this reflects the heart of the problem of speed on our roads – the denial that speeding is a fundamental safety issue.

The poor attitude of communities towards speeding needs to be addressed by a community attitude change programme. Such programmes have been successful in other areas, such as drink-driving, anti-smoking, and cancer prevention (sun-smart) campaigns. A similar success can be achieved with speeding; however, it requires an intensive and sustained campaign of education, enforcement, and publicity. Behavioural change is possible but does not happen overnight.

Enforcement is a fundamental mechanism for improving safety on our roads, and this Part also attempts to show the role that enforcement plays in reducing speed-related trauma. However, enforcement is just one strategy that needs to be employed. Just as important are publicising the enforcement and having a penalties system that reinforces safer behaviour. Part C concludes by returning to the comparisons, made in earlier sections of this review, of the relative risks of crashing when exceeding the speed limit or when under the influence of alcohol. Penalties for behaviours with similar relative risks are contrasted.

# 1: Driver Capability at Different Vehicle Speeds

### Identifying and Responding to Hazards

As noted earlier, safe driving relies on two important human functions: perception and cognition. Drivers must not only observe and respond to the constant and predictable features of the road, but must also identify and respond to potential hazards in the traffic system. There is a wide range of potential hazards – for example, the vehicle in front stopping suddenly, a pedestrian stepping out, a vehicle turning in from a side street, a child running out, a cyclist swerving to avoid a pothole, or an animal sitting on the road. The detection of hazards or potential hazards requires constant vigilance on behalf of the driver. The ability to detect hazards is one of the skills that differentiates experienced from novice drivers (McKenna, 1999).

Once a hazard has been detected, the driver then has to make a decision about how to respond and to act accordingly. Várhelyi (1996) likened the driver to a complex "information processing system", continuously monitoring the traffic situation and reacting accordingly. In order to drive safely, the driver has to *"perceive, attend to, and comprehend relevant information, make decisions, and have the necessary skills and motivation to carry out the necessary manoeuvres"* (p21).

As a driver's vehicle speed increases, so does the speed with which the traffic situation "approaches" the driver. In addition, the higher the speed, the further ahead the driver has to monitor. Therefore, with the speed increase, the driver has to deal with more information and make more decisions per unit of time. There is, however, a limit to our information-processing capacity, and, if the amount of information presented in a certain space of time exceeds that capacity, not all of the information will be able to be processed. Therefore, given the same level of driving experience, a driver travelling at higher speeds has a greater risk of missing or misinterpreting visual or auditory information about potential hazards – or of even missing the critical cues altogether – than a driver travelling at lower speeds (Várhelyi, 1996).

Not only does a limited information-processing capacity affect the ability to detect hazards at high speeds, but so does the way the eyes are focused at high speeds. Häkkinen (1979, cited in Várhelyi, 1996) observed that, as speed increased, drivers' eyes tended to focus further ahead in the distance, giving less attention to peripheral observation. Hence, the detection of hazards, such as approaching pedestrians, in the peripheral view became more difficult.

Furthermore, when travelling at higher speeds, there is less time to make the appropriate response in order to avoid a hazard than there is at lower speeds. In Part A, we discussed how stopping distance factored into the relationship between speed and the risk of crashing. That is, a speeding vehicle will not only travel further than a slower-moving vehicle during the driver's reaction time, but it will take longer to come to a stop once the brakes are applied. Another way of looking at this is to compare sight distance – that is, the distance from a hazard at the time it is first viewed – with total stopping distance. At low speeds, the sight distance usually far exceeds the total stopping distance (given normal levels of friction). However, at high speeds, the sight distance may well be less than the total stopping distance required and, in such cases, a collision with the hazard (or another object in the attempt to avoid the hazard) is almost certain. Fildes and Lee (1993) termed driving at speeds where the stopping distance exceeds the sight distance "over-driving" (p17).

McLean et al (1994) determined the relationship between initial speed and stopping distance from an examination of 176 fatal pedestrian-vehicle collisions in the Adelaide area between 1983 and 1991. The relationship is presented in Figure C1 below. The straight, horizontal sections of each curve represent the distance covered during the driver's reaction time; that is, from the time the driver first views a pedestrian to the time the brakes are applied. During this time, the vehicle travels at the same speed as the initial travelling speed. Once the brakes are applied, the vehicle's speed decreases with distance travelled, slowly at first then more rapidly. McLean et al use Figure C1 to demonstrate the following example:

*"Consider two cars travelling side by side at a given instant, one car travelling at 50 kph and the other overtaking at 60 kph. Suppose that a child runs onto the road at a point just beyond that at which the car travelling at 50 kph can stop. The other car will still be travelling at 44 kph at that point, a collision speed at which a pedestrian has more than a 50% probability of being fatally injured"* (p40-41).

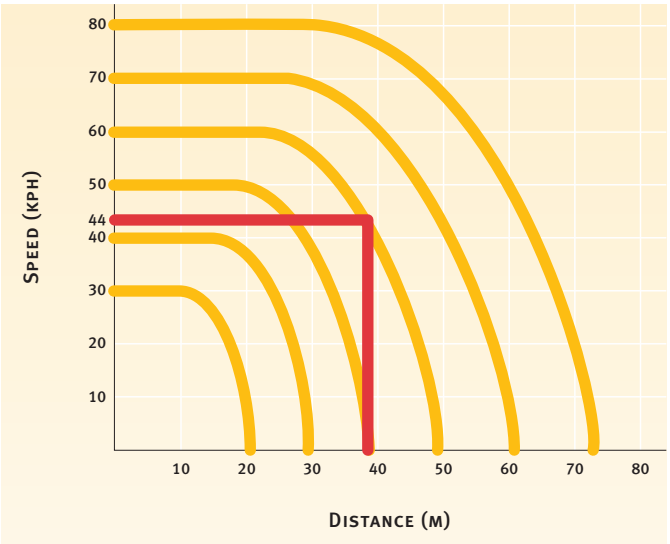



**Figure C1 – The relationship between speed and distance travelled under emergency braking once the hazard is first viewed**

**Source: McLean et al, 1994, p40.**
**Notes: The straight, horizontal part of the curve represents reaction time. In the example, represented by the red line, the car travelling at 60 kph is still travelling at 44 kph at the point where the first car is stopped.**

Even if a driver believes he or she is such a good driver that he or she can control a vehicle at high speeds, the distance required to stop follows the laws of physics and is not related to driver skill. Therefore, if a driver encounters a hazard on the road that necessitates emergency braking, the driver's ability to control the vehicle at high speeds will have no bearing on how quickly he or she can stop. Drivers may believe they can avoid a hazard altogether through skilled manoeuvring; however, often there is not enough space to manoeuvre around a hazard, particularly on New Zealand's narrow roads.

McKenna (1999) recently provided evidence that the ability to detect hazards influences driving speed in a simulated situation. He trained a group of drivers so that their hazard perception skills were improved. Following the training, the drivers were given a (laboratory) task that assessed the speed at which they chose to travel. McKenna found that the drivers with the hazard perception training chose a lower speed on the task than a control group who had not received any training. A likely reason for the lower speed choice was that the drivers trained in hazard perception skills had learnt that to reliably detect hazards they needed to travel at a speed that was reasonable, and not too fast. The control group, however, who were perhaps less aware of the importance of detecting hazards, were also not taking into

account that higher speeds reduced the time available for hazard detection. It is important to note, however, that these results were conducted within a laboratory and may not necessarily transfer to the on-road environment.

In addition to limiting their own ability to detect hazards and make the appropriate response, drivers travelling at high speeds also affect other road users' risk of crashing. In particular, because of the speed at which the speeding vehicle approaches other road users, these other road users will have less time to react to the speeding vehicle (Lay, 1984, cited in Zaal, 1994). The speeding driver may also endanger other road users because they underestimate the speeding driver's speed. For example, as discussed in Section 1 of Part A, Kloeden et al (1997) found that the most common types of crashes in their Adelaide study were those in which a vehicle turned right, either from the primary road itself or from a side street, across the path of vehicles travelling at free speeds on a primary road. Kloeden et al hypothesised that these crashes occurred because the approaching vehicle was travelling at excess speed and the turning driver misjudged the gap because he or she mistakenly assumed the approaching vehicle was travelling at about the same speed as the other free-flowing traffic on the road.

The findings by Kloeden et al (1997) demonstrate people's poor ability to judge the speed of approaching vehicles. Our sensory system was not designed to judge such high speeds, since such a skill is not ecologically necessary for walking or even running. Unfortunately, we overestimate our ability to judge the speed of traffic travelling at high speeds. Recent research at Monash University in Melbourne by Jennie Oxley and Andrea Dale (Fildes, 1999) has found that this poor ability to judge speeds is even worse in older people than in younger people, especially older pedestrians who are less mobile. These researchers hypothesise that a pedestrian's first judgement of whether it is safe to cross the road or a driver's first judgement of whether it is safe to execute a turn across traffic is based on the distance away from approaching vehicles, then this judgement is modified by the speed of the approaching vehicle. Since older people are much slower than younger people at making decisions, and also have poor judgement of speed, they may rely on distance alone and consequently get caught out by speeding vehicles.

### Speed Adaptation

Another situation in which speed influences the risk to a driver and other road users is when the driver has been travelling at high speed for some time and then has to slow down to a lower speed – for example, when travelling on a rural road and then an urban road or when exiting a motorway into a residential area. At the lower speed, the driver tends to greatly underestimate his or her speed. This perceptual phenomenon, known as "speed adaptation" (for example, Fildes and Lee, 1993, p58), can lead to drivers travelling at speeds well above the speed limit in reduced speed areas, without being aware of it, hence creating a dangerous situation for themselves and other road users.

### Conclusions

- Safe driving relies on two important human functions: perception and cognition. To drive safely, drivers must be able to identify and respond in a timely manner to potential hazards in the traffic system.
- Increased speed tends to decrease drivers' abilities to detect hazards and to make the appropriate response to them.
- When a hazard is encountered, the distance required to stop to avoid the hazard increases with increasing speed.
- Travelling at high speeds endangers other road users by increasing their risk of crashing, since other road users have less time to react to a speeding vehicle and may also underestimate the speed of a fast travelling vehicle.
- Travelling at a higher speed and then slowing to a lower speed (such as when moving to an area with a lower speed limit) can lead to an underestimation of the level of the reduced speed. Travelling at high speeds in areas requiring low speeds increases the crash risk to the driver and to other road users.

# 2: The Impact of Enforcement on Vehicle Speed

Enforcement of speeding laws is based on the assumption that a driver chooses the speed at which to travel and that that choice is made through a rational process of weighing the perceived advantages and disadvantages of exceeding the speed limit (Fildes and Lee, 1993). Perceived advantages may include time savings and thrill gains; perceived disadvantages may include the possibility of being caught by enforcement authorities and/or an increased chance of a crash. The aim of enforcement is to deter the driver from driving too quickly by increasing one of the disadvantages of speeding – the perceived likelihood of being caught. Enforcement is also used to detect and apprehend the speeding drivers for whom the increased risk of apprehension alone does not act as sufficient deterrent.

## 2a: Deterrence

Deterring the driver from speeding can be achieved by two different police enforcement mechanisms: specific deterrence and general deterrence (Fildes and Lee, 1993). In the speeding context, **specific deterrence** is targeted at the individual speeding driver and aims to change the specific individual's behaviour by catching and imposing some penalty (or punishment) upon that individual. Specific deterrence *"is based on the assumption that drivers who are caught and punished for speeding will be discouraged from committing further speeding offences"* (Fildes and Lee, 1993, p37). It often deters a driver from speeding at a particular site.

**General deterrence** targets the general population and aims to have a widespread effect on speeding by increasing public perception that speeding drivers will be caught, regardless of whether or not there is an actual increase in enforcement activities. The perception that enforcement is of a high intensity is encouraged when members of the population observe enforcement activities occurring (for example, seeing police apprehend a speeding driver) and when there is associated publicity about enforcement activity. General deterrence *"is based on the assumption that those exposed to the enforcement, apprehended or not, will be discouraged from speeding for fear of detection and punishment"* (Fildes and Lee, 1993, p37).

The effect of deterrence on the driver's decision to speed or not is dependent on the driver's perception of the risk of being caught, the driver's fear of being caught, and the driver's fear of the likely punishment (Zaal, 1994). The perceived risk of being caught has been identified as the most important factor in deterring the driver from speeding (Shinar and McKnight, 1985). For example, a study of the effects of a two-week police strike in Finland, during which time there was effectively no traffic enforcement, observed a 50% to 100% increase in the number of serious speeding offences (Summala, Naatanen, and Roine, 1980, cited in Fildes and Lee, 1993).

Contrary to expectations, some attitudinal studies conducted in the 1970s demonstrated that changes in the level of perceived risk of being caught when speeding do not necessarily correlate well with changes in enforcement levels. Ostvik and Elvik (1990) reviewed a number of the Scandinavian studies conducted in the 1970s in which enforcement levels in a region changed. They found that, when enforcement levels were increased on a given road, the perceived risk of being caught did not increase to the same extent that enforcement levels had. However, what is unknown is what questions were asked in the attitude surveys and the extent to which publicity associated with the increased enforcement also increased. More recent evaluations have demonstrated clearly that enforcement must be combined with publicity to have an effect on the perceived risk of apprehension (Havard, 1990).

The effectiveness of deterrence is also dependent on three punishment factors: the perceived certainty, the severity, and the swiftness (immediacy) of punishment. Evidence that the **perceived certainty** of punishment deters inappropriate driving behaviour was shown with the reduction in drink-driving crashes during the Random Breath-Testing campaign in Australia (Fildes and Lee, 1993). The campaign increased the probability of a drink-driver being caught and therefore incurring the associated penalty. Fildes and Lee (1993) also suggest the ongoing campaign led to a change in attitudes about drink-driving. However, Fildes and Lee (1993) caution that the threat of punishment alone is unlikely to have achieved the change in drink-driving attitudes during the campaign. For example, publicity, education, and penalties would have played some part in the attitude change.

The **severity** of punishment appears not to have as important an influence on behaviour as the certainty of

punishment. For example, in 1982, the fines for speeding in Sweden were doubled. Even though one-third of drivers knew of the new fine amounts, no changes in speeding behaviour were observed following the change (Aberg, Engdahl, and Nilsson, 1989, cited in Fildes and Lee, 1993). Similarly, no change in speeding behaviour was found when the fines were raised again in 1987 (Andersson, 1989). However, the effectiveness of the severity of punishment is dependent on the perceived risk of being caught. Therefore, if the perceived risk is higher, the severity of the punishment may play a larger role in deterring speeding drivers. For example, the evaluation of the intensive speed camera programme in Victoria between 1990 and 1991 found that receiving a traffic infringement notice in the mail affected speed behaviour for approximately two weeks (Rogerson, Newstead, and Cameron, 1994).

The effect on speeding behaviour of the **swiftness** of the punishment does not appear to have been studied; however, it will be discussed in the subsection on automated speed enforcement that follows.

Overall, the aim of speed enforcement is to apprehend speeding drivers and to deter all drivers from speeding. The methods used to enforce speed restrictions were reviewed extensively by Zaal (1994). Zaal divided the review into two enforcement approaches: traditional speed enforcement and automated speed enforcement. A discussion of each of these approaches follows.

## 2b: Traditional Speed Enforcement

The traditional approach to speed enforcement is to catch and punish the speeding driver at the site where the speeding offence occurred (or was detected). Usually, this involves the use of some form of speed measuring device – for example, a radar device operated from a parked police vehicle, or the police vehicle itself in the traffic stream – to detect the speeding offence. The offending driver is then stopped by the police at the nearest possible location, and is issued with some form of penalty notice, depending upon the severity of the speeding offence committed (Zaal, 1994).

