MONASH University
Accident Research Centre

THE IMPACT OF LOWERED SPEED LIMITS IN URBAN AND METROPOLITAN AREAS

TRANSPORT ACCIDENT COMMISSION

THE IMPACT OF LOWERED SPEED LIMITS IN URBAN AND METROPOLITAN AREAS

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THE IMPACT OF LOWERED SPEED LIMITS IN URBAN/METROPOLITAN AREAS

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Abstract:
The majority of all traffic accidents occur in the urban environment, where there is a more complex traffic environment and a higher predominance of road users that are more susceptible to injury and fatality in the event of an accident. A relatively straightforward and cost-effective speed management measure, involves reducing speed limits. The relationship between vehicle speed, accident risk and accident outcome severity is well established in traffic safety literature. Research shows that reduced speed is likely to bring about a reduction in average travel speed and have a positive impact on both the number of accidents and accident outcome severity. Other secondary benefits are also derived including: reduced fuel and vehicle operating costs, and significant reductions in vehicle emissions and noise. A key issue surrounding the effects of lowering speed limits in urban and metropolitan areas concerns the impact on mobility and the environment. A hypothesis that is investigated in this literature review is that a reduction in average travel speed brought about by reducing urban speed limits, is only likely to have a marginal impact on travel time. Research tends to support this notion given that average speeds are influenced by many other factors including driver attitudes and preferences; roadway design; forms of traffic regulation at intersections; and prevailing traffic conditions (levels of congestion; weather; etc). Research studies in Australia in relation to the then proposed reduction of the default urban speed limit from 60 to 50 km/h, indicated only minimal impact on individual travel times and large benefits to society as a result of the reduction in crash trauma. Findings following the introduction of the default urban speed limit indicate the overall success of this measure and high level of community support. Recent research suggests that there are still large benefits to be gained by introducing an "*across the board*" reduction of speed limits to 50 km/h on all types of urban and metropolitan roads that presently have a 60 km/h speed limit. National traffic safety philosophies such as the Swedish '*Vision Zero*' recognise the importance of restricting speed to appropriate levels to ensure that there are no serious or fatal injuries. Safety and energy efficiency must be prioritised in order to achieve sustainability in the transport system. As a first step in this direction, the default urban speed limit on residential streets in Stockholm, Sweden has been reduced to 30 km/h. Other European towns are now following this example, and a growing interest can be noticed in Australia for similar speed limits to be introduced in order to meet the designated targets of the national Safe System approach and State and Territorial road safety strategies and actions plans.

Key Words:
Road safety, mobility, urban speed limits, and travel (journey) times.

Disclaimer

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Preface

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Introduction

The increasing and sometimes conflicting goals of the transport system such as overall performance and efficiency, mobility, safety and environmental sustainability, have become increasingly difficult to achieve without major investments in the road infrastructure. New and affordable ways of reducing levels of road trauma that have a minimal impact on mobility are keenly sought by the Australian Government, federal and state road authorities and by society at large. This particular literature study addresses a number of the issues surrounding a lowering of speed limits in urban areas; a relatively low-cost measure that is believed to have a positive impact on safety but also a negative impact of some magnitude on mobility.

This literature review focused specifically on speed limit reduction and the impact this has on mobility and general traffic system performance. In particular, more information was sought on the relationship between speed and travel time. The search included national and international literature in areas related to engineering, psychology and traffic safety.

The Speed-Accident Relationship

The relationship between vehicle speed and accident outcome severity is well established. A major study conducted by the OECD and the ECMT in 2006 concluded that speeding is the number one road safety problem in most countries around the world, and that reductions in average speeds of approximately 5 per cent would yield a reduction in fatalities by as much as 20 per cent (OECD/ECMT, 2006). Research also indicates that even modest speed reductions can prevent the occurrence of collisions and significantly reduce the outcomes of those crashes that do occur; particularly those that involve vulnerable road-users who are more predominant in the urban environment (e.g. Kloeden, et al., 1997; 2001; Elvik et al., 2004; Nilsson, 2004).

In addition to safety, there are other potential benefits to be gained by speed limit reductions in urban areas. Those suggested in the literature include an increase in traffic flow and consequent reduction in congestion and delays, particularly where the roads are functioning at near capacity. Further, reductions in speed bring about a reduction in vehicle operating costs with less wear and greater energy (fuel) efficiency, and less pollution and noise (see e.g. Carlsson, 1997; Kallberg and Toivanen, 1998; Cameron, 2000; Elvik and Vaa, 2004).

Speed Management

While the most elementary method of managing travel speed is by imposing speed limits. In order to be effective speed limits must be compatible with the design speed of the road. Research has shown that the design speed tends to have a greater effect on a driver's choice of speed than the actual speed limit (Varhelyi, 1996). On the basis of studies in many different countries, Elvik and Vaa (2004) suggest that speed limits are most often set in accordance with three main principles: adapting the speed limit to actual speed levels; varying the speed limit to the standard and design of the road; and, choosing a speed limit that minimises the total costs to society (e.g. accident costs, travel time costs, vehicle operating costs, road maintenance costs, and environmental costs). In practice, a combination of these principles is used.

Generally, a driver expects a good level of mobility in the traffic system such that it takes as little time as possible to get from A to B, but also a reasonable level of safety. It has been suggested that some drivers may sacrifice their own personal safety (and therefore also the safety of others) by adopting higher travel speeds in order to achieve shorter journey times. In the decisions regarding a suitable travel speed, drivers weigh-up factors including road geometry, the amount of traffic, accident rates, car performance, levels of enforcement and own driving skills (Elvik and

Vaa, 2004). However, posted speed limits are perhaps the most significant factor in determining a driver's choice of speed. Research suggests that younger and inexperienced drivers tend to overestimate their own skills and underestimate potential hazards. It is a fair assumption that if posted speed signs did not exist, many drivers would adopt unsuitably high speeds. Speed enforcement is probably the most common mediator between speed limit and speed choice. There is ample evidence that drivers respond to perceived enforcement by adjusting their behaviour, most notably by reducing their speed (see e.g. Shinar and McKnight, 1985; cited in TRB, 1998).

Another approach to speed control is through road design. Traffic safety strategies aimed at reducing speeds in the urban environment have often been based on a combination of different physical measures such as speed-humps, chicanes, raised intersections and rumble strips, etc. While there is a great deal of research suggesting the success of such traffic calming measures, many of the measures are not suitable for urban arterial streets, particularly where these serve commuter and commercial traffic and carry emergency vehicles (see e.g. Fildes and Lee, 1993; Elvik and Vaa, 2004). A further problem is related to the migration of traffic to less suited neighbouring streets.

Operational measures can also be effectively used to slow traffic. In some neighbourhoods, multi-way stop or yield signs, traffic signals, turn prohibitions, and one-way streets can be used effectively to manage speed. Because such measures require driver compliance, some operational measures are less effective than other physical measures in reducing driving speeds. Taylor (2000) suggests that if traffic-signalling systems are correctly timed and coordinated with posted speed limits, they can be a highly effective means for controlling travel speeds, particularly on urban collector and arterial roads. This has also been suggested by other researchers (see e.g. Fildes and Lee, 1993; Elvik and Vaa, 2004). New infrastructure based technologies such as variable message signs are often used to inform drivers of adverse road and/or weather conditions, or other factors that require an increase in awareness and a reduction in speed. Variable speed limits are also used to offer drivers guidance on appropriate maximum (or minimum) speed limits based on real-time monitoring of prevailing traffic and roadway conditions using dynamic information displays (Parker and Tsuchiyama, 1985).

A more direct means of reducing speed is through the introduction of speed limiting or intelligent speed adaptation (ISA) devices within the vehicle. Speed limiters are often used to control the maximum speed of heavy vehicles (on open roads) and are common in Australia and most European countries. ISA devices have the ability to warn drivers or physically limit the speed of a vehicle in accordance with speed limits on all classes of roads. Many studies have been conducted to examine the effectiveness and acceptability of ISA systems (Carsten, Tate and Liu, 2006). In Australia, ISA has been trialled as one of several Intelligent Transportation Systems (ITS) believed to enhance safety in the TAC SafeCar project (Regan et al., 2006).

Driver attitudes also have an important role in relation to speed compliance. The Australian Transport and Safety Bureau's (ATSB) report on community attitudes to road safety for 2004 showed that there is a general and increasing awareness of the dangers of driving at increased speeds, with 96 per cent of respondents agreeing that a crash at 70 km/h will be more severe than one at 60 km/h, (Pennay, 2005). Additionally, 73 per cent of respondents agreed that if speed was increased by 10 km/h they would be more likely to be involved in a crash, (55% in 1995, and 70 per cent in 2003). Furthermore, 83 per cent of respondents believed that speed limits were generally set at reasonable levels.

Somewhat inconsistent with these more positive views regarding speed and speeding, was the proportion of respondents who believed that it was acceptable to speed provided that one drives safely. This item on the questionnaire remained constant at approximately 32 per cent.

The Relationship between Travel Time, Speed Limits, Speeding Behaviour and Safety

A general and often misleading assumption made by drivers is that increasing their speed will, to a similar degree, reduce overall travel time. In the urban environment, drivers must frequently stop or slow down for different forms of regulatory control at intersections (traffic signals, stop signs or yield signs), pedestrian crossings, rail crossings and reduced speed areas near schools and shopping zones. Speeds are also affected by congestion where preceding vehicles prevent the adoption of a discretionary free-flow speed. Factors such as these cause large amounts of variance in individual speed profiles even during off-peak periods.

TRB (1998) reports that travel time may be more dependent on congestion and roadway design and geometric factors, than on the posted speed limits. During times of congestion, posted speed limits are often believed to have little effect on driving speed, except during the build-up of queues and their later dispersion. It can therefore be argued, that reducing a speed limit by 5 or 10 km/h during peak hours when the level of congestion is high is unlikely to result in any significant safety benefit. Hypothetically at least, reduced speed limits should have their greatest safety impact under medium congestion levels, where traffic is periodically able to travel at or near the speed limit. At such levels, a lower speed limit may actually *reduce* overall travel time by allowing a more harmonic traffic rhythm, this is particularly the case on urban arterials and urban motorways where there is likely to be less lane-changing friction, less speed dispersion, and greater headways that result in less shock-waves and fewer accidents (see e.g. Noland and Quddus, 2005).

The insight that travel speed is dependent on factors such as road type, levels of congestion, and driver's personal speed preferences, suggests that the relationship between speed limits and travel time is far more complex than most drivers are willing to admit. Given that average trip distances in metropolitan areas are relatively small (see e.g. Robertson and Ward, 1998), it is interesting to see how much additional time is needed for a 10 kilometre journey when the average speed is reduced by 5 km/h, only 16 seconds with a reduction of 110 to 105 km/h and 80 seconds with a reduction of 50 to 45 km/h. This data suggests that the impact of a 5 km/h reduction are greater at lower speeds. Nevertheless, these time impacts are negligible.