### Halo Effects

A difficulty with traditional enforcement is in ensuring that the deterrence effect does not occur only at the site of enforcement (TRB, 1998). The distance or time that the deterrence effects last from the enforcement site or activity are known as "halo effects" (Fildes and Lee, 1993). The **distance halo effect** refers to the distance (usually measured in kilometres) on either side of the enforcement site over which there is a reduction in speeding behaviour. The **time halo effect** typically refers to the time (in days) from the enforcement activity during which speeds at the enforcement site are reduced.

Barnes (1984, cited in Zaal, 1994) examined the extent of distance halo effects around enforcement from a marked police car in New Zealand. Reduced speeds began more than two kilometres before the site (due to headlight flashing, radar detectors, and so on) and lasted between four and six kilometres after the site – a total of up to eight kilometres. When the enforcement is more strategically used, the distance halo effect is estimated to be larger. For example, Brackett and Edwards (1977, cited in Ostvik and Elvik, 1990) evaluated the effects of an American study in which a stationary police car was randomly moved from place to place along a long stretch of road. The aim was to create the impression that there was a massive concentration of enforcement along that road. They found that speeds were reduced up to 20 kilometres from the stationary car.

Hauer, Ahlin, and Bowser (1982) examined both distance and time halo effects at enforcement sites. They found that mean speeds at the enforcement sites were reduced, but that the effect of the enforcement – the level of the reduction in mean speeds – reduced by half every 900 metres downstream from the enforcement site. The time halo effect was examined by observing individual vehicles over several days during and after enforcement. They found that vehicles exposed to enforcement at a site only once reduced their speeds at the site for up to three days following the enforcement. Vehicles that encountered enforcement at a site over five days reduced their speeds at the site for at least six days after the last day of the enforcement.

Nilsson and Sjorgen (1982, cited in Fildes and Lee, 1993) compared time halo effects after repeated exposure to a site and after a single exposure. A number of different types of enforcement procedures were examined: marked and unmarked police cars, radars, and helicopters. They found a significant difference in speeds over time between vehicles exposed only once to the radar or marked police car and vehicles repeatedly exposed to the enforcement over six days. Also, for those exposed to six days of radar or marked police car enforcement, the reduction in speeds remained

for an average of 10 days, and six days of helicopter surveillance led to a time halo effect of 17 days. However, there was no time halo effect for exposure to the unmarked police car.

More recently, Vaa (1997) examined the time halo effects of six weeks of very high enforcement levels (averaging nine hours per day) on a 35-kilometre length of highway in Norway. Speeds were measured (unobtrusively) in 60- and 80-kph speed-limit zones for two weeks before the enforcement, again during the enforcement, and again for eight weeks afterwards. In the 60-kph zone, "speeding" was defined as exceeding 70 kph; while, in the 80-kph zone, it was defined as exceeding 80 kph[35]. During the enforcement period, there was a reduction in the proportion of drivers who were speeding in both of the speed zones. In the 60-kph zone, this reduction lasted up to eight weeks after the enforcement period. In the 80-kph zone, the reduction in the proportion of speeding drivers lasted up to six weeks.

In summary, the size of the time and distance halo effects appears to depend on the enforcement strategy. When enforcement is of a high intensity, the effects can last up to eight weeks. When enforcement is of a high intensity and randomly placed, a reduction in speed behaviour can extend up to 20 kilometres from the site.

### Enforcement Visibility

Traditional speed enforcement can be based on either a high-visibility or a low-visibility approach (Zaal, 1994). The **high-visibility approach** aims to reduce speeds by deterring drivers from speeding at the site of the enforcement and by increasing the overall perceived risk of being caught. The **low-visibility approach** aims to reduce speeds by making drivers aware that enforcement is not predictable and, hence, they cannot predict when to slow down to avoid being caught. Both approaches rely on high levels of publicity about the presence of enforcement.

Some evidence of the effectiveness of the high-visibility approach was demonstrated in a study of crash "black spots" (sites involving a high crash history) on a sample of New Zealand rural highways (Graham, Bean, and Matthews, 1992). The study involved measuring vehicles' speeds at six sites from November 1988 to April 1989 and from late November 1989 to March 1990. At three of the sites, traffic patrols were placed in random, highly visible positions and required to patrol the sites for one- and two-hour periods on 13 days each month from December 1988 to March 1990. The remaining three sites were used as control sites. All sites were about 18 to 30 kilometres in length, without towns, major intersections, or terrain that would affect normal open-road speeds. Graham et al found small reductions in median speeds at the test sites compared to the control sites[36]. The size of the speed reduction at each site was dependent on the level of enforcement activity.

A similar enforcement approach to that of Graham et al (1992) was conducted throughout Queensland, Australia (Newstead, Cameron, and Leggett, 1999). The approach, known as the Queensland Random Road Watch programme, involved dividing each police jurisdiction in Queensland into a number of sectors and the week into a number of time blocks. Enforcement was then randomly assigned to a sector for an entire week, with the time of day of the enforcement also randomly assigned. Enforcement involved a conspicuous stationary marked vehicle undertaking general road safety enforcement duties during the randomly assigned time in the randomly selected sector. Newstead et al (1999) found that in the first year of the programme there was a reduction in crashes of all severities in all police jurisdictions (this reduction was statistically significant for all but one police jurisdiction), with the largest reduction occurring for fatal crashes. For example, outside metropolitan Brisbane there was an estimated 31% reduction in fatal crashes and an estimated 13% reduction in serious injury crashes. A broadly similar programme to the Queensland Random Road Watch programme, known as "Bullseye", is currently being conducted in New Zealand (see Garvitch, 1999, for details).

The low-visibility approach, when utilising traditional enforcement methods, tends to be less effective at deterring drivers from speeding than the high-visibility approach. For example, Galizio, Jackson, and Steele (1979, cited in Fildes and Lee, 1993) found that the presence of a marked police vehicle resulted in a significant speed reduction, but the presence of an unmarked police car resulted in no change in traffic speed. However, as Parker and Tsuchiyama (1985, cited in Zaal, 1994) stated, the effectiveness of an unmarked police vehicle on speed reduction is dependent on the perception by road users that any vehicle could be an unmarked police vehicle. This perception can be encouraged by high levels of publicity regarding the use of unmarked vehicles in enforcement programmes, as well as increasing the visibility of situations in which an unmarked police vehicle stops a speeding motorist. For example, visibility can be increased if

35 The definitions differed between speed-limit zones because of software constraints.

36 Relative to the changes at the control sites, the median speeds decreased at the test sites by 1.8 kph, 0.3 kph, and 1.1 kph in the mornings, afternoons, and evenings respectively.

a police car uses flashing lights when apprehending a speeding driver. The low-visibility approach has been found to be effective in the area of automated speed enforcement. This will be discussed later in this section.

### Enforcement Mobility

Whether to use stationary or moving police vehicles has been another area of research on enforcement. Shinar and Steibel (1986) compared the speeds of vehicles in the presence of stationary or moving police vehicles. They found that the presence of either type of enforcement reduced speeding by 95% at the enforcement sites. The magnitude of the initial speed reduction was the same when encountering either the stationary or the moving police vehicle. However, police vehicles moving within the traffic stream had a greater effect on the speeding behaviour of individual road users for a longer time and over a longer distance.

Armour (1984) has suggested that moving police vehicles are more effective overall because of the limitations in the use of stationary vehicles, such as the limited number of suitable sites and the rarity of road users encountering more than one stationary vehicle on a journey. Southgate and Mirrlees-Black (1991, cited in Zaal, 1994) have suggested that stationary speed enforcement could be more effective if there was tactical placement of stationary vehicles. For example, using two or more vehicles located short distances apart would increase the distance halo effect and increase the overall perception of the risk of being caught.

Overall, it has been suggested (Bailey, 1987, cited in Zaal, 1994) that stationary vehicles should be used at locations with high crash rates, because of their effect on speed reduction at a site. Also, moving vehicles should be used on stretches of road where speeds are higher than appropriate, because of their effect on the speeds of drivers over a long distance. This type of approach is less relevant now with the availability of speed cameras (see Section 2c).

### Optimising Traditional Enforcement

It appears from the research that traditional enforcement may be effective if it is employed strategically. Jernigan (1986, cited in TRB, 1998) reviewed selective enforcement programmes in the United States and found that the most successful programmes were:

- *"deployed at specific locations and at times when unwanted behaviour is most likely to occur;*
- *made highly visible to the public; and*
- *maintained for more than a single year"* (cited from TRB, 1998, p151).

Hunt, McKenzie, and Edgar (1992) conducted a study in New Zealand that aimed to optimise traditional enforcement. They developed an enforcement programme for six urban and five rural sites in the Manawatu area of New Zealand that had a high crash history ("speed black spots"). The sites were subjected to intensive enforcement over a two-month period. Along with low-visibility enforcement techniques (such as the use of unmarked police vehicles), there was a large publicity campaign at both the national and local level. At the national level, the campaign was conducted during the middle four weeks of the enforcement period. The aim of the campaign was to educate the public about "speed black spots" and about the intent to vigorously enforce speed limits in such areas. At the local level (Manawatu area), education was provided – for example, through newspaper advertisements – about where the speed back spots were. In addition, a new traffic sign was erected at each of the black spot areas, printed with the words "SPEED BLACK SPOT".

Speed surveys were conducted at the enforcement sites and at eight control sites, both before and after the trial. A public attitude survey was also conducted both before and during the trial. Hunt et al (1992) found decreases in mean speed from before to after the trial at all enforcement sites, ranging from 1.8 to 4.6 kph. The difference in mean speeds between the enforcement and control sites was significant for urban areas. Using Nilsson's (1982) formula (discussed in Part A), Hunt et al calculated that the speed reductions of the magnitude obtained could result in a 17% reduction in urban injury crashes and a seven-percent reduction in rural injury crashes. Results from the public attitude survey indicated that the publicity about black spots increased the public's understanding of the term and increased awareness of the speed enforcement.

A small subsequent study was conducted by Hunt et al (1992) in the Bay of Plenty region, in which the "SPEED BLACK SPOT" signs were displayed at local black spot areas; however, there was no associated enforcement. They found that vehicle speeds did not decrease at the sites even when the drivers knew what the signs referred to. Together, these studies demonstrate that, to achieve a reduction in speeds, both targeted, visible enforcement and supporting publicity about the enforcement are needed.

### Problems with Traditional Enforcement

*"The problem with traditional enforcement methods is that [the] limited policing resources available, as compared to the relatively high number of speeding motorists, results in a low perceived risk of apprehension"* (Zaal, 1994, p79). As reported earlier, the perceived risk (or the perceived certainty) of being caught has been identified as the most important factor in deterring the driver from speeding (Shinar and McKnight, 1985). Zaal (1994) reported that the *"perceived risk [of being caught] is dependent upon the level of enforcement activity, the use of associated publicity, and whether or not motorists actually observe the reported increase in enforcement"* (p79). Thus, although publicity is important, if enforcement levels are low, publicity tends not to deter drivers from speeding in the long term (Harvard, 1990). Hence, low enforcement activity and low levels of publicity lead to a low perception of being caught, which, in turn, leads to an increase (or at least no reduction) in speeding behaviour. Unfortunately, because of limited policing resources, it is difficult to increase and maintain the increase of speeding enforcement activity. Recent developments in enforcement technology can, however, overcome these problems.

## 2c: Recent Enforcement Technology: Automated Speed Enforcement

Automated speed enforcement technology typically consists of a detection device (such as a radar device), a processing unit, and an image recording device (such as a still camera or a video camera). The detection device measures the speed of each oncoming vehicle and feeds this information to the processing unit. If the vehicle's speed exceeds a predetermined level, the recording device records an image of the vehicle and the driver. Also typically recorded on the image is the time and date of the offence and the speed of the vehicle. The information is then used to identify the owner and, if necessary, the driver of the vehicle. An infringement notice or warning letter is then mailed to the registered owner of the vehicle (Zaal, 1994).

### Advantages of Automated Enforcement

Automated speed enforcement devices have several advantages over traditional enforcement (Zaal, 1994; Rothengatter, 1990; TRB, 1998). For example:

1. They increase the probability of detection without overextending front-line police resources, since the police do not have to spend long periods of time detecting and apprehending speeders. This also means that the "enforcement pause" is eliminated; that is, the device does not need to temporarily cease operation while the speeding driver is apprehended.
2. They increase road users' perceptions of the risk of getting caught, through direct observation, associated publicity, and/or receiving a ticket when they were unaware they had been detected. Hence, the devices have a higher deterrence effect.
3. They increase the fairness of enforcement by taking "officer discretion" out of the equation.
4. They have been reported to lead to less dispute by motorists regarding their fine and, hence, provide a more efficient ticketing and payment process.
5. They can be used in locations where patrol vehicles cannot be safely and effectively deployed.

Overall, the largest benefit of automated speed detection devices appears to be in increasing the perceived risk of apprehension (Rothengatter, 1990). This is most effectively achieved through the widespread and highly publicised use of the devices.

The most common automated speed enforcement device is the speed camera. Several studies have examined the effectiveness of these devices.

### International Speed Camera Use

The first study that examined the use of speed cameras, conducted in West London, demonstrated that speed cameras were very successful at reducing speeds (Winnett, 1994). Another early study examined the effect of speed cameras introduced on a section of German autobahn (motorway) (Lamm and Kloeckner, 1984). German autobahns are not subject to a national speed limit, although approximately 30% have a local speed limit. The section of highway on which the speed cameras were introduced had a very high crash rate[37] and in 1972, the year before the introduction of the speed cameras, the section was given a speed limit of 100 kph[38]. The imposition of the speed limit led to an immediate 30-kph reduction in mean speeds, and the introduction of speed cameras reduced mean speeds by a further 20 kph. The combined effect of the speed limit and the cameras reduced crashes on the autobahn by 91%. This compared to a 56% reduction on the entire autobahn network in the same period (Ostvik and Elvik, 1990).

37 The section of highway had a steep downgrade with a design speed of 100 kph. There were about 200 crashes per year in 1970 and 1971 on a section 7.2 kilometres in length.

38 Prior to 1972, there was no speed limit for passenger vehicles on the autobahn. The majority of vehicles on the studied section exceeded 100 kph during this time.

Since the early study, speed cameras have been further introduced and evaluated in England. For example, the introduction of 32 fixed speed camera sites in Oxfordshire resulted in an overall reduction in fatal and serious injury crashes at the speed cameras sites (and up to 1 km each side of the site) of 23% (Hook, Kirkwood, and Evans, 1995). Corbett (1995) also evaluated the introduction of fixed speed cameras in England. In the first six months, mean speeds reduced by 10% (Darbyshire, 1993; cited in Corbett, 1995) and crashes dropped by 22%. Furthermore, 29% of drivers surveyed reported driving more slowly in general, although these drivers tended to be those who reported they did not know the camera locations.

Norway is another country that has introduced speed cameras and found a positive effect. For example, Elvik (1997) found that the introduction of speed cameras (known as photo radars in Norway) at permanent sites resulted in a decline of 20% in the number of injury crashes, when controlling for general trends in the number of crashes and "regression to the mean effects"[39].

Australasia appears to be an area where speed camera programmes have been used extensively. There have been several evaluations of these programmes in Australia. For example, a study of the introduction of speed cameras in New South Wales found they were associated with a 22% reduction in crashes at the speed camera locations (Loyola College, 1995).

Cameron, Cavallo, and Gilbert (1992) conducted an evaluation of the speed camera programme in Victoria (Australia). Speed cameras were introduced extensively in 1989 in response to a rising road toll[40]. The speed cameras were supported by an intensive mass media publicity campaign. In the first two years of the programme, every vehicle in the state of Victoria was on average having its speed checked by the cameras once in every six-week period (Ogden, Bodinnar, Lane, and Moloney, 1992). The number of measured vehicles exceeding the enforcement threshold was 23.9% in December 1989, the year the programme was first introduced; this had declined to 13% by December 1990, and it declined further to 9.4% by December 1991 (Bourke and Cooke, 1991, cited in Zaal, 1994). An analysis of the change in casualty crashes due to speed cameras during times of the day when alcohol consumption was low[41] revealed a 32% reduction in such crashes on Melbourne's arterial roads, a 20% reduction in country towns, and a 14% reduction on rural highways. The severity of injuries resulting from casualty crashes reduced across Victoria by between 28%, between July 1990 and February 1991, and 40%, between March and December 1991.

An evaluation of the localised effects of the Victorian speed camera programme found a significant reduction in casualty crashes within one kilometre of a speed camera site (Rogerson et al, 1994). They also found that speeding behaviour was reduced for approximately two weeks after a speed camera ticket was received.

### The New Zealand Speed Camera Programme

In New Zealand, speed cameras were introduced in October 1993. They were placed on stretches of road with a record of speed-related crashes. The stretches of road (or "sites") were signposted with "SPEED CAMERA AREA", and the cameras were highly visible. At rural sites, the cameras were mobile and vehicle-mounted. At urban sites, the cameras were either mobile and vehicle-mounted or fixed and mounted on poles. Thirteen fixed cameras were rotated around the 55 urban sites. The cameras at all sites were set to deploy when vehicles travelled at greater than the 85th percentile speed for the site, as measured unobtrusively (Mara, Davies, and Frith, 1996). There was substantial publicity both before and after the introduction of speed cameras.

Mara et al (1996) examined the effects of the New Zealand speed camera programme. They calculated that the programme resulted in significant reductions of 23% in fatal and serious crashes at urban speed camera sites and 11% in fatal and serious crashes at rural speed camera sites. However, they failed to detect any significant effects outside speed camera sites, except at urban sites at low alcohol times[42]. They suggested that the speed camera programme needed to be examined to determine how the effects could be generalised to areas where cameras were not in operation.

39 Regression to the mean effects refer to a high number of crashes one year followed by a number closer to the mean number of crashes (lower) the following year (or vice versa).

40 The Random Breath Testing programme was also introduced in response to the rising road toll.

41 Eighty-two percent of the speed camera enforcement was conducted during times of low alcohol consumption.

42 Low alcohol times are between 3am and 10pm. Approximately 96% of speed camera enforcement was conducted during low alcohol times.

A suggested variation in the New Zealand speed camera programme that was predicted to generalise its effectiveness past the limits of the speed camera sites was to use hidden cameras rather than visible ones. Hidden cameras with publicity have the potential to reduce the predictability of the cameras and hence have a more generalised effect. A trial of hidden cameras was therefore conducted on open roads in the Midland[43] police region of New Zealand from July 1997. All of the speed camera sites in the Midland region that had previously used visible speed cameras were signposted with "HIDDEN CAMERAS MAY OPERATE" and enforced with hidden cameras that could be operated from a free-standing tripod or a hidden vehicle. In other parts of New Zealand, visible cameras continued to be operated[44]. Substantial publicity was given about the trial, particularly in the month before it.

Keall, Povey, and Frith (in press) evaluated the effectiveness of the hidden cameras, during their first year of operation in the Midland region, compared to the visible speed cameras operated outside the Midland region. They calculated that mean speeds in the Midland region fell by 2.3 kph at speed camera sites and 1.6 kph outside speed camera sites, compared to the rest of the country. The speed reductions at the speed camera sites were associated with a 22% reduction in crashes and a 29% reduction in casualties at the sites. Furthermore, in the Midland region, there was an 11% reduction in the open-road crash rate and a 19% reduction in the casualty rate. The greater effect on casualties than on crashes indicates an effect on crash severity. The findings of an effect on crashes at the sites and throughout Midland indicate that the hidden speed cameras in the Midland region had both a specific and a general deterrence effect. Attitudes by the public in the trial region, as measured by the Annual Public Attitudes Survey (Land Transport Safety Authority, 1999a), initially indicated a growing acceptance of hidden cameras and a recognition that drivers did not seem to be speeding as much as before. However, this effect weakened to pre-trial levels after the first year of the trial.

Overall, speed cameras have reduced crash rates and speeds in the many countries that have employed them (Elvik, 1997). However, the full potential of speed cameras is as yet untested as, in many jurisdictions, political considerations have limited their usage.

### Issues Relating to the Use of Automated Enforcement

One issue regarding automated enforcement is the delay between the offence and punishment (Zaal, 1994). In New Zealand, the delay tends to be between approximately two and three weeks. Automated enforcement tends to create a high level of punishment certainty (Zaal, 1994) and, combined with the high level of perceived risk of being caught that speed cameras generate, punishment swiftness is probably less important in the process of deterring drivers from speeding. Furthermore, studies of speed camera programmes have found significant reductions in speeding behaviour, indicating that they are effective at deterring drivers despite the delay in punishment.

Another identified problem with automated enforcement is that the speeding driver often does not immediately realise that his or her offence has been detected (Rothengatter, 1990). However, this problem may be reduced by prompt ticketing of offenders and by other visible means such as the use of flashes on the cameras. Oei (1993, cited in Zaal, 1994) indicated that another way this problem may be overcome is by placing a board several hundred metres after the enforcement site that displays information regarding the driver's speeding offence. However, this mechanism will only be effective if all drivers detected speeding are given an infringement notice.

Community acceptance of speed cameras is also identified as a potential problem with their use (Zaal, 1994). However, in New Zealand, the Annual Public Attitudes Survey (Land Transport Safety Authority, 1999a) found the support for speed cameras was high (see Part E).

43 The Midland police region includes the Waikato, Bay of Plenty, and Gisborne local government regions, plus the Wairoa District.

44 There was a net increase in camera hours of 26% in the Midland region relative to the rest of the country.

## Conclusions

- Enforcement activities aim to deter drivers from speeding.
- Specific deterrence aims to change a specific individual's speeding behaviour, often at a particular site; general deterrence aims to have a widespread effect on speeding behaviour.
- The effect of deterrence on the driver's decision to speed or not is dependent on:
  - the driver's perception of the risk of being caught;
  - the driver's fear of being caught;
  - the driver's fear of the likely punishment.
- The most important of these seems to be the driver's perception of the risk of being caught, which is boosted by publicity about the enforcement activities.
- The effect of deterrence appears to also be dependent on the severity and swiftness of the associated punishment, although these effects can be rather subtle and unpredictable.
- Traditional approaches to speed enforcement usually involve activities associated with the on-site detection, apprehension, and punishment of the speeding driver.
- The distance halo effect refers to the distance in kilometres from an enforcement site within which speeds are reduced. The time halo effect refers to the days from enforcement activities that speeds at the enforcement site are reduced.
- Under certain police operational conditions, time and distance halos of two weeks and 20 kilometres, respectively, can be expected.
- Traditional speed enforcement can take a high-visibility or low-visibility approach; however, there must be a high level of associated publicity to increase the perceived risk of being caught, particularly with the low-visibility approach.
- A randomised visible traditional enforcement approach has produced large reductions in crash levels in Queensland, Australia.
- Careful planning of traditional speed enforcement approaches can optimise its effectiveness.
- Research supports the suggestion that stationary enforcement vehicles be used at known crash locations and moving enforcement vehicles be used on stretches of road where speeds are high.
- Traditional enforcement tends to result in a low level of perceived risk of being caught when police resources are low.
- Automated speed enforcement typically involves recording the image of a vehicle exceeding a predetermined speed limit. The image is used to identify the vehicle owner, who is mailed a speed infringement notice.
- The largest benefit of automated speed detection devices is that of increasing the perceived risk of being caught.
- Speed cameras have had positive effects on crash rates and speeds in the many countries that have employed them.
- Hiding site-based speed cameras, and widely publicising their potential presence, has shown benefits in the Midland police district of New Zealand, producing general as well as specific deterrence.

# 3: Publicity

Throughout the above discussion of enforcement effectiveness, the use of publicity has been mentioned. In the context of speed enforcement, publicity is often used to inform road users of the likelihood of being caught and punished for committing a speeding violation. Hence, it aims to increase the perceived risk of being caught. Publicity is, however, only effective in the long term when it realistically portrays enforcement levels. Publicity alone, without enforcement, tends not to deter drivers in the long term from committing a speeding offence (Havard, 1990). Similarly, enforcement without publicity is less effective at deterring speeding in the long term.

Several studies have examined the combined use of publicity and speed enforcement. For example, Riedel, Rothengatter, and de Bruin (1988) examined speeding behaviour on the open road following publicity and enforcement. They found that publicity alone produced some speed reductions. However, the combined use of publicity and enforcement had a much larger effect.

Cameron et al (1992) examined the effect of a speed camera programme combined with publicity in Victoria, Australia. They found that, when the publicity began, there was an initial significant reduction in the frequency of casualty crashes. This reduction occurred independently of the actual increase in the level of speed camera enforcement. However, greater reductions occurred during periods when high levels of publicity were combined with high levels of enforcement. Zaal (1994) concluded from the study that *"media publicity can be an effective means of initially raising and then maintaining community awareness of speed camera enforcement operations, but… [that] the greatest speed reduction benefits result from the enforcement operations themselves"* (p96).

As well as increasing the perceived risk of being caught, publicity has the benefit of increasing community awareness of and support for an enforcement programme (Zaal, 1994). For example, Freedman et al (1990, cited in Zaal, 1994) found that publicity associated with the introduction of speed cameras resulted in high levels of awareness of and community support for the use of speed cameras.

Recent publicity to reduce speeding behaviour in New Zealand has focused on both enforcement activities and the consequences of a crash. For example, the advertising side of the Supplementary Road Safety Package (SRSP) in New Zealand comprises advertisements about enforcement as well as graphic advertisements about the physical and emotional consequences of a crash. The SRSP was introduced in 1995/96 to build on the success of the high-intensity Compulsory Breath Testing (CBT) and speed camera interventions, which it supplemented with additional enforcement resources and hard-hitting national advertising. Vulcan and Cameron (1998) conducted an independent evaluation of the SRSP. They estimated the savings in road casualties associated with the SRSP during its first two years were 109 fatalities and 1,029 serious injuries. The analysis of the effectiveness of the components of the SRSP aimed at speeding indicated that, during low alcohol hours, there was a 14% reduction in serious casualty crashes in urban areas (but no reduction for rural areas) during the first year of the SRSP. During the second year, however, there was a 26% reduction in serious casualty crashes in the urban areas and a 14% reduction in such crashes in the rural areas (again, during low alcohol hours).

### Conclusions

- Publicity is very important for increasing the effectiveness of enforcement.
- Publicity alone can reduce speeds in the short term; however, publicity without enforcement will not have long-lasting speed reduction effects. Likewise, enforcement without publicity will not have long-lasting speed reduction effects.
- Hard-hitting publicity can be based on the emotional and physical consequences of a crash as well as on enforcement activities. Some campaigns have successfully combined these approaches.
- New Zealand's Supplementary Road Safety Package, for example, has been shown to be very effective in reducing the death and injury toll on our roads.

# 4: Tolerance Levels on Speed Limits

A speed tolerance represents *"a margin above the maximum speed limit within which drivers are not apprehended or punished"* (Fildes and Lee, 1993, p49). Most speed enforcement agencies employ speed tolerances, although the level of the tolerance varies across agencies due to legal requirements or equipment constraints. *"In Australia, speed tolerance levels of 10% plus 3 kph above the posted speed limits or a fixed margin of 10 kph are common policing practice"* (Zaal, 1994, p97).

The rationale for enforcing above a speed tolerance is to allow for errors in a vehicle's speedometer, as well as inaccuracies in the speed measurement equipment and procedure, that could be used as a challenge to a penalty in the courts (Fildes and Lee, 1993). Furthermore, since a speed tolerance means enforcement is concentrated on the fastest speeders, public acceptance of the enforcement is more likely. However, the other side to using a speed tolerance is that, as the public become aware of the tolerance level, they may use it as the de facto speed limit (Fildes and Lee, 1993). Furthermore, the tolerance level may for some drivers become the desired speed of travel, or even a guide to the minimum speed at which to travel (Nilsson, 1990).

Evidence that the public use the tolerance levels in deciding their choice of travel speed was demonstrated in a study by Andersson (1989). Andersson evaluated the effects of a 3- to 6-kph reduction in tolerance levels in the urban areas of two Swedish cities. There was a high level of publicity about the reduction in tolerance levels. Four cities in which the tolerance did not change were used as a control. During the year of the reduced tolerance, vehicle speeds fell in the two cities by approximately 1 kph, whereas at the control sites vehicle speeds increased by 0.5 kph. Andersson suggested that the lower speed was due to the increased risk of detection, which affected a large group of motorists.

Speed tolerances cannot be eliminated entirely, because of the possibility of technical challenges in courts. However, Fildes and Lee (1993) suggest that *"the only realistic solution seems to be… [to adopt] minimal tolerance levels in conjunction with rationalised speed limits based on what is an appropriate and acceptable travel speed"* (p50).

# 5: Penalties

The threat of incurring a penalty for committing a speeding offence is a crucial component of the deterrence process. The following describes some types of penalties and their effectiveness.

### Fines

The most common penalty imposed on drivers who are caught committing a speeding offence is a fine (Zaal, 1994). Table C1 displays the current fines for speeding within New Zealand.

| Offence: Exceeding the speed limit by… | Infringement Fee ($) | Demerit Points |
|---|---|---|
| up to 10 kph | 30 | 10 |
| 11 - 15 kph | 80 | 20 |
| 16 - 20 kph | 120 | 20 |
| 21 - 25 kph | 170 | 35 |
| 26 - 30 kph | 230 | 35 |
| 31 - 35 kph | 300 | 40 |
| 36 - 40 kph | 400 | 50 |
| 41 - 45 kph | 510 | 50 |
| 46 - 50 kph | 630 | 50 |

**Table C1 – Current fines, and demerit points, for exceeding the speed limit by up to 50 kph in New Zealand**

Sources: LTSA (1999b) and Schedule 4, Part II of the Land Transport Act, 1998.
Note: Demerit points do not apply to speeding offences detected by a speed camera.

Fines are an important enforcement tool. The effect of the size of the fine is less clear. For example, as discussed above, when the size of the fine was increased in Sweden, there was no detectable change in speeding behaviour (Aberg et al, 1989; Andersson, 1989, cited in Fildes and Lee, 1993). However, Fildes and Lee (1993) suggest that there is likely to be a floor limit, above which the size of the fine does have an effect on speeding behaviour. They predict this limit was not reached in the Swedish studies.

### Demerit Point Schemes

Another system of penalties is the allocation of demerit points. Every time an individual commits a speeding offence (or another relevant traffic infringement), a number of points are allocated and recorded against that person's driving record. If the driver accumulates more than the maximum number of points permitted within a specified period of time, additional penalties, such as licence suspension, are imposed (Zaal, 1994).

In New Zealand, demerit points are given for all speeding infringements other than speeding offences detected by a speed camera. If a driver accumulates 100 points within two years, he or she will be suspended from driving for three months. Also displayed in Table C1 above are the demerit points allocated to each speeding offence.