Other research has also shown that maintaining short headways, changing lanes and other aggressive behaviours such as accelerating hard from traffic lights and other stops are often exhibited by drivers in the belief that they will reduce their journey time (RACV, 1990). The differences in travel time between aggressive and non-aggressive drivers in motorway conditions were also compared in a recent experiment conducted by the University of Queensland, (Panwai and Dia, 2006). In this study, aggressive drivers were found to reduce travel time by as little as one minute for a 44 km journey. In addition, the fuel consumption and CO_2 emissions from aggressive driver's vehicles as much as four times that of non-aggressive drivers.

Elvik and Vaa (2004) have reviewed the existing literature in relation to speed limits. The literature concerns either a transition from unrestricted speeds to signed limits, or reducing existing limits. The authors indicate that, across all studies, the total effect of reducing or introducing a speed limit is a reduction in accident frequency by 13 per cent. This level of effect can be assumed where there is an average speed reduction of 11 km/h. Larger percentage reductions are found for fatal accidents when compared to injury accidents, and for injury accidents when compared to property damage only accidents. For higher speeds, a reduction from approximately 110-115 km/h to approximately 88-97 km/h is predicted to reduce fatalities crashes by up to 54 per cent and reduce injury crashes by up to 6 per cent. For lower speed limits the ratio is approximately 2:1 between fatal and injury crashes.

In Australia in 1997 the federal government decided not to impose a reduction in the default urban speed limit (DUSL) from 60 km/h to 50 km/h. However, New South Wales was quick to adopt the lower 50 km/h speed limit and other States and Territories (excluding Northern Territory) soon followed this example. In Australia, in the lead up to re-zoning many 60 km/h residential zones to 50 km/h, Cairney and Donald (1996) suggested that any journey time increases due to lowered speed limits would be negligible. Their argument was that the main source of delays on such roads relates to intersections, traffic hold-ups and negotiating corners – all situations generally unaffected by the prevailing speed limit. Reviewing the Unley (South Australia) experience of setting a city-wide 40 km/h speed limit, Dyson, Taylor, Woolley and Zito (2001) noted that travel time declined to only a small degree, and not directly proportional to the reductions in posted speed limits. The authors suggest that smoother traffic flow may have served to minimise the losses in travel time.

In research reported by SMEC and Nairn (1999), the effect of reducing cruising speed on travel time was simulated for Melbourne traffic during morning peak hours. Results indicated that reducing the speed limit on all roads by 10 km/h would, in the short-term, result in an increase in travel time by up to 5 per cent (reducing down to 1 per cent in the long-term due to behavioural adaptation), but also bring about a 13.5 per cent decrease in accidents. With a reduction of 10 km/h for roads other than freeways, travel time was found to increase by only 3 per cent (reducing to 0.6 per cent in the long term), with a 10.3 per cent decrease in accidents.

Taylor (2000) also used a simulation approach to study urban traffic under a number of different scenarios including varying speed limits and different congestion levels. The model was used for examining the potential outcomes of engineering modifications to the actual network. Taylor found that regardless of congestion level and speed limit (40, 50 or 60 km/h), and whether traffic signals were coordinated or un-coordinated, predicted mean travel speeds were always less than the posted speed limits. This was an expected finding due to the complex nature of the traffic system. Taylor also found reduced delays at lower speed limits. These were believed to be due to a smoother traffic flow. Further, it was found that increases in the speed limits from 40 to 50 km/h, and 50 to 60 km/h, produced increases in average journey speed, as expected. Overall fuel consumption and emissions were found to be higher for the lower speed limits. Of the three speed limits, 60 km/h (with coordinated traffic signals) resulted in the best performance. Again, it should be pointed out that these results are based on a traffic simulation study.

In a report prepared for the National Road Transport Commission, Haworth, Ungers, Vulcan and Corben (2001) modelled the travel times costs associated with a national decrease in the general urban speed limit from 60 to 50 km/h. They found that a 50 km/h default urban speed limit on local streets, collector roads and arterial roads would, on the assumption of a 5 km/h reduction in travel speed, result in the prevention of an estimated 3,000 casualty crashes and an increase in average travel time per trip of less than 10 seconds. Further, they found that a 10 km/h reduction in average cruise speed would prevent over 8,000 casualty crashes per year while at the same time increasing average travel time by less than 26 seconds per trip.

Woolley (2005) has reviewed the effectiveness of the default urban speed limit in different Australian jurisdictions. Findings suggest substantial savings in terms of casualty crashes and fatalities even through the reduction in average travel speed was generally quite small. Large reductions were found, however in the numbers of vehicles travelling at excessively high speeds. An interesting finding was that there was a spin-off effect on other 60 km/h roads where the speed limit remained unaltered. Reductions in average travel speed on these roads was believed to be responsible for a reduction in casualty crashes and fatalities.

Weighing-up the Costs and Benefits of Lowered Speed Limits

Studies and research in Europe and Australia have suggested ways in which the social costs and benefits of increased travel time, decreased road trauma, vehicle operating costs, emissions, noise, etc. resulting from reductions in posted speed limits and their estimated influence on travel speed can be assessed (Kallberg and Toivanen, 1998, Ward et al., 1998; Thoresen, 2000; Cameron, 2000). In most cases, these studies suggest significant overall benefits to society as a result of lowering speed limits. However, when these benefits are weighed against the costs associated with increased travel times the net result is often negative. This has led to a debate relating to the assumptions of the economic rationalist approaches and how safety and travel time benefits and costs are estimated. Particular concern lies with the question of how appropriate and meaningful it is to aggregate small increments in travel time, and whether individual's tasks or activities will be noticeably affected by increases of a few seconds (see e.g. Ward, Robertson and Allsop, 1998).

The recognized need for a common unit of value that enables a trade-off between mobility and safety brings with it the philosophical question of whether mobility (e.g. measured through indicators such as travel time) ought to be sacrificed for safety. In many other transport domains such as air travel, the safety is given highest priority and passengers must accept the time spent waiting on the ground for safety reasons. In the road transport domain however, it is suggested that health losses from crashes are "…*major, but to some extent acceptable, consequences of mobility*" (Tingvall and Haworth, 1999). The Swedish parliament has now taken an important step by adopting a new road transport philosophy. This envisions moving toward a transport system that is designed to eliminate the occurrence of fatalities and injuries from which the road-user does not recover. Noticeable trends are now beginning to emerge, the Stockholm City council in Sweden has now adopted a 30km/h default speed limit on local and residential roads. Similar visions have been established in other countries around the world including Australia. The Australian Safe System approach has now provided a basis for the road safety strategies for many of the State and Territorial Governments.

Conclusions and Future Research

On the basis of the literature reviewed, the most important conclusions in relation to the potential impact of lowered speed limits in urban and metropolitan areas are summarised below:

- Lowered average travel speeds brought about by a reduction in speed limits in urban and metropolitan areas will bring about considerable reductions in road trauma
- A relatively minor impact on average travel times (mobility) will occur at the individual level; at the societal level there are likely to be overall benefits depending on how values are assigned to travel time increases
- Achieving community acceptance and support for speed limit reductions is critical as is the need to encourage better safety awareness by changing attitudes toward speeding and giving greater consideration to the needs of less prioritized road users
- Vulnerable road users (pedestrians and cyclists) are likely to benefit most from reductions in average travel speeds
- Lowered speed limits encourage better and safer forms of interaction between different types of road users which in turn should lead to a more attractive and liveable environment
- Lowered average travel speeds should bring about an increase in energy efficiency with a corresponding reduction in fuel consumption and vehicle running costs, and a reduction in vehicle emissions (Greenhouse gases) and noise; for this to be achieved it is important

to maintain road transport system efficiency, e.g. through the better use of coordinated or self-optimized signalling and other infrastructure and vehicle-based ITS

- Lowering speed limits is a necessary path in the fulfilment of the long-term goals and intermediate targets for a sustainable and safe road transport system according to the national Safe System approach and the State and Territorial traffic safety strategies and action plans

A number of areas requiring further research have been identified by this review. Most importantly, there is a need for more detailed travel surveys in Metropolitan areas, such as Melbourne, that can serve as a basis for research. Given the increasing emphasis on energy efficiency, these travel surveys should facilitate macroscopic modelling that can assess the impact of alternative forms of transportation. More research is also required into the use of new technology to provide, for example, dynamic variable speed limits in the metropolitan network on all types of roads. Other technologies include dynamic forms of intelligent speed adaptation that also consider prevailing road conditions. Furthermore, given the introduction of 30 km/h default speed limits on residential roads in some European cities, it would be of value to investigate, trial and evaluate the same approach in designated metropolitan residential areas to gain insight into the potential of this concept for Australia. Finally, a program of research also needs to be undertaken to find ways of providing useful information and changing the attitudes of motorists in relation to the risks associated with excessive speeding and the minimal gains in travel time.

Chapter 1 Introduction

1.1 Background

The increasing and sometimes conflicting goals of the transport system such as overall performance and efficiency, mobility, safety and environmental sustainability, have become increasingly difficult to achieve without major investments in the road infrastructure. New and affordable ways of reducing levels of road trauma in the transport system that have a minimal impact on mobility are keenly sought by the Australian government, the national and state road authorities, and by society at large. This particular study addresses the issues surrounding a lowering of speed limits in urban areas as a potential low-cost solution. An assumption that has found some support in the literature, is that a reduction in vehicle speeds in the urban environment would bring about a tangible reduction in road trauma while at the same time having relatively little impact on mobility measured by performance indicators such as travel time.

From a safety perspective, the relationship between vehicle speed and accident outcome severity has been well established. A major study conducted by the OECD and the ECMT in 2006 concluded that speeding is the number one road safety problem in most countries around the world, and that reductions in average speeds of approximately 5 per cent would yield a reduction in fatalities by as much as 20 per cent (OECD/ECMT, 2006). Research also indicates that even modest speed reductions can prevent the occurrence of many collisions and significantly reduce the outcomes of those accidents that do occur, particularly for vulnerable road-users (i.e. pedestrians and cyclists) that are predominant in the urban environment (Kloeden, et al., 1997; 2001; Elvik et al., 2004, Nilsson, 2004).

From a traffic system performance perspective, reductions in speed are likely to bring about a reduction in vehicle operating costs with less wear and greater energy efficiency, less pollution and less noise. An increase in traffic flow and consequent reduction in congestion and delays has also been suggested (TDM, 2007). Studies and research in Europe and Australia have suggested ways in which the social costs and benefits of increased travel time, decreased road trauma, vehicle operating costs, emissions and noise, resulting from reductions in posted speed limits and their estimated influence on travel speed can be assessed (Kallberg and Toivanen, 1998, Ward et al., 1998; Thoresen, 2000; Cameron, 2000). There are, however, a number of widely debated assumptions with economic rationalist approaches and in particular how safety and travel time costs and benefits are estimated for such purposes. Building on the European MASTER framework for cost benefit analysis, Cameron (2000) has suggested that optimal speed limits for various classes of urban roads have the potential to yield large benefits to society.

Australian researcher Taylor (2000) has also looked at the impact of different speed limits on the traffic system. In the study, it was estimated that a 1 km/h reduction in average speed in normal traffic conditions would provide a 6 per cent reduction in accidents on urban main roads and residential streets that already have low average speeds, and similarly, a 4 per cent decrease on medium speed urban roads and a 3 per cent decrease on high speed urban roads.