Dingle (1985, cited in Zaal, 1994) indicated that the benefits of a demerit point scheme are:

1. It provides positive feedback for those drivers who rarely speed, and may provide additional motivation to maintain a good driving record.
2. It provides drivers who occasionally commit some form of minor speeding offence with *"the necessary incentive to modify their driving behaviour in order to avoid obtaining further points and risking the chance of receiving a more severe penalty"* (p103).
3. It quickly affects drivers who regularly exceed the speed limit and are regularly caught doing so.

The effectiveness of the demerit point scheme has been demonstrated in a study by Haque (1987, cited in Zaal, 1994) of the scheme in Victoria. Haque found a statistically significant increase in the time between committing a second and third speeding offence, compared to between the first and second speeding offence. The results indicated that road users were modifying their behaviour as the threat of more severe penalties increased.

### Licence Suspension

Licence suspensions are typically given to repeat speed offenders and those drivers who commit more serious speeding violations (Zaal, 1994). In New Zealand, licence suspension occurs for drivers who receive 100 demerit points within two years or who are apprehended for exceeding the speed limit by more than 50 kph. Drivers who exceed the speed limit by more than 50 kph receive an immediate suspension of their licence for a 28-day period. If the driver attempts to drive during these 28 days and is detected by the police, his or her vehicle is impounded.

Licence suspension has three main advantages (Zaal, 1994). First, it deprives drivers of the ability to drive lawfully. Second, it deters drivers who commit serious speeding offences, or who regularly speed, from speeding. Third, since drivers who have received a licence suspension are not permitted to drive, it reduces the number of high-risk drivers in the traffic stream. Several studies have found, however, that some suspended drivers do drive during their period of licence suspension (Duncan et al, 1990, cited in Zaal, 1994).

Evidence that licence suspension deters speeding was provided by Berland et al (1989, cited in Zaal, 1994). They compared the speeding offence records of drivers who had in the past received a period of licence disqualification compared to a control group who had received a fixed fine. The researchers reported that the licence disqualification group had 38% fewer subsequent speeding offences than the control group. A follow-up survey found that 65% of the drivers who had been disqualified had modified their speeding behaviour in some way as a result of the licence disqualification, compared to only 24% of the control group.

### Comparison of Speeding Penalties with Drink-Driving Penalties

In Part A, we reported Kloeden et al's (1997) study. The study demonstrated that the risk of involvement in a casualty crash when travelling at 70 kph in a 60-kph speed-limit zone in Adelaide was similar to that for a blood alcohol concentration (BAC) of 80 mg/100 ml (the legal limit in New Zealand). Kloeden et al reported that, despite the similarity in risk, the penalties for these two offences in South Australia are very different. For example, a driver without previous drink-driving convictions who is caught driving with a BAC between 80 and 149 mg/100 ml receives a A$500 to A$900 fine and has their licence suspended for six or more months. By contrast, a driver travelling at between 61 and 74 kph in a 60-kph zone receives a fine of A$110.

In New Zealand, there are even larger differences between the base penalties for speeding and drink-driving (see Table C2). A driver apprehended with an excess blood or breath alcohol level will appear in court. If convicted, the maximum penalty is a three-month prison sentence or a $4,500 fine, and mandatory licence disqualification for at least six months (except in special circumstances). A third or

subsequent excess blood or breath alcohol conviction results in a maximum penalty of a six-month prison sentence or a $6,000 fine, and mandatory licence disqualification for at least one year (except in special circumstances).

Despite the similar relative risk of crashing, and injuring or killing themselves or someone else, the driver travelling at 70 kph in a 60-kph zone will receive a roadside ticket, or a ticket will be sent to the owner of the vehicle through the Police Infringement Bureau. The fine for exceeding the speed limit by up to 10 kph[45] is $30 (see Table C1). A speeding driver apprehended by the police will receive 10 demerit points, and needs to accumulate 100 demerit points before the driver's licence is suspended for three months. A speeding driver apprehended through use of a speed camera does not receive any demerit points.

## Conclusions

- Legal sanctions such as fines, demerit points and licence suspension increase the effectiveness of enforcement by their presence, when they are sufficiently large.
- There is, however, a disparity in the severity of the punishment for speeding and for drink-driving, when the risks of crash involvement are similar.

| | Base Offence | Relative Risk for Offence* | Penalty |
|---|---|---|---|
| Drink-driving | Exceeding 80 mg/100 ml blood alcohol concentration (if 20 years or older) | 3.2# | • maximum 3 months prison or $4,500 fine (maximum 6 months prison or $6,000 fine for third or subsequent offence) and<br>• 6 months licence disqualification (12 months for third or subsequent offence), except in special circumstances |
| Speeding | Travelling 70 kph in a 60-kph zone (speed limit exceeded by not more than 10 kph) | 4.2 | • fine of $30 and<br>• 10 demerit points (unless a speed camera offence)<br>• 100 demerit points in 2 years results in a 3-month licence suspension |

**Table C2 – Comparison of penalties for similar drink-driving and speeding offences in New Zealand, for a similar relative risk of involvement in a casualty crash**

Sources: LTSA (1999b), Kloeden et al (1997).
Notes: *Relative risk of BAC is compared to zero; for speeds, it is relative to travelling 60 kph in a 60-kph zone (from Kloeden et al, 1997). #Relative risk is for all drivers, not separated by age.

45 The fine for exceeding the speed limit by 10 kph is the same regardless of the speed-limit zone. For example, despite the different crash and injury risk, a driver travelling at 110 kph in a 100-kph zone will receive the same fine as a driver travelling 60 kph in a 50-kph zone.

# Part D

## Time, Fuel, Environment

The previous Parts of this review have discussed the "costs" of excessive vehicle speed in terms of the resultant increase in crash risk and injury severity. In this Part, other costs of vehicle speed will be discussed, such as increased fuel use and the effect on the environment. A perceived benefit of increased vehicle speed – decreased travel time – will also be discussed.

By deliberately looking beyond the central safety issue, it is recognised that the speed at which we drive on our roads is linked directly with other factors, wider costs, and benefits. Particularly in the area of travel time, the discussion soon reduces to the trade-off between using motor vehicles to increase our mobility and our interaction with the world, and restricting that mobility in order to manage the associated risks[46].

If we see our possible responses to this trade-off as positions along a continuum, at one end is the suggestion that we reduce the speeds of motor vehicles to a walking pace, or even slower – however, this would entirely defeat the useful purpose of the available technology. At the other end of the continuum is the proposition that we remove all design and human restrictions on speed and let motor vehicles travel as fast as they can and their drivers wish. From our current position on that continuum, one of the questions to consider is the extent to which we are prepared to restrict mobility and speed in order to reduce the toll of injury and death from excess and inappropriate speed. A discussion of travel time is important in this context.

There are also wider benefits and costs in environmental terms associated with the speed at which we drive. Fuel consumption, particularly in terms of the dollar cost associated with high speeds, and vehicle emissions are distinct issues on their own. Together with travel time, these issues provide a perspective on speed as a general road transport issue, not just an issue to do with our safety on the road.

## 1: Travel Time

The time available to travel a specified distance often influences a driver's choice of speed. It is usually assumed that the faster the speed, the less time the journey takes. However, this is not always true; for example, the increased crash risk at high speeds increases the probability that the journey will not be completed. Also, in urban environments, where the motorist must frequently stop or slow down for controls at intersections (traffic lights, stop and give-way signs, roundabouts, etc), for pedestrians, and for other disruptions, a faster speed may not necessarily lead to a shorter journey. In general, though, in rural environments, where travel speed can be more constant, the travel speed does affect travel time.

As discussed in Part A, the National Maximum Speed Limit (NMSL) was introduced in the USA in 1974 for all highways (rural roads) and was set at 55 mph at that time. The TRB (1984) compared data gathered (in 1982) after this change came into effect with data from 1973, before the NMSL existed (when states set their own speed limits, which tended to be higher than 55 mph). The TRB calculated the extra time spent travelling on highways in 1982 compared to the time taken for the same travel given pre-1974 speed limits. They found that motorists spent 1 billion extra hours travelling the same distance under the 1982 mean speed than the 1973 mean speed.

The majority of the increased travel time calculated by the TRB (1984) was by passengers in personal vehicles[47]. Since most personal travel trips are short, the increased travel time for each trip was small, but, when the data from across the entire USA were added together, these small increases in travel time led to a large overall increase. There is, however, a great deal of debate about whether it is appropriate or meaningful to add such small increments in time (Ward, Robertson, and Allsop, 1998). For example, adding the travel time increases of 3,600 different road users, where each road user's travel time increase is one second, gives one hour of extra travel time overall. A problem with the approach, then,

46 Restricting mobility is only one way of reducing crashes. An alternative is to maintain mobility and reduce an individual's risk of crashing.

47 It is very difficult to determine the cost of "private" travel.

is whether one second is a significant or meaningful increase in travel time for each individual road user. An individual's tasks or activities will generally not be affected by travel time increases – or decreases – of this magnitude. For example, the shopping time of a road user travelling to town to shop will not be noticeably reduced by an additional few seconds of travel. Or, if a road user's travel time was decreased by a few seconds, this would not usually allow him or her to complete a task he or she would not normally have done, such as mowing the lawns. Since small increments in travel time are relatively insignificant, in some countries in Europe these small increases in travel time are disregarded when calculating a nationwide travel time increase (Ward et al, 1998). That is, travel time increases below a certain threshold are disregarded in determining the increased travel time due to lower speeds.

Speed limit changes affect travel times through changes in mean speed. However, travel time is more dependent on congestion and roadway geometry than on speed limits. In the USA, the 55-mph NMSL had a greater travel time effect on roads with low congestion and good geometry, such as rural interstate highways, than on more congested roads, such as rural collectors. Similarly, congestion played a larger part than the speed limit change on travel time for commuter drivers in peak-hour traffic (TRB, 1994).

In general, the main road user group who had their travel time affected by the 55-mph speed limit change were passenger vehicles, although their short trip distances meant the effect was not large (TRB, 1994). In comparison, commercial truckers, who have long trip distances, did have their travel time adversely affected. However, the lower speed limit also had major benefits for commercial truckers, such as lower fuel and maintenance costs.

Overall, the effect of reduced speed limits in the USA had some effect on motorists' travel time. However, the relationship between speed limits and travel time is not straightforward. For example, travel speed is dependent on road type and congestion. Furthermore, the road user is generally only affected by a small increase in travel time (see Table D1), particularly since the majority of trips are short. For example, the New Zealand Household Travel Survey, conducted between July 1989 and July 1990, found that only 7.7% of trips made in light four-wheeled vehicles were over 20 kilometres in length (Ministry of Transport, 1990). Similarly, a study in Germany found that 80% of journeys are shorter than 10 kilometres (Kloas, 1993, cited in Robertson and Ward, 1998). Furthermore, even when the trip distance is relatively large, the travel time savings from increased speed are small. For example, a driver travelling consistently at 120 kph for 100 kilometres compared to another driver travelling at 100 kph for 100 kilometres would save only 10 minutes[48]. In reality, it is very difficult in New Zealand to travel consistently at 100 kph or higher for 100 kilometres, given road type and other traffic; therefore the actual difference between these two hypothetical drivers is likely to be even smaller.

| Original Speed (kph) | 50 | 70 | 90 | 110 | 130 |
|---|---|---|---|---|---|
| Reduced Speed (kph) | 45 | 65 | 85 | 105 | 125 |
| Extra Travel Time (minutes:seconds) | 1:20 | 0:40 | 0:23 | 0:16 | 0:11 |

**Table D1 – Extra travel time on a journey of 10 km when average speed is reduced by 5 kph**

Source: Adapted from ETSC (1995).

The example given above of saving 10 minutes travel time by travelling at 120 kph instead of 100 kph over a 100-kilometre journey raises the philosophical question of whether mobility should be traded for safety. For example, is the increased risk of crashing acceptable in the interests of saving 10 minutes travelling time? Or, in an urban environment, is the increased risk of killing a pedestrian acceptable in the interests of saving time?

In areas of transport outside the road environment, the transport user never considers mobility more important than safety. For example, in air travel the safety of the aircraft before it leaves the ground is given top priority – the time spent waiting on the ground for safety reasons is fully accepted by passengers. In contrast, in the road transport system, health losses from crashes *"are major, but to some extent acceptable,*

48 A driver travelling at 120 kph for 100 kilometres would take 0.83 of an hour (100 km divided by 120 kph), or 50 minutes, to complete the journey. In comparison, a driver travelling at 100 kph would take one hour (100 km divided by 100 kph).

*consequences of mobility"* (Tingvall, 1999, p1). Sweden has recently taken the important step of not tolerating such a philosophy in road transport. In October 1997, the Swedish parliament developed their "Vision Zero" strategy, which envisions moving to a transport system that is designed so that fatalities, and injuries where the victim does not recover, do not occur. "*This means that safety is more important… than other issues in the road transport system (except for health related environmental issues)*" (Tingvall, 1999, p4) and that mobility must always come second to road safety.

One means offered for implementing Vision Zero is to lower speed limits so that they do not exceed the capacity of the human body to survive a crash (see Part A). For example, speed limits on undivided lanes outside built-up areas could be reduced to 70 kph (Tingvall, 1999). Another possible means of implementing the strategy is to reconstruct road environments (for example, by dividing roads or adding effective roadside barriers) so that severe crashes do not occur, but still allow travel speeds between 90 and 110 kph.

In spite of whether increased travel time is perceived as an advantage or disadvantage, the European Transport Safety Council (ETSC, 1995) summarises the effects of speed on travel time by stating that the overall costs – such as increased crash risk and injury severity, as well as fuel and environment costs (discussed below) – of an increase in speed above appropriate levels clearly outweigh any advantage of decreases in journey times.

### Conclusions

- As vehicle speed increases, travel time tends to decrease somewhat, although this also increases crash and injury risks.
- Trips in passenger vehicles are less affected by increased travel time because they tend to be short trips, and the total increase in travel time tends not to be substantial.
- Long haul freight operators are more affected by increased travel time, but lower speeds also provide fuel and maintenance savings for operators.
- Reducing the travel speed of a 10-kilometre trip from 90 to 85 kph increases travel time by only 23 seconds.

## 2: Fuel Use and Other Vehicle Operating Costs

The relationship between fuel use and vehicle speed has been well known for some time. For example, in response to the oil crisis of the early 1970s, New Zealand imposed an open-road speed limit of 50 mph (80 kph) in December 1973 as a fuel-saving measure. Similarly, in 1974, the USA imposed the 55-mph (89-kph) NMSL to conserve oil.

Several studies have been conducted to estimate the reduction in fuel consumption after a reduction in vehicle speed. For example, the European Conference of Ministers of Transport (ECMT, 1996) reported that the results of several German studies have estimated that, *"for a car fleet of the type found in Germany, a reduction of x percent in average driving speeds on rural road networks can reduce fuel consumption by 0.8 [times] x percent"* (p17).

In France, it has been estimated that, if the speed limits were strictly complied with, there would be a saving of 350,000 tonnes (1.4%) of oil out of the 25 million tonnes consumed annually by car drivers (ECMT, 1996). In the Netherlands, when speeds on motorways with a 100-kph speed limit were heavily enforced so that mean speeds fell from 111 to 104 kph, there was a saving of 40 million litres of petrol and 40 million litres of LPG (ECMT, 1996).

A study in the USA calculated the effect on fuel use when steady driving speeds increased from 55 mph (89 kph) to 70 mph (113 kph). The result was a 17% increase in fuel consumption (ECMT, 1996). In New Zealand in 1996, it was estimated that an increase in speed limits from 100 to 110 kph would increase fuel consumption by around 10% (Waring, 1996).