The obvious benefits of reductions in average speed have led to the adoption of national, regional and local safety strategies in many countries, including Australia, to try and reduce the occurrence of speeding and by reducing speed limits on various classes of roads and localized areas where there is a large predominance of pedestrians and/or cyclists.

In 2000, the Victorian Government proposed a Regulatory Impact Statement regarding regulations to reduce the default urban speed limit to 50 km/h. This was based on an evaluation of private vehicle travel time for business and commuter travel. Most Australian jurisdictions have now adopted a 50 km/h default speed limit for local residential roads in an attempt to improve safety while maintaining a reasonable level of mobility.

Typical speed reduction measures besides posted speed limit reductions include (see e.g. Elvik and Vaa, 2004):

- Traffic calming (roadway design measures that force drivers to reduce speed e.g. chicanes and speed humps, and which separate different types of road-users)
- Speed enforcement using new and more sophisticated techniques including speed camera
- Driver education and public service announcements
- Traffic signal synchronization to encourage less stops if legal speeds are maintained
- Signs that provide speed feedback to drivers to increase their awareness of speeding
- Infrastructure based intelligent transportation systems such as variable speed signs that attempt to harmonize traffic flow through speed management strategies
- In-vehicle based intelligent transportation systems that provide mandatory or informative speed adaptation support

Many of these speed reduction countermeasures have shown some degree of success, but often provide only localized reductions in average speed with the risk of causing a shift in travel patterns to less desirable roads or areas.

Understanding driver behaviour is an important issue in speed management. Many accidents are believed to be the result of incorrectly adapted speed in relation to the prevailing road conditions (see e.g. Carsten et al., 1989). The literature also suggests that drivers often misperceive the saving in time gained by driving faster, particularly on shorter journey lengths (e.g. RACV, 1990). This suggests a general lack of knowledge by drivers regarding the relationship between choice of speed and the effect this has on travel time under different traffic conditions (e.g. levels of congestion) in urban areas. Furthermore, the relationship between speed and accident risk seems to be understood by drivers, but not acted upon where many consider it okay to drive above the speed limit as long as one drives safely (Pennay, 2005) .

Posted speed is undoubtedly a significant factor in determining driver's choice of speed, although research has also shown that speed choice is affected by factors such as: roadway design, geometry, forms of traffic regulation, prevailing weather conditions, time of day, purpose of trip, and levels of congestion (see e.g. Varhelyi, 1996; TRB, 1998). Importantly, setting suitable speed limits and designing traffic regulation strategies as part of integrated traffic control strategies need to consider and balance safety and mobility for all types of road-users and classes of transport. Finding a correct balance between these conflicting objectives is often a particularly difficult exercise for traffic engineers and transport planners (Elvik and Vaa, 2004).

Travel time is only one indicator that is representative of overall transport system efficiency in a traffic network of interest. It is often regarded as one of the more intuitive and easier measures to understand. Travel time is represented by the distance travelled divided by average speed (more specifically link length/speed of traffic flow for travel time estimation purposes). Another common measure of transport system efficiency is delay. This takes into consideration the difference in travel time as opposed to an optimal time in free flow traffic conditions bearing in mind the posted (maximum) speed limits for each part of the journey. Other traffic system or network performance measures include queue-lengths and the time needed for a queue to dissipate, average speeds, traffic flow rates, traffic throughput measured at stop-lines or across sections, saturation flows at traffic lights, numbers of stops and average waiting times at intersections and pedestrian or railway crossings, and various other indicators.

Particularly in urban areas, the prevalence of intersections and demand for mobility from many different classes of road-users during morning and afternoon peak periods suggests that posted speed limits may be only one of a multitude of factors that influence the outcome of travel time for a specific route. Based on the simulation of a synthetic grid network, Taylor (2000) suggested that the differences in overall travel speeds and journey times brought about by the reductions in speed limits were in fact not directly proportionate to the differences in the speed limits reductions themselves (due to other complex traffic system influences).

The benefits and disbenefits that are likely to be brought about at relatively low cost as a result of lowering speed limits in the urban environment require further investigation and analysis. A key objective of this report is to review the current literature relating to changes in posted speed limits and the impact this is likely to have on the traffic system. The findings of this review should provide a more qualified estimation of the safety, mobility and environmental impact that can be linked to speed limit changes.

1.2 Aims and Objectives

There is substantial research evidence to suggest that reductions in posted speed limits in the urban/metropolitan traffic environment will have significant safety benefits (i.e. fewer crashes and reduced crash trauma) provided that a reduction in average speeds is achieved. A common belief among transport planners and traffic engineers is that the safety benefits resulting from lower speed limits will be incurred at a significant cost to mobility and perhaps the environment, the other major transport system objectives. A key hypothesis in this literature review is that reductions in posted speed limits and average speeds may have little significant impact on mobility, as measured by transport system indicators such as travel time.

In summary, the purpose of this literature review is to:

(a) Examine the current state of knowledge in relation to speed management where this has a known potential to bring about improvements in road safety (i.e. a reduction in the number of crashes and crash outcome severity)

(b) Further examine the relationship between speed limits changes and actual speeds in the urban/metropolitan environment and the potential impact on transport system objectives other than safety, such as mobility (e.g. travel times, delays, queues) and the environment (e.g. noise, air pollution)

(c) Suggest future research directions that aim to exemplify and quantify the potential benefits of lowering speed limits given the relative simplicity and ease with which this measure can be applied

1.3 Scope and Report Structure

This literature review is confined to traffic networks in built-up urban and metropolitan areas. Other literature and research findings considered relevant to the main research themes will, however, be considered where appropriate. The report is divided into seven main chapters including the introduction and conclusions. Chapter 2 reviews the current state of knowledge in relation to vehicle speed, crash risk and crash outcome severity suggesting the need for lower speeds in urban and metropolitan areas where there is a high predominance of vulnerable road users such as pedestrians and cyclists. The third chapter is concerned with speed management issues and the need to achieve a balance between the key transport system objectives related to safety, mobility and environmental impact. Aspects related to roadway design and traffic control are discussed along with various measures in the roadway infrastructure and in the vehicle to help achieve speed compliance.