The reason for the changes in fuel consumption at different vehicle speeds is due to variation in the fuel efficiency of the vehicle. Recently, West et al (1997, cited in TRB, 1998) examined the relationship between fuel efficiency and driving speed of a small sample of 1988 to 1995 model automobiles

and light duty trucks[49]. Figure D1 below shows the results. Fuel efficiency was shown to peak at about 55 mph (89 kph). The drop in fuel efficiency after 55 mph is due primarily to the effect of aerodynamic drag (that is, the engine has to work harder to account for this). The low fuel efficiency at low speeds occurs because of engine friction, tyres, and accessories (such as power steering)[50] (TRB, 1995, cited in TRB, 1998).

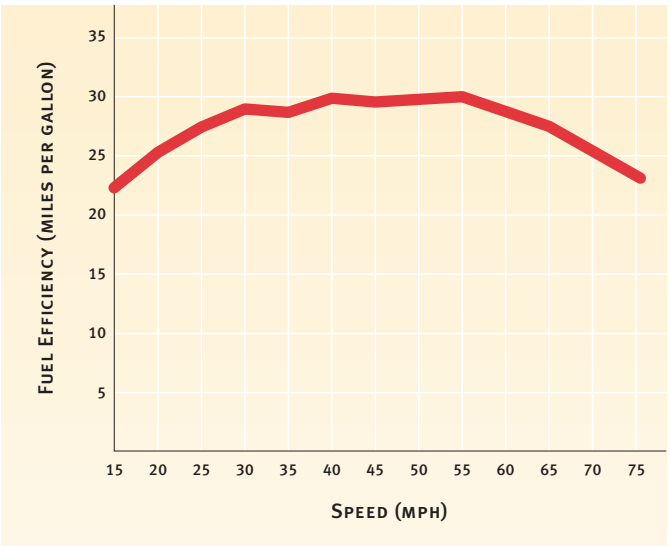



**Figure D1 – Fuel efficiency as a function of speed – model year 1988-1995, automobiles and light-duty trucks**

Source: Davis (1997, p3-51, cited in TRB, 1998, p69).
Note: 1 mph = 1.609 kph; 1 gal = 3.8 L.

For heavy duty diesel trucks, fuel efficiency tends to decline sharply at speeds above 50 mph (80 kph) (TRB, 1995, cited in TRB, 1998). The decline is largely due to aerodynamic drag. Fuel efficiency also tends to be poorer for sport utility vehicles, mini-vans, and pick-up trucks (TRB, 1998). Aside from fuel efficiency, tyre wear tends to increase with increasing speed (TRB, 1998). However, the cost is minor compared to the increased fuel cost with increased speed.

Overall, the relationship between increased vehicle speed and increased fuel use is well known. As the mean speed on the open road decreases, fuel efficiency also improves. The following section looks at the effect on the environment of decreasing fuel consumption.

## Conclusions

- At high vehicle speeds, fuel use increases due to poorer fuel efficiency of the vehicle.
- Fuel efficiency has been estimated to peak at 89 kph for cars and light trucks and at 80 kph for heavy diesel trucks.

49 The vehicles were examined under steady-state cruise type driving conditions. (Note that it is very difficult to measure fuel efficiency.)

50 Energy is required to overcome air resistance, tyre rolling resistance, and the power taken to drive such accessories as the cooling fan, the alternator, the fuel and oil pumps, etc. The energy required does not increase linearly with speed, but as some power of the speed. These energy losses require the expenditure of fuel other than in just moving the vehicle, and thus cause fuel efficiency to be low at low speeds and also to reduce as speed increases above a certain level (55 mph in Figure D1).

# 3: Environment

*"A clear link exists between high vehicle speeds and the volume of gaseous emissions from vehicles"* (ECMT, 1996, p17). The major pollutants from vehicles are carbon monoxide (CO), hydrocarbons (HC), oxides of nitrogen ($NO_x$)[51], and particulates[52] (Ward et al, 1998). These pollutants are produced in different quantities at different speeds.

Several models have been developed to describe the interaction between different emissions at different speeds. Figure D2 gives an example application of the model VETO, which demonstrates *"how the estimated levels of emissions vary with speed for a stream of vehicles (85% cars, 10% heavy lorries [that is, trucks], and 5% medium lorries) at steady speeds between 30 and 90 kph on flat roads"* (Hammarström and Karlsson, 1987, cited in Ward et al, 1998, p4). Figure D2 indicates that fuel use and emissions of both CO and $NO_x$ are minimised at 40 kph, whereas particulate emissions are minimised at 50 kph and HC emissions at approximately 70 kph. As speed increases above 50 kph, the level of emissions of CO, $NO_x$, and particulates increases.

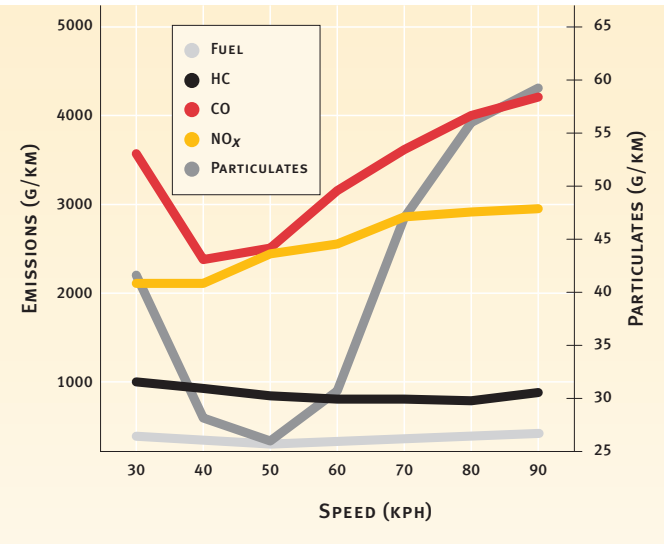



**Figure D2 – Gaseous emissions as a function of speed**

Source: Ward et al (1998, p5).
Notes: Data based on 2,000 vehicles per day, of which 15% are trucks and 80% use catalysts. "g/km" = grams per kilometre.

Emissions also vary under different conditions. Emissions increase greatly when the engine is cold (Ward et al, 1998), and emissions such as CO and Volatile Organic Compounds (VOCs) are very high in heavily congested stop-and-go traffic (TRB, 1995, cited in TRB, 1998). Another finding is that harsh acceleration increases vehicle emissions sharply. For example, De Vlieger (1997, cited in Ward et al, 1998) compared the emissions of seven cars in Belgium under "calm", "normal", and "aggressive" driving conditions[53] and found emissions were generally higher during aggressive driving than normal driving.

The substances such as CO and $NO_x$ degrade air quality. Another substance emitted from motor vehicles, which is not toxic but does have other adverse effects, is carbon dioxide ($CO_2$). $CO_2$ is a gas that traps heat in the upper atmosphere, thus warming the earth; this global warming, principally as a result of $CO_2$ emissions, is known as the Greenhouse Effect. $CO_2$ is produced in proportion to fuel consumption. Unfortunately, motor vehicles are the largest source of $CO_2$ emissions in New Zealand and the USA, and these emissions are highest at high speeds as a result of the poorer fuel efficiency at high speeds[54]. The TRB (1997, cited in TRB, 1998) claimed that, *"in 1994, motor vehicles accounted for about one-quarter of all US $CO_2$ emissions. The United States, in turn, is the largest emitter of $CO_2$, accounting for one-quarter of global emissions"* (p71). In New Zealand in 1997, domestic transport accounted for 40.3% of the 28 million tonnes of $CO_2$ produced (Ministry of Commerce, 1998).

A small number of studies have examined the relationship between changes in speed limits or mean speeds, and vehicle emissions. When the speed limit was lowered from 130 to 100 kph in Austria, there was a 17% reduction in $NO_x$ emissions and a 25% reduction in $CO_2$ emissions (ECMT, 1996). Similarly, when the mean speeds on motorways in the Netherlands decreased from 111 to 104 kph, $CO_2$ emissions decreased by 34% and $NO_x$ emissions by five percent.

Gaseous emissions are controlled by vehicle catalysts. Vehicle catalysts are substances that promote (speed up) chemical changes in exhaust gases without being changed in any way themselves[55]. Unfortunately, the catalysts are generally only tested in urban environments; hence their effectiveness at high speeds is unknown. Furthermore, the

51 CO is a poisonous gas, HC causes photochemical smog, and $NO_x$ causes acid rain.

52 Particulates are substances emerging from the exhaust that are solids, not gases. From diesel engines, they are largely particles of carbon resulting from incomplete combustion of the fuel. From petrol engines, they are carbon particles and also metals and metal compounds resulting from combustion of fuel and lubricating oil. The dangerous particles are those less than two microns in size, though sub-10-micron particles are also considered undesirable. The danger to health comes from (a) the carcinogens trapped on their surfaces, particularly from diesel fuel combustion, and (b) the inability of the lungs to clear sub-two-micron particles from deep in the lungs, so that carcinogenic chemicals remain in contact with the tissues for long periods of time.

53 "Calm driving" was anticipating movements of other drivers. "Normal driving" had moderate acceleration and braking. "Aggressive driving" was sudden acceleration and heavy braking.

catalysts are not effective when the vehicle is cold[56]. Since the majority of trips in New Zealand are short, the catalyst is unlikely to be effective because the vehicle remains cold for the duration of the journey.

Another environmental effect of speed is noise. Traffic noise is produced by two main sources: the power unit of vehicles and the interaction between vehicle tyres and the road (Ward et al, 1998). Figure D3 demonstrates the general relationship between vehicle speed and the noise from these two main sources. As shown in Figure D3, the noise from the tyre-road interaction increases with increasing speed, whereas the power unit noise remains reasonably constant across speeds. In new cars, the noise from the tyre-road interaction dominates the noise from the power unit of the vehicle above the speed range 20 to 40 kph. For new trucks, this occurs between 30 and 60 kph, whereas for older vehicles the tyre-road noise dominates at about 10 kph higher, due to the higher power unit noise (Ward et al, 1998). Overall, though, vehicle noise increases with increasing speed.

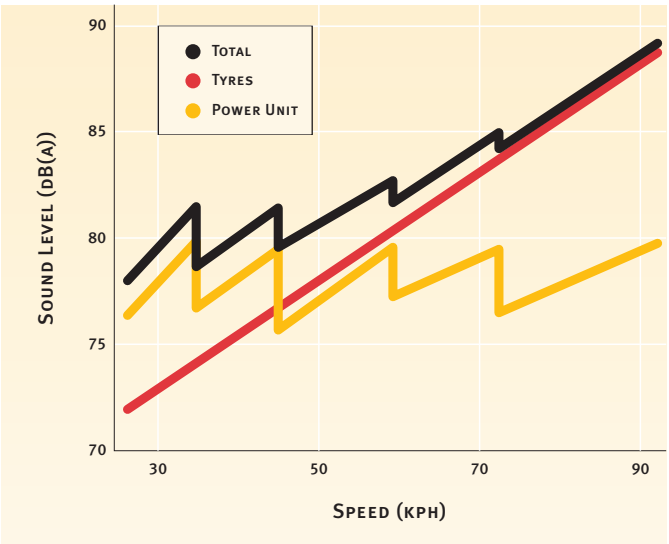



**Figure D3 – Effect of speed on noise produced by a vehicle**

Source: Ward et al (1998, p7).
Note: "dB(A)" stands for A-weighted decibel, which is the normal measurement of human response to traffic noise.

The relationship between noise and speed limits was examined on a German autobahn when the speed limit was reduced from 100 to 80 kph. The noise level for those living near the autobahn reduced by 3.9 dB (decibels) following the speed limit change (ECMT, 1996, p17).

## Conclusions

- As speed increases above 50 kph, the level of emissions of CO, $NO_X$, and particulates increases.
- At low speeds in congested traffic, gaseous emissions such as VOCs and CO are high.
- At high speeds, emissions of $CO_2$ are high, which contributes to the Greenhouse Effect. Motor vehicles are the largest source of $CO_2$ emissions in New Zealand.
- Reducing the mean speed of vehicles reduces the level of gaseous emissions.
- Vehicle noise increases with increasing speed due to noise from the tyre-road interaction.

54 Carbon dioxide emissions are linearly proportional to the fuel used – about 3.7 kilograms of carbon dioxide is produced for every kilogram of fuel used. As explained in footnote 50, more fuel is used to cover a given distance at high speed than at low speed, primarily due to increased wind resistance, but also because of increased tyre rolling resistance and unnecessary extra power used by accessories.

55 What is needed is rapid oxidation of unburned hydrocarbons and carbon monoxide, to carbon dioxide and water, and rapid reduction of oxides of nitrogen to nitrogen and oxygen. Typically, the only catalysts that meet the requirements are mixtures of rare (and costly) metals (such as platinum, palladium, rhodium, and so on). Platinum is the best, usually, because it starts working at a lower temperature than the others. The metal is distributed (as thinly as possible) on a ceramic substrate, which provides the largest possible surface in contact with the exhaust gas.

56 Generally, catalysts only start to work at upwards of 250 degrees Celsius. The average New Zealand car trip is not long enough to heat the catalyst up so that it starts to work. Hence, putting catalysts on every car will not solve our pollution problems until pre-heated catalysts are available.

# Part E

## New Zealand and the Speeding Problem

Speeding lies at the core of the road safety problem throughout the motorised world. This is because, as we have seen, excess and inappropriate vehicle speed increases the risk of crashes, and increases the severity of injuries resulting from crashes, regardless of whether speed was a contributing factor in the crash. These risks are not peculiar to New Zealand, and so, to better understand these risks, and the measures available to reduce them, the analysis so far has been undertaken from a predominantly international perspective.

The speeding problem in New Zealand has some unique aspects. Our geography, our weather, our roadside environment, our spread of population – all are factors in our roading network that make our speeding problem unique to New Zealand. In a more fundamental sense, however, the speed problem in New Zealand is anything but unique, because of the consistent way in which speed impacts on safety. New Zealand conditions compound the problem, but they are not the problem in themselves. We do not have interstates or autobahns as they do in the USA and Germany, and we do not have a large proportion of flat, straight roads as they do in Australia. The first section of Part E looks at features of our roading environment and associated crash statistics.

We need to better adapt to our roading environment by reducing our speed. If we do not reduce travel speed generally in New Zealand, the injury and death toll will remain the same and will even increase with a growing population, growing motor vehicle registrations, and growing traffic volumes.

This Part of this review also examines current New Zealand data related to speeding. As we have seen, speeding both increases the chances of being involved in a crash and increases the chances of being injured or killed in a crash. However, the effect of excess or inappropriate speed on crashes cannot always be "captured", because speed may not be identified as the main cause of the crash. For example, if a motorist is faced with an oncoming vehicle on the wrong side of the road, his or her travel speed may make the difference between avoiding the vehicle and crashing, between suffering severe injuries and not being injured at all, or between suffering a fatality and living to tell the tale. What we can capture is how New Zealanders perceive speeding as a safety issue.

As a community, there is a slow dawning of understanding emerging about the effects of speeding. However, twice as many New Zealanders still believe they can drive safely while speeding, as believe they can drive safely after drinking alcohol. We can and must do more to change New Zealanders' attitudes towards speed and reduce the impact of vehicle speed on our lives.

# 1: The Impact of New Zealand Conditions on Vehicle Speed

In New Zealand, there are about 92,000 kilometres of road, over 2.3 million vehicles, and over two million licensed drivers. A breakdown of the network by road type is shown in Table E1. Vehicle ownership levels are second only to the USA. With a wide spread of metropolitan and provincial cities, there are high volumes of inter-regional traffic north of Taupo and north of Wellington. Some major two-lane, two-way roads in Auckland, the Waikato, and the Bay of Plenty frequently approach or exceed capacity, and this over-capacity relative to the state of the roading network is contributing to the road toll, with little likelihood of major relief in the immediate future. Achievement of improved road safety performance will require a major capital works programme to improve road design by increasing the length of divided highways and improving the overall standard of other roads. However, even if such a programme started tomorrow, it would take some years before the changes had a major impact on the road toll. In the meantime, it is necessary to look at additional ways of improving the safety of the roading infrastructure, such as applying black spot treatments and using any of the other road and traffic design features listed in Part B. Most importantly, New Zealand drivers must drive safely by avoiding speeds that are excessive or inappropriate for the road conditions. This section looks at New Zealand's different road conditions and their relationships with crash rates.

### Road Type

The New Zealand roading system is made up of six major road types (see Table E1). The motorways and divided state highways are based around the major cities, particularly Auckland. The other open roads – mostly two-lane, two-way roads – are spread throughout the country. The risk of head-on crashes is increased on roads such as these, because drivers may cross the centre line on a road (for example, by swinging wide on a bend) and crash into an oncoming vehicle. The severity of the crash is dependent on the speeds of the vehicles involved. In 1998, approximately 27% of fatal crashes on rural roads involved head-on collisions (see Figure E1).

| Road Type | Length (in kilometres)* | Approximate Percentage of Total Road Length |
|---|---|---|
| Motorway | 335 | 0.3 |
| Divided state highway | 61 | 0.1 |
| Other state highway | 10,005 | 10.1 |
| Other open road | 73,271 | 73.9 |
| Major urban | 5,519 | 5.6 |
| Minor urban | 10,019 | 10.1 |

**Table E1 – Length of New Zealand roads by road type**

Source: LTSA Crash Analysis System.
Note: *The lengths of road are calculated from vectors in the Crash Analysis System. On dual carriageways, there are parallel vectors, hence the length on both sides of the road is counted. This approach means the total of the lengths of road given above is slightly higher than the actual total of 92,000 km of road in New Zealand.

In addition to increasing the risk of head-on crashes caused by a driver inadvertently crossing the centre line, two-lane, two-way roads also increase the risk of overtaking crashes, in which a driver has deliberately crossed the centre line. On these two-lane, two-way roads, drivers are often slowed by vehicles travelling in front of them at a slower speed. When this occurs, the driver who wants to travel faster than the vehicle in front may attempt to overtake that vehicle by crossing into the lane used by the oncoming traffic. Because of the nature of our roading system, therefore, a high number of overtaking manoeuvres are undertaken on New Zealand roads. In general, overtaking vehicles have to travel at high speeds during the manoeuvre, and this fact increases both the risk of a crash and the crash severity. In 1998, in approximately six percent of the fatal crashes and two percent of the injury crashes, the driver action of overtaking was identified as a factor contributing to the crash[57] (see Figure E2).

57 For these statistics, the driver action of overtaking includes changing lanes on multiple lane roads as well as overtaking on two-way, two-lane roads.

The overtaking and head-on crash rate could be reduced significantly if New Zealand could afford to upgrade main roads that are not already divided to four lanes (two lanes each way), with the addition of a median divider. Also, the provision of suitable passing opportunities is a significant countermeasure in reducing overtaking crashes. Transit New Zealand has a policy for passing lanes that is currently being examined by two research projects, which indicates the importance placed on this area. Another approach to reducing overtaking crashes is to reduce the number of drivers travelling at excess speed. That is, if these drivers travel at a lower speed, their need to overtake other vehicles would be reduced.

Urban environments consist of major roads, such as arterials, and minor roads, such as residential streets. Some arterial routes travel through residential areas, which contain a large number of access points, such as driveways. Because of this, on some arterial roads there is a high risk of crashes involving children running onto the road or vehicles entering or exiting the road via a driveway. From 1996 to 1998, for example, there was an average of 10 fatal crashes and 460 injury crashes per year involving a vehicle entering or exiting a driveway in an urban area (including pedestrian casualties).

Evidence that the number of access points affects the crash rate was demonstrated by Jackett (1992). He conducted an analysis of urban crashes in the areas between intersections, known as "mid-blocks", and found that the crash rate per vehicle-kilometre travelled was higher for residential/industrial mid-blocks, which contain a high number of access points, than for mid-blocks with no development. Access to all main roads should, therefore, be limited as much as possible to reduce the number of potential conflict points.

### Basic Statistics on Road Crashes

The following are some basic statistics on road crashes produced annually by the Land Transport Safety Authority (LTSA, 1999c). These statistics give an indication of the types of crashes that occur in New Zealand each year.

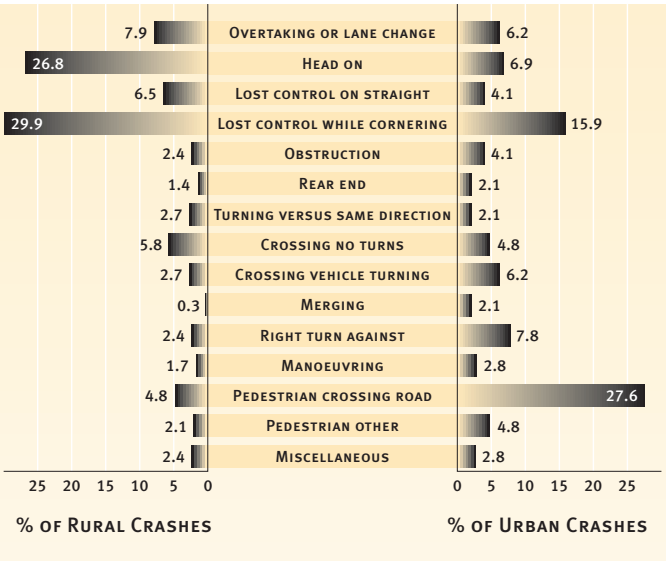



**Figure E1 – Movement classification of fatal crashes in 1998**

Source: Generated from LTSA (1999c, Tables 16 & 17, p41).
Notes: "Urban" refers to all speed limit areas of 70 kph and under, and to limited speed zones; "Rural" refers to all speed limit areas of over 70 kph.

Figure E1 demonstrates that, in 1998, fatal crashes on rural roads were most likely to involve loss of control while cornering (29.9%) and were almost as likely to involve a head-on collision (26.8%). Loss of control while cornering typically occurs when the driver is travelling too fast for the conditions or is a drink-driver[58]; the same is also often true for the (usually) inadvertent crossing of the centre line that leads to head-on collisions. In urban environments in 1998, fatal crashes were most likely to involve a pedestrian crossing the road (27.6%). This demonstrates that pedestrians are vulnerable even to the lower speeds in urban environments. A smaller but sizeable proportion (15.9%) of the fatal crashes in urban areas involved loss of control while cornering.

Figure E2 shows the factors identified as probably contributing to crashes in 1998, separated according to whether the crash was fatal or involved injury (but no fatality). The figure demonstrates that travelling too fast for the conditions was the factor contributing to the largest proportion of fatal crashes (32%) and was a major contributor to injury crashes (17%).

58 Part of the reason drink-drivers are over-represented in this type of crash is because they make inappropriate decisions about travelling speed.

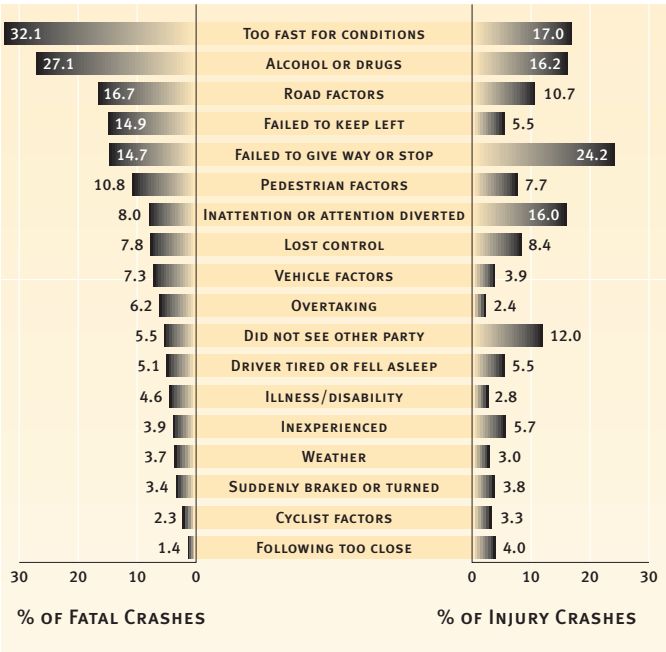



**Figure E2 – Factors probably contributing to crashes in 1998**

Source: LTSA (1999c, p49).

### Design Speed

The design speed of a road is the maximum speed for which the road is designed. It is based on such factors as curvature and sight distance. In New Zealand, a significant proportion of the rural roading network was constructed under a 50-mph/80-kph open-road speed-limit regime. Improvements to some parts of the network have been made since it was constructed, to bring the design speed up to 100 kph. Similar road networks in other developed countries often have speed limits of 80 or 90 kph. Thus, rural roads in New Zealand tend to have much lower design speeds than the speeds at which modern vehicles are capable of travelling and do indeed travel. Unfortunately, with the increased in-vehicle comfort even when travelling at high speeds, there is the temptation for road users to travel at high speeds on roads that appear appropriate for high speeds, when, in fact, such speeds are not appropriate.

The safe travel speed in urban areas generally has as much to do with roadside development and access as with road design.

### Roadside Environment

Compared with Australia, for example, New Zealand's rural roadsides are much less forgiving. For instance, there are often ditches[59] on the side of our rural roads, many of which are not easily visible from the road, despite their proximity. A vehicle leaving the road at high speeds would almost certainly enter the ditch, most likely still at close to full speed, causing a serious crash with severe injuries to the vehicle's occupants. In 1998, for instance, 15% of the injury crashes in which an object was struck on rural roads involved a vehicle running into a ditch (see Figure E3).

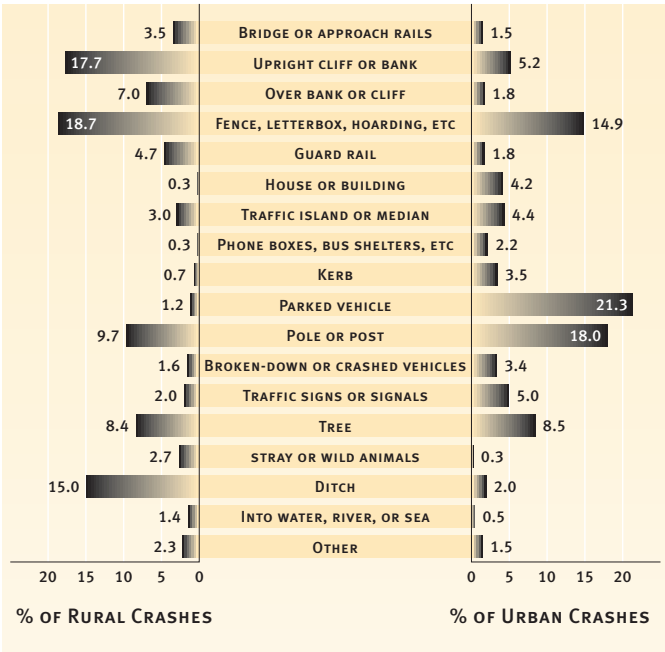



**Figure E3 – Objects collided with in injury crashes on rural and urban roads in 1998**

Source: Generated from LTSA (1999c, Table 22, p45).
Notes: A crash will appear more than once in this figure if the vehicle(s) involved struck more than one object. The percentages given are as a proportion of only those crashes in which an object (other than a moving vehicle) was struck. "Urban" refers to all speed limit areas of 70 kph and under, and to limited speed zones; "Rural" refers to all speed limit areas of over 70 kph. Fatal crashes are not included in this figure.

Figure E3 demonstrates that, in injury crashes where an object was struck, the following are among those struck most frequently: upright cliffs or banks, fences or letterboxes, poles or posts, and trees[60]. All of these objects are common on New Zealand's roadside, and, as with ditches, the higher the speed at which the object is struck, the more severe the crash consequences. The incidence of striking these objects could be reduced with the addition of "audible edge lines", which let drivers know immediately that they are leaving the road and, hence, allow earlier responses. Also, the road shoulders could be widened to allow more room for vehicles that travel off the carriageway to recover. Another modification that would reduce crashes is the use of hard shoulders rather than gravel, as this would give drivers better control when

59 Usually water races.

60 In fatal crashes in which an object was struck, the most frequently struck objects were the same as for injury crashes.

they leave the road. In 1997 and 1998, there were, on average, 12 fatal crashes and 124 injury crashes per year in which a driver lost control when returning to seal from an unsealed shoulder (LTSA, 1999c).

Of the objects struck in urban environments, parked vehicles are also commonly struck. For example, in 1998, there were nine fatal and 410 injury crashes in which a parked vehicle was struck.

### Rural Roading Environment

Rural roads in New Zealand frequently pass through farming areas, such as sheep and dairy farms. This can be a problem if an animal escapes onto the roadway, particularly at night. Crashes with wandering stock tend to be rare, but, when they do occur, there is high potential for death or serious injury. For example, from 1996 to 1998, there were, on average, three fatal crashes and 58 injury crashes per year in which it was identified that a farm animal probably contributed to the crash[61]. High speeds exacerbate this risk, because the driver has less time to react when encountering an animal on the road, the stopping distance will be greater, and the severity of the collision with the animal increases with higher speeds.

### Road Geometry

Road geometry includes the horizontal curvature (bends and curves) and vertical curvature (hills and raised sections) of a road. New Zealand roads often pass through mountainous terrain, and these mountain roads tend to be very narrow and windy with steep gradients. The problems associated with these road geometry features are compounded by poor weather conditions, such as rain and ice. To overcome these problems, the entire roading network needs appropriate skid resistance, and the design of the roads needs to be carefully considered to ensure that the curvature and width of the road are appropriate to the geometry of the terrain, typical weather patterns, and traffic volume.

### Emergency Services

The population of New Zealand is small and, particularly in rural areas, is spread over a large area. Because of this, the nearest town may be some distance away from a crash site and the time taken for emergency services to attend can sometimes be large. In serious crashes, this increases the chance that crash victims will die from their injuries before the emergency services arrive or that their injuries will worsen to the extent that they will be seriously affected for the rest of their lives. As McVey, Atkin, and Vulcan (1988) stated, "*some injuries are time critical and, although they may be the minority of cases, outcome does relate to the time interval between injury and the commencement of appropriate definitive treatment*" (p51). Brain injuries and injuries involving severe blood loss are examples of injuries for which the time between injury and initial treatment is important. Thus, the response and transportation times for emergency services can be very important in determining the long-term outcome for crash victims.

## Conclusions

- Apart from very small lengths of motorway and divided highway, New Zealand's rural road network comprises two-way, two-lane roads, often passing through mountainous country. The risk of head-on crashes on these roads is increased; the severity of these crashes is dependent upon the speed of the vehicles involved.
- The most common types of fatal crashes in New Zealand are those in which a driver has lost control, a situation that is usually associated with excess or inappropriate speed. Overtaking crashes are also associated with excess and inappropriate speed. The most common urban crash involves a pedestrian crossing the road.
- New Zealand's rural roading environment is quite unforgiving, with cliffs, fences or letterboxes, posts, trees, and ditches the most frequently struck objects. Parked vehicles are also commonly struck in urban environments.