Chapter 4 represents the central core of this review, focusing on previous research related to speed limit changes and the impact on mobility (mainly travel time) and the factors that influence driver's choice of speed in relation to the posted speed limits. Some emphasis is given to the work in Australia in relation to the re-zoning of urban speed limits from 60 km/h to 50 km/h. Environmental impact and the increasing importance of energy efficiency is also discussed. The fifth chapter looks at driver's attitudes toward road safety policy and speeding and what has been termed the speed paradox, referring to the mismatch between driver's intended and actual behaviour. Chapter 6 looks at cost benefit analysis as a means to estimate the impact of speed management policies at the societal level and some of the controversial issues related to this type of approach.

In the seventh and final chapter, the general conclusions based on the literature review are summarised and a number of suggestions for future research in this area are stated.

1.4 Methodology

1.4.1 Literature Review

A targeted review of literature on travel time and speed limit reductions has been conducted. This has included international psychological, engineering and traffic safety literature using the following sources:

- Road safety and transport research institutions' websites including: Transportation Research Laboratory (TRL, Crowthorne, England); Swedish Road Administration (SRA); SWOV Institute for Road Safety Research (Netherlands); Insurance Institute for Highway Safety (IIHS, USA); federal Highway Administration (FWHA, USA)
- Electronic databases through the Monash University library including: Compendex, Engineering Village, TRIS, ATRI, Transport Database, and IEEE databases. The IATSS Journal and Transportation journals were also explored
- An internet Google Scholar search
- Numerous individual road safety related websites were explored including ARRB, Austroads, ATSB, NHTSA, BTSB, ICTCT, Danish Road Directorate, University College London, and the EUROPA, PROSPER and MASTER project web pages.

1.4.2 Input from Research Experts

A number of prominent research experts were contacted directly and asked for their input on various issues as part of this review. Those who responded included:

- Lárus Ágústsson (Danish Road Directorate)
- James Bonneson (Texas Transportation Institute, TAMU).
- Jeff Paniati (Federal Highway Administration, U.S. Department of Transportation)
- Mike Taylor (Transport Systems Centre, University of South Australia)

- Davey Warren (Federal Highway Administration, U.S. Department of Transportation)
- Jeremy Woolley (Centre for Automotive Safety Research, The University of Adelaide**)**
- Bill Young (Department of Civil Engineering, Monash University)

A number of other international experts in this field have also been approached. However, many have been unable to respond to the questions posed to them as part of this work. The non-respondents include: Richard Allsop (Centre for Transport Studies, University College, London); Martin Lepinski (Department of Civil Engineering, The University of Memphis); Heather Ward (Centre for Transport Studies, University College, London); or Fred Wegman (SWOV Institute for Road Safety Research, The Netherlands).

Chapter 2 Vehicle Speed, Crash Risk and Crash Outcome Severity

2.1 Speed as a Causal Factor in Crashes

The traffic safety literature provides overwhelming evidence that there is a strong relationship between speed and crash risk, and outcome severity in the event of a crash. Even at relatively low speeds there is a high risk for serious injury or fatality for pedestrians that are struck by a vehicle. A meta-study of research findings on speed and injury risk by Elvik and colleagues (2004) has concluded: "*The mean speed of traffic is the most important risk factor for road accident fatalities. It has a more powerful effect on road accident fatalities than any other known risk factor, including the overall amount of travel. Speed as a risk factor is always present. Many other risk factors, like darkness or a slippery road surface, are not always present*."

Many road authorities in Australia and the rest of the world conduct in-depth crash investigations when traffic accidents result in fatalities or serious injuries. Data from this type of investigation suggests that excessive or inappropriate speed may be a contributing factor in 10 to 30 per cent of all road crashes (see e.g. Carsten et al., 1989; Perrett and Stevens, 1996). While few traffic safety experts would deny the importance of speed in accident causation and the severity of injuries sustained by those involved in an accident, the TRB (1998) suggest a number of reasons why great caution should be taken when inferring speed-crash causation relationships of this character:

1. In-depth studies require conclusive evidence that a driver was in fact driving at excessive speed before coding speed as a contributory factor.
2. In-depth studies are subject to investigator preconceptions about what is *'excessive'* speed. Preconceptions such as these are heavily influenced by the prevailing notions of what an appropriate speed is for the road conditions. Over the years, expert opinion about appropriate speeds has been modified and this modification has generally been downward, particularly for urban roads. This makes it unwise to rely on expert assessments of appropriate speeds made in studies carried out some 10 or 20 years ago.
3. In-depth studies have not generally looked at each accident with the scenario of lower speeds and then asked whether the accident would have been avoided under such circumstances (and also whether an accident would have incurred a less severe outcome).

While caution is needed in determining the factors underlying road crashes, there has been a great deal of research to suggest the importance of maintaining correctly adapted speed. At lower speeds, there is a greater safety margin for any given time to collision, in other words more time for the driver to intervene and avoid the impending collision. Furthermore, drivers have less chance of losing control particularly during heavy braking or swerving to avoid a collision. Loss of control at speed is a particular problem for heavy vehicles given their greater mass and instability (George, 2003). This is a matter of Newtonian physics where it is known that the kinetic energy dissipated in a crash increases with vehicle mass and the square of collision speed. Lowering vehicle speed therefore not only reduces the risk for crash involvement, but also dramatically affects the risk for serious injury or fatality in the event of a crash.