61 These statistics refer only to farm animals, not household pets, wild, or other animals. When looking at all animals, in 1996 to 1998 there were, on average, six fatal and 72 injury crashes per year that were identified as probably caused by animals. These animals may not necessarily have been struck in the crash, but were identified as having caused the crash.

# 2: Data Analysis

### Crash Data

The numbers of deaths and reported injuries from road crashes within New Zealand have, generally, declined fairly steadily in recent years (see Table E2). Despite the decline, the numbers of deaths and injuries on New Zealand roads – and the associated social cost[62] of these – are very high. In 1998, the social cost of fatal and reported injury crashes was approximately $2.77 billion (costed at 1999 prices).

Excess or inappropriate speed is a major contributing factor in road crashes (see Table E2). For example, in 1998, it probably contributed to 32% of fatal crashes and 20% of injury crashes. However, it is often difficult to determine if speed was a factor in a crash – it is rare for a driver to admit he or she was speeding. This means that the identification of speed as a factor in a crash often depends on physical and/or witness evidence, and this may be inconclusive or unavailable. In general, speed is identified as a contributing factor in a crash if:

- either the police officer attending the crash reports that the driver was travelling at excess or inappropriate speed, and the Land Transport Safety Authority, whose staff code crash reports, agree with the officer and code the report with the factor "travelling too fast for the conditions";
- or the Land Transport Safety Authority staff who code crash reports determine from the evidence in the crash report, and based on their experience, that speed probably contributed to the crash.

Overall, it is assumed that speed is under-reported in data on crash factors because of the difficulty identifying it. That is, it is assumed that there are a substantial number of crashes in which excess or inappropriate speed was a contributing factor but which could not be identified as speed-

| | 1995 | 1996 | 1997 | 1998 |
|---|---|---|---|---|
| **Deaths** | | | | |
| Total road deaths | 582 | 515 | 539 | 502 |
| Deaths from crashes where speed was a factor | 221 | 177 | 162 | 162 |
| Percentage of total road deaths where speed was a factor | 38.0 | 34.4 | 30.1 | 32.2 |
| **Serious Injuries** | | | | |
| Total reported serious injuries | 3,153 | 2,939 | 2,613 | 2,400 |
| Reported serious injuries where speed was a factor | 670 | 645 | 608 | 539 |
| Percentage of total reported serious injuries where speed was a factor | 21.2 | 21.9 | 23.3 | 22.5 |
| **Minor Injuries** | | | | |
| Total reported minor injuries | 13,717 | 11,857 | 10,764 | 10,012 |
| Reported minor injuries where speed was a factor | 2,318 | 2,161 | 1,917 | 1,896 |
| Percentage of total reported minor injuries where speed was a factor | 16.9 | 18.2 | 17.8 | 18.9 |

**Table E2 – Casualties from all road crashes and where excess or inappropriate speed was identified as a contributing factor, 1995-1998**

Source: LTSA Crash Analysis System.

62 "Social cost" includes all loss of life and life quality, medical treatment, related enforcement, and property damage. The cost of loss of life and life quality is the amount people are willing to pay to avoid the risk of death or injury from motor vehicle crashes.

related crashes. Furthermore, it is expected that there are a substantial number of crashes that are not coded as involving excess or inappropriate speed, but for which the injuries sustained in the crash would have been considerably less had the vehicle(s) involved been travelling at a lower speed.

Despite the limitations of the speed data, Table E2 demonstrates that, over the years 1995 to 1998, the number of injuries from crashes in which excess or inappropriate speed was identified as a contributing factor has declined slightly. However, the number is still very high and represents a significant proportion of the road toll.

The majority of deaths from crashes involving excess or inappropriate speed occur on rural roads. For example, 68% of the deaths from crashes involving speed in 1998 occurred on rural roads (see Table E3), whereas the minor injuries from crashes involving excess or inappropriate speed were approximately equally likely to occur on urban or rural roads. A similar proportion of rural to urban casualties occurs for crashes in which speed was not identified as a contributing factor. The higher speeds on rural roads are part of the reason there are more people killed on these roads. As we discussed in Part A of this review, this is because the higher the speed of a vehicle involved in a crash, the greater the injury severity for the vehicle occupants.

| | Rural | Urban | % Rural |
|---|---|---|---|
| **Crashes without Speed as a Factor** | | | |
| Deaths | 240 | 100 | 71 |
| Reported serious injuries | 958 | 903 | 52 |
| Reported minor injuries | 3,128 | 4,988 | 39 |
| **Crashes with Speed as a Factor** | | | |
| Deaths | 110 | 52 | 68 |
| Reported serious injuries | 326 | 213 | 60 |
| Reported minor injuries | 991 | 905 | 52 |

**Table E3 – Casualties from rural and urban crashes with and without excess or inappropriate speed identified as a contributing factor, 1998**

Source: LTSA Crash Analysis System.
Notes: "Urban" refers to all speed limit areas of 70 kph and under, and to limited speed zones; "Rural" refers to all speed limit areas of over 70 kph. The data refer to the number of casualties, not the number of crashes.

The proportion of all road deaths that occur outside urban areas (that is, in rural areas) in New Zealand is particularly high internationally. For example, 73% of the road crash deaths in New Zealand in 1997 occurred outside urban areas (Figure E4). Only in Norway, Spain, Austria, and Germany did a higher proportion (up to 80%) of deaths from road crashes occur outside urban areas in 1997. By comparison, in Japan, Poland, and Iceland, only just over 50% of road fatalities occurred outside urban areas.

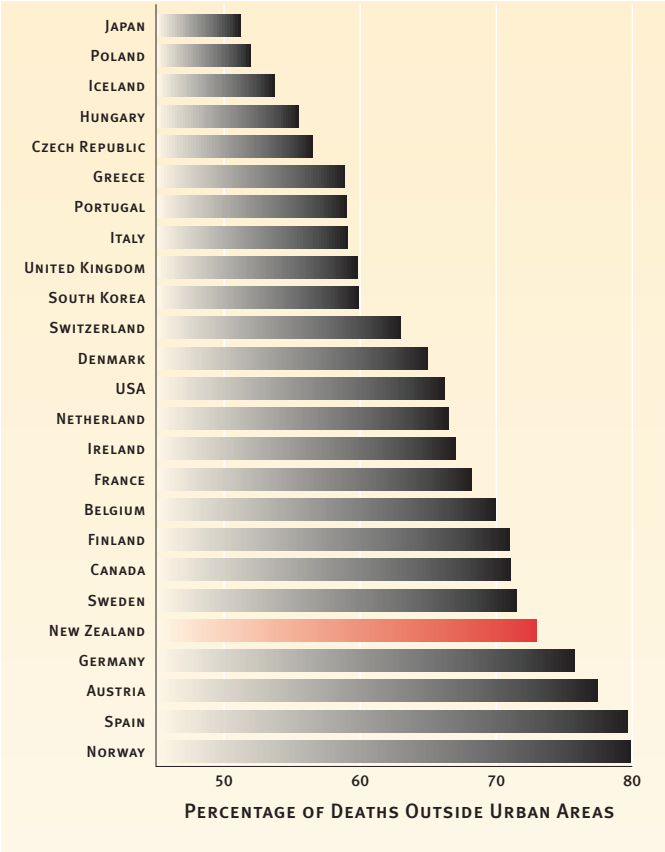



**Figure E4 – International comparison of percentage of road deaths that occur outside urban areas**

Source: LTSA (1999c, Table 7, p157).

It is important to note that in urban environments there are high numbers of vulnerable road users, such as pedestrians. Therefore, despite the lower speed in urban environments, these vulnerable road users have a high likelihood of being killed if hit by a vehicle. From 1996 to 1998, there were 132 pedestrians killed in crashes with a motor vehicle in urban areas. Of these 132 pedestrians, 13 were killed in crashes in which excessive speed was identified as a contributing factor (Table E4).

| Road User Killed | Rural | Urban | Total |
|---|---|---|---|
| Speeding driver* | 165 | 52 | 217 |
| Passenger with speeding driver* | 111 | 48 | 159 |
| Speeding motorcycle rider | 32 | 25 | 57 |
| Pillion with speeding motorcycle rider | 4 | 5 | 9 |
| Pedestrian | 3 | 13 | 16 |
| Other road users | 32 | 10 | 42 |
| Total | 347 | 153 | 500 |

**Table E4 – Type of road user killed in crashes where excess or inappropriate speed was identified as a contributing factor, 1996-1998**

Source: LTSA Crash Analysis System.
Notes: *Excludes motorcycle riders/pillions. "Urban" refers to all speed limit areas of 70 kph and under, and to limited speed zones; "Rural" refers to all speed limit areas of over 70 kph.

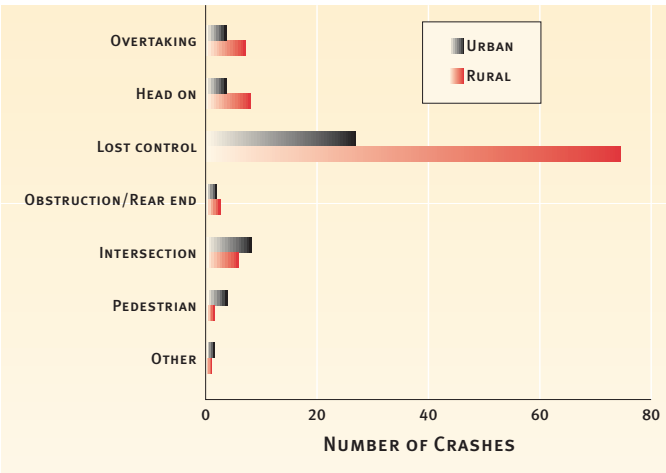



**Figure E5 – Types of fatal crashes with excess or inappropriate speed identified as a contributing factor (annual average 1996-1998)**

Source: LTSA Crash Analysis System.
Notes: "Urban" refers to all speed limit areas of 70 kph and under, and to limited speed zones; "Rural" refers to all speed limit areas of over 70 kph.

In crashes in which excess or inappropriate speed was identified as contributing to the crash, the speeding driver and his or her passengers are the road users most likely to be killed (Table E4). Speeding motorcycle riders also represent a high number of those killed in crashes in which excessive speed was identified as contributing to a crash.

In fatal and injury crashes involving excessive speed, by far the most common type of crash is one in which the driver lost control of the vehicle (see Figures E5 and E6). The data shown in Figures E5 and E6 include both single-vehicle and multi-vehicle crashes. Single-vehicle crashes are those in which the driver lost control of the vehicle either on a straight or when cornering and collided with an object (or pedestrian) in the roadside environment; multi-vehicle crashes are those in which the driver lost control and crashed into another vehicle. The majority of crashes are, however, single-vehicle crashes. For example, of the fatal rural crashes in which excessive speed was a contributing factor and the driver lost control of the vehicle, 72% were single-vehicle crashes. Similarly, 76% of the fatal urban lost-control crashes involving excessive speed were single-vehicle crashes.

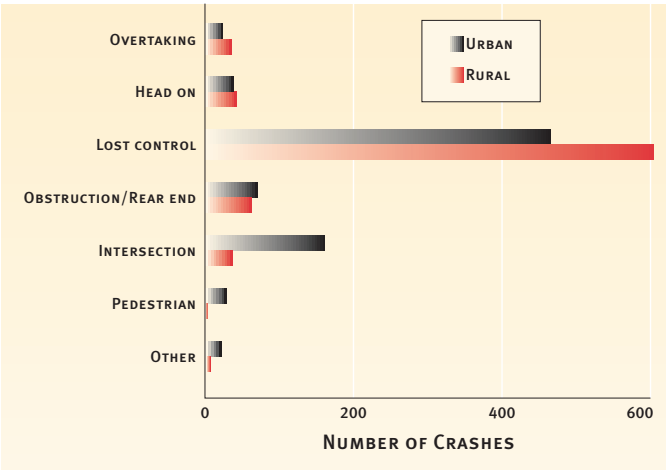



**Figure E6 – Types of injury crashes with excess or inappropriate speed identified as a contributing factor (annual average 1996-1998)**

Source: LTSA Crash Analysis System.
Notes: "Urban" refers to all speed limit areas of 70 kph and under, and to limited speed zones; "Rural" refers to all speed limit areas of over 70 kph.

The 15- to 24-year-old age group has the greatest number of drivers identified as travelling at excess or inappropriate speeds in fatal crashes (see Figure E7). Of the 15- to 24-year-old drivers involved in fatal crashes between 1996 and 1998, 35% were identified as travelling at excess or inappropriate speeds, compared to 17% for 25- to

64-year-old drivers. Hence, speed is disproportionally represented in crashes involving a young driver. Across all age groups, male drivers involved in fatal crashes are also more likely to have been travelling too fast for the conditions than are female drivers. For example, 77% of the drivers involved in fatal crashes from 1996 to 1998 were males, and 85% of the drivers in fatal crashes involving excessive speed were males.

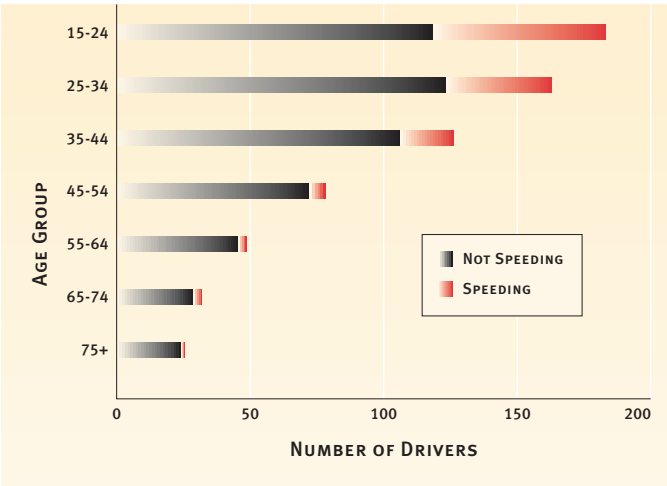



**Figure E7 – Drivers identified as travelling at excess or inappropriate speeds in fatal crashes by age group (annual average 1996-1998)**

Source: LTSA Crash Analysis System.

From 1996 to 1998, 21% of car and van drivers and 39% of motorcyclists involved in fatal crashes were identified as travelling at excess or inappropriate speeds (see Figure E8). Only eight percent of truck drivers involved in fatal crashes were identified as travelling at excess or inappropriate speeds.

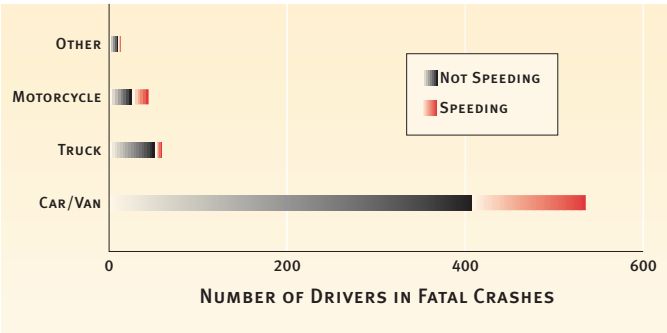



**Figure E8 – Drivers involved in fatal crashes by vehicle type and by whether excess or inappropriate speed was identified as a contributing factor (annual average 1996-1998)**

Source: LTSA Crash Analysis System.

Of the car or van and truck drivers identified as travelling at excess or inappropriate speeds in fatal crashes from 1996 to 1998, just over half (58% and 60% respectively) were killed in the crash. However, of the motorcycle riders identified as travelling at excess or inappropriate speeds in fatal crashes, the vast majority (89%) were killed in the crash. This illustrates the greater vulnerability of motorcyclists over other vehicle occupants.

### Travel Speed Data

The Land Transport Safety Authority conducts surveys of driver speeds at a sample of sites around New Zealand each year during winter. The survey involves unobtrusive roadside measurements of vehicle speeds over a period of about two hours. The speeds measured are for cars travelling at "free" speeds, unimpeded by other vehicles or by the road environment (the sites at which vehicle speeds are measured are on straight sections of road, away from traffic lights and intersections).

Table E5 displays the national results of the speed surveys since 1995. At the national level, rural mean speeds remained relatively constant from 1995 to 1999, with the exception of a decrease in speed in 1997 (the increase in mean speed from 1997 to 1998 was statistically significant at the five-percent level). In contrast, national urban mean speeds appear to have fallen each year since 1995 (although the differences from one year to the next are not necessarily statistically significant).

| Speed | 1995 | 1996 | 1997 | 1998 | 1999 |
|---|---|---|---|---|---|
| Rural, mean | 102.4 | 102.3 | 101.6 | 102.2 | 102.1 |
| Rural, 85th percentile | 115 | 115 | 113 | 113 | 113 |
| Urban, mean | 57.4 | 56.5 | 56.3 | 55.9 | 55.8 |
| Urban, 85th percentile | 65.5 | 63.5 | 63.0 | 63.0 | 62.5 |

**Table E5 – Speed data from the annual national winter speed surveys, 1995-1999**

Source: LTSA Crash Analysis System.
Notes: The speed at the 85th percentile is the speed at or below which 85% of the vehicles travelled; that is, 15% of vehicles travelled above this speed. "Urban" refers to 50-kph speed-limit zones. "Rural" refers to 100-kph speed-limit zones.

Overall, from 1995 to 1999, mean speeds in both rural and urban environments at the national level were above the speed limit. The mean speed in the urban areas was further

above the limit than the mean speed in the rural areas. Furthermore, the speeds at the top end of the speed distribution (above the 85th percentile) were very high, particularly in rural areas. This is a concern because, as discussed in the first section of this Part, the open road in New Zealand was designed for speeds of approximately 80 kph, with some sections of road upgraded to a 100-kph design speed. A large proportion of drivers are therefore travelling at speeds above the speed for which the road was designed to be safely travelled on. This means that drivers travelling above the design speed who encounter objects on the road in the distance will have less chance of stopping under emergency braking and avoiding a collision with the object. Also, by travelling above the design speed, there is a high chance of losing control of the vehicle on curves. As seen above, the loss of control scenario represented a large proportion of the crashes in which excessive speed was a contributing factor.

The high mean speed in urban areas is also of concern because of the presence of vulnerable road users. For example, a pedestrian hit by a vehicle at the 1999 mean speed of 55.8 kph would have over an 80% chance of being killed (see Figure A15, in Part A). Furthermore, the chance of a pedestrian being killed if hit by the fastest 15% of urban traffic before their brakes are applied is close to 100%.

It is estimated that, if the rural mean speed could be reduced by 4 kph, from 102 to 98 kph, there would be fewer people killed and injured on New Zealand's rural roads each year. Nilsson's formulae from Section 1a of Part A can be used to calculate the size of the reduction in deaths and injuries from reducing the rural mean speed. Although the formulae apply to crash reductions, they can be generalised to injury reductions because the ratio of casualties to crashes remains approximately constant.

Table E6 displays the injury savings when the mean speed is reduced from 102 to 98 kph. For example, in 1998 350 people were killed on New Zealand's rural roads. Applying Nilsson's formula, we can see that the number of people killed if the mean speed was reduced from 102 to 98 kph would be 298. Hence 52 people's lives would have been saved if the mean speed was reduced by 4 kph. Similarly applying Nilsson's formula, the 4-kph mean speed reduction would save 185 people from being fatally or seriously injured, and would save 442 people from being injured in a crash.

| Injury Type | Number of Injuries in 1998 (rural roads) | Nilsson's Formulae: Number of Injuries if Mean Speed Reduced from 102 to 98 kph | Number of Injuries Saved |
|---|---|---|---|
| Fatal | 350 | $(98/102)^4 \times 350 = 298$ | 52 |
| Fatal and Serious | 1,634 | $(98/102)^3 \times 1{,}634 = 1{,}449$ | 185 |
| All Injuries | 5,753 | $(98/102)^2 \times 5{,}753 = 5{,}311$ | 442 |

**Table E6 – Injury savings on rural roads in 1998 given a reduction in the mean speed from 102 to 98 kph**

Source: LTSA Crash Analysis System.

### Attitude Data

The New Zealand Public Attitudes Survey has been undertaken periodically since 1974, and annually since 1994, to evaluate attitudes to road safety issues, primarily alcohol-impaired driving and speed. Face-to-face interviews about these issues are conducted in May and June of each year with respondents aged 15 and over, in towns, cities, and rural areas throughout New Zealand. In 1999, 1,645 people were interviewed, including 1,417 who held drivers' licences (LTSA, 1999a).

New Zealanders' awareness of speed as a road safety issue in 1999 has dropped slightly since 1998, returning to 1997 levels. When asked what factors make travelling on New Zealand roads unsafe, just over half spontaneously mentioned speeding (see Figure E9). One fifth (21%) identified speed as the **main** factor that made New Zealand roads unsafe.

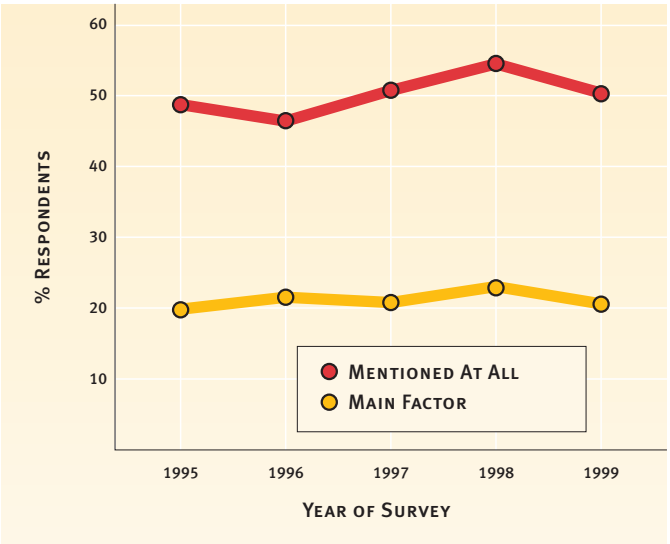



**Figure E9 – Things that make travelling on NZ roads unsafe: speed**

Source: LTSA (1999a).

Despite this recognition of speed as a major road safety issue, the speeding culture is still strong. For example, 44% of male drivers and 32% of female drivers say that they enjoy driving fast on the open road. This attitude is particularly strong among drivers under 35 years (see Figure E10). For example, 56% of 25- to 29-year-olds say that they enjoy driving fast on the open road.

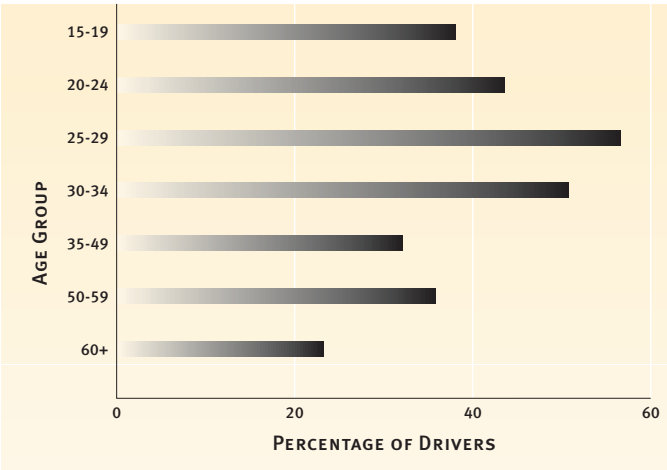



**Figure E10 – Percentage of drivers in each age group that said they enjoy driving fast on the open road.**

Source: LTSA (1999a).

The perceived risk of a crash when speeding is not understood as well as the perceived risk of a crash when drink-driving (see Figure E11). For example, 22% of male drivers and 14% of female drivers agree that "there isn't much chance of an accident when speeding if you are careful". In comparison, 10% of male drivers and six percent of female drivers agree that "there isn't much chance of an accident when driving after drinking if you are careful". Drivers in the 50-plus age group are more likely to agree with the statement "there isn't much chance of an accident when speeding if you are careful" than younger drivers. For example, 26% of drivers in the 60-plus age group agreed with the statement, compared to 13% of 20- to 24-year-old drivers.

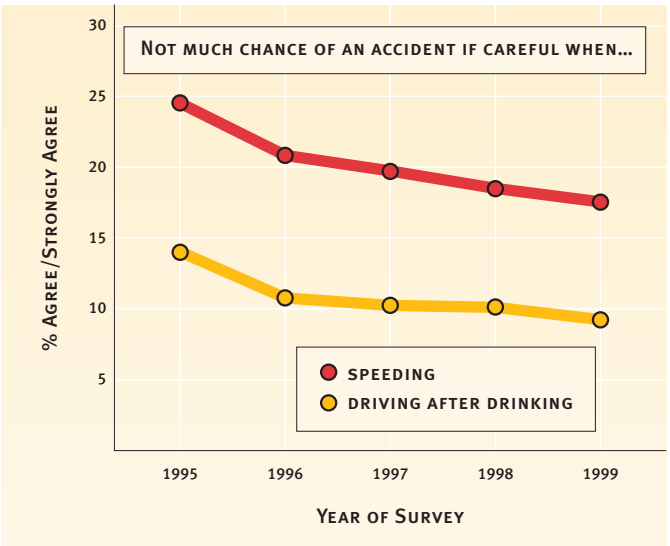



**Figure E11 – Percentage of New Zealanders who agreed or strongly agreed with the statements "There is not much chance of an accident if you're careful when speeding" or "when driving after drinking"**

Source: LTSA (1999a).

The findings relating to speed enforcement were generally positive. They were:

- Three-quarters of New Zealand adults agree that **enforcing the speed limit** helps to reduce the road toll. However, 41% think that the risk of being caught speeding is small.
- Fewer New Zealanders now believe that **penalties for speeding** are not very severe. In 1997, 38% of people agreed with this statement, but by 1999 this had reduced to 32%.
- Sixteen percent of drivers (18% of males and 13% of females) reported receiving a **speeding ticket** in the previous year. Drivers under the age of 35 years were most likely to report receiving a speeding ticket (see Figure E12). For example, 23% of 15- to 19-year-old drivers reported receiving a speeding ticket in the previous year.

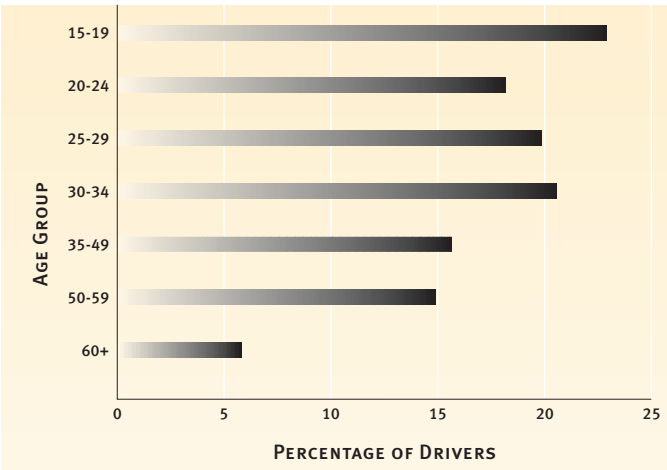



**Figure E12 – Percentage of drivers in each age group that reported receiving a speeding ticket in the previous year**

Source: LTSA (1999a).

- Most people find **extremely high speeds** unacceptable. Eighty-five percent supported automatic loss of licence for drivers caught speeding at 150 kph on the open road and 88% supported this for drivers caught at 90 kph in a 50-kph zone.
- Support for **retaining speed limits** at current levels was high (71% for open roads and 77% for 50-kph zones). There was less support than in previous years for introducing additional 60-kph and 80-kph speed limits for some roads (52% support in 1999, compared to 58% in 1998 and 64% in 1995). These speed limits have been introduced in some areas over the last four years.
- Support for **speed cameras** has reduced slightly since 1998, back to 1997 levels. Sixty percent of New Zealanders agree that the use of speed cameras helps lower the road toll and 63% think that they are operated fairly (compared to 68% and 70% respectively in 1998). Opinion is fairly evenly divided over whether speed cameras should be hidden or in full view, with many people supporting a mixture of the two modes.
- More people think that they would be likely to **receive a ticket** from a speed camera than from a police officer (see Figure E13). For instance, when driving at 120 kph in a 100-kph zone, 83% would expect to receive a ticket from a speed camera[63], but only 59% (an increase from 50% last year) would expect a ticket from a police officer who was present. The higher perceived risk of detection for speed cameras over police officers was discussed in Part C.

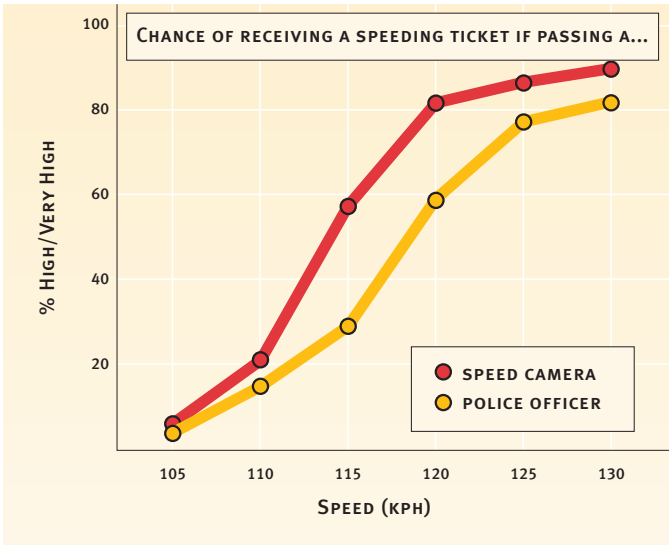



**Figure E13 – Percentage of New Zealanders who felt that the chance of receiving a speeding ticket if passing a speed camera or a police officer was high or very high**

Source: LTSA (1999a).
Note: The question relating to the speed camera implied that the speed camera was operational at the time.

63 The question about receiving a ticket if passing a speed camera implied that the speed camera was operational at the time.

## Conclusions

- Speeding contributed to 162 deaths, 539 serious injuries, and 1,896 minor injuries in 1998. Speeding is likely to be under-reported in data on crash factors because of the difficulty in identifying it.
- The majority of speed-related crashes in which someone dies occur on rural roads, whereas minor injury crashes involving speed are almost equally likely to occur on urban or rural roads.
- The 15- to 24-year-old age group has the greatest proportion of drivers identified as travelling too fast for the conditions in fatal crashes.
- From 1996 to 1998, 21% of car and van drivers and 39% of motorcyclists involved in fatal crashes were identified as travelling too fast for the conditions.
- From 1995 to 1999, national surveys have indicated that mean speeds in both rural and urban environments are above the speed limit.
- Attitudinal surveys indicate that:
  - one-quarter of respondents identified speeding as the main factor that made New Zealand's roads unsafe.
  - 44% of male drivers and 32% of female drivers say that they enjoy driving fast on the open road.
  - 16% of drivers reported receiving a speeding ticket in the previous year.

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