2.2 Average Speed and Crash Risk

When considering speed management strategies to reduce speed it is important to consider the average mean speed reduction that various speed countermeasures actually achieve. In the mid-1990s, Finch and colleagues (1994) reviewed an extensive body of literature on the relationship between traffic speed and injury accident risk. Most of the studies that they reviewed were before and after studies based on the number of accidents following an intervention that resulted in a change in travel speed. They fitted models to the data reported from the various studies. Their overall conclusion was that, for each 1 km/h change in mean speed, the best estimate of the change in accident risk was approximately 3%. More recent work has confirmed this relationship as a general rule, but has also concluded that there is an important contribution related to road quality and road function.

Andersson and Nilsson (1997) concluded that, for a given type of road, the injury accident rate changes with the square of a change in mean speed (where the new mean speed is expressed as a proportion of the old mean speed), the severe injury (including fatal) accident rate changes with the cube of speed change and the fatal accident rate changes with mean speed change to the power of four (see Figure 1 below). Nilsson (2004) has recently reviewed these statistical models on the basis of new data and found support for his earlier findings.

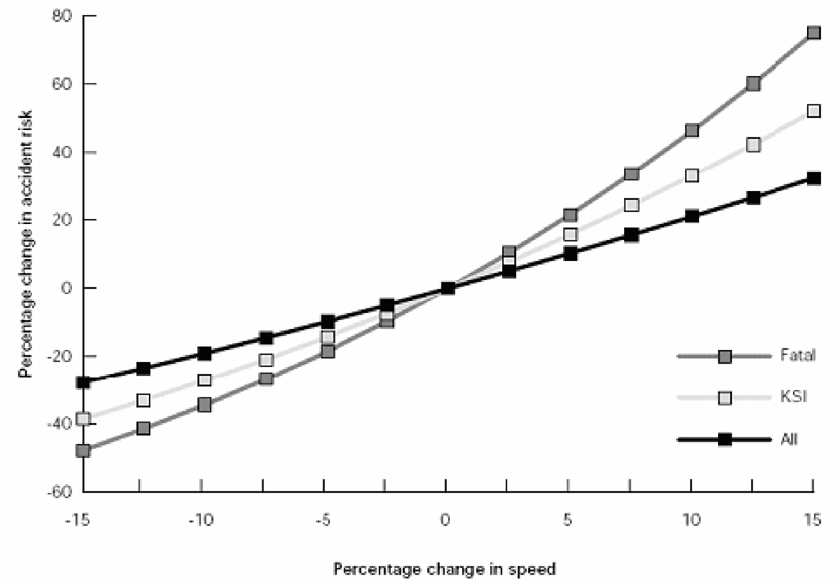

Figure 1. *Relationship between change in speed and change in accidents (from Andersson and Nilsson, 1997).*

Similar models to Nilsson's have been developed in other countries. For a further review of statistical relationships between speed (absolute and relative) and accident risk and their corresponding empirical validity see, for example, Aarts and van Schagen (2006) and Cairney and Donald (1996).

In a meta-analysis by Elvik and colleagues (2004) which covered 98 earlier studies it was concluded that the exponents in Nilsson's power model could be refined by separating out the various severity levels more cleanly. The conclusion was that the exponent for fatal accidents was 3.6, for serious injury accidents 2.4, and for slight injury accidents 1.2. The same study pointed out that reductions in traffic speed were the most effective means for reducing road accident fatalities, more effective in fact than other safety interventions such as reducing the amount of drink driving or night-time travel.

2.3 Speed Compliance and Crash Risk

Recent studies have found that risk only increases with travel speeds above the mean speed of traffic, or travel speeds above the speed limit. Kloeden and colleagues (1997) investigated the relationship between speed compliance on urban roads and the risk of a vehicle being involved in a crash on 60 km/h road in the Adelaide metropolitan area. The study used a case-control methodology, in which there were case vehicles that had been involved in crashes where at least one person was transported to hospital by ambulance (speed before crashing was calculated by accident reconstruction), and control vehicles that were matched by observing vehicles in the traffic stream (see Figure 2 below). The researchers found that with each 5 km/h increase in travelling speed, the risk of involvement in a crash involving injury doubles. In particular, their study suggested that the higher the speeds in urban areas the greater the risk of crashing. This was believed to be due to a combination of factors including the reduced time available to detect and respond to hazards in the driving environment and the increased stopping distance.

A limitation of this study was the fact that only accidents involving injury were considered. A subsequent re-analysis of the same data, using logistic regression modelling, came to much the same conclusion about risk above the speed limit, but also concluded that vehicles travelling *below* the speed limit in free-flow conditions had a reduced risk (Kloeden et al., 2001).

It has also been argued that accident risk is related to the variability of travel speed around a mean average value. Higher speed variance leads to an interrupted and less smooth road operation with greater risk for shock waves. High speed variance can result from the large differences in speed between different categories of road user and/or vehicle types (e.g. slow heavy vehicles and fast cars, or slow elderly drivers and fast young drivers); but also in situations where there are high traffic flow rates along a road (near saturation level) which generate sudden decelerations in the traffic stream. There is research that suggests the importance of minimizing speed variation in order to reduce accident risk. Early research suggested that crashes were more likely to occur on roads with skewed speed distributions. This idea has since been revoked in light of the lack of important information leading to the cause of the skewed distribution (Kloeden et al., 1997).

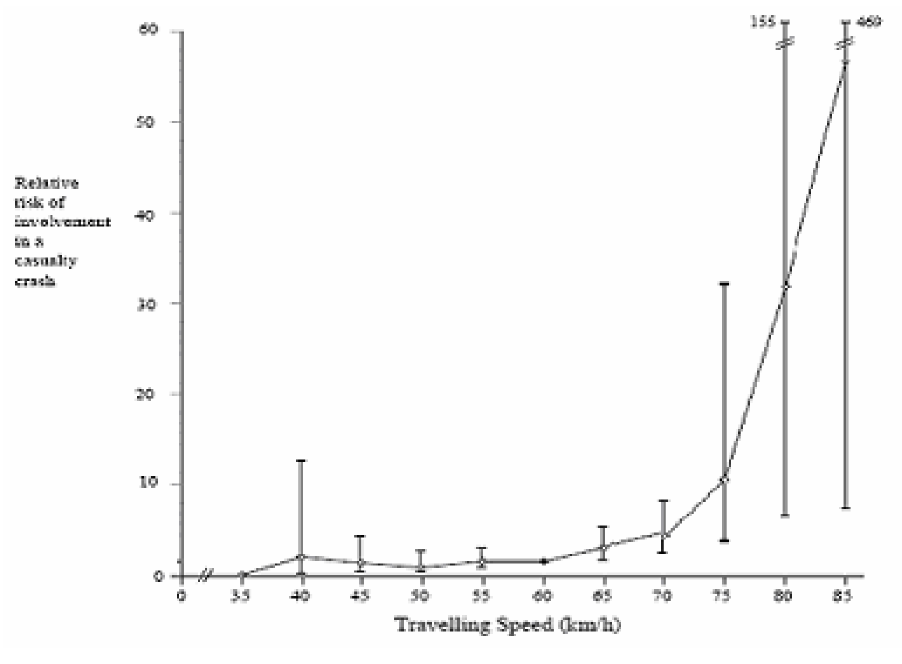

Figure 2. *Travelling speed and the risk of being involved in a serious injury crash relative to travelling at 60 km/h in a 60 km/h speed limit zone (Kloeden et al., 1997).*

Fildes and colleagues (1991) also found that crash involvement rates were lower for vehicles travelling below the average speed, thereby providing support for the importance of speed itself to crash probability. Other research by Baruya and Finch (1994) suggests that the effect of mean speed on accident rates was stronger than the effect of speed variation. As an approach to managing speed, it has also been suggested that attempts to reduce speed variation are not beneficial to safety since this might encourage slower drivers to drive faster at speeds that may appear less comfortable (Zaal, 1994).

2.4 Speed Variation and Accident Risk

Many studies demonstrate a relationship between mean speed and speed variation. The research literature suggests that increasing speed differentials between vehicles, often leads to: an increase in passing manoeuvres and improper lane changing; tailgating (driving too close to a slower vehicle in front); frustration among drivers who desire to travel faster; and the formation of platoons of traffic. Reducing speed limits is often intended to make traffic flows more uniform by bringing slower drivers closer to the average speed of traffic. This is also known to have the effect of reducing traffic conflicts and crashes. Some early work in this area of study was conducted by Solomon (1964) who demonstrated a parabolic relationship between speed deviation from the mean speed (faster or slower) and the frequency of crashes.

The findings of Solomon have since been corroborated by other researchers. Harkey and colleagues (1990) found a minimum risk of crash involvement at around the 90th percentile speed on urban roadways in the United States. Other more recent studies have also supported the association between speed variation in the traffic streams and crashes, including Garber and Gadiraju (1998), and Garber and Ehrhart (2000). Generally, research has shown that speed dispersion plays an important role in crash risk on most road types.

2.5 Vehicle Occupants, Crash Types and Crash Risk

Research suggests that the injury risk for occupants of motor vehicles is related to impact severity, i.e. the greater the severity of the impact; the greater the risk for more severe injury outcomes. Injury risk for the occupants of vehicles involved in crashes is, however, rather complex. Occupant injury risk is dependent on at least two different factors – the relative impact speed of the occupant's vehicle in relation to the object that is stuck (e.g. a vehicle or fixed object) and the change in velocity (referred to as delta-v) to which the occupant is exposed in the crash (Scully et al., 2007). Injury risk is also affected by other (confounding) factors, including the occupant's age and gender, the level of protection provided by the occupant's car, and the aggressiveness and mass of the other vehicle involved. This makes the estimation of injury risk for different impact scenarios complicated. In all vehicle crashes, impact severity, impact speed and delta-v play a key role in determining the outcome severity. It should also be noted that these factors contribute differently to injury risk depending on the type of impact (side-impact, head-on, rear-end, etc.)

In the study by Scully and colleagues (2007) several mathematical functions describing the probability of fatality for the driver involved in a two-car collision were estimated. These functions are based on models developed by Evans (1994; cited in Scully et al., 2007) who used empirical crash data to estimate delta-v crash-risk models. The models suggested by Evans are believed to be reasonable given their general consistency with Nilsson's power model. As part of their study, an expert panel was used to estimate the relationship between the risk of death and impact speed for three scenarios including:

- Scenario 1 - 50 km/h for frontal crash with a narrow rigid object;
- Scenario 2 - 50 km/h for struck-side with another vehicle; and,
- Scenario 3 - 70 km/h for frontal crash with another vehicle.

Figure 3 below, shows the resulting relationships between risk of fatality and delta-v for each of the scenarios, together with Evan's estimate for the risk of a driver being fatally injured irrespective of the crash configuration (the line denoting "All Crashes"). Although these curves are based on a number of assumptions (see Scully et al., 2007 for more information) they can be used to approximate the relationship between risk of fatality and impact speed. Unfortunately, no curves could be derived for the risk of serious injury only. Scully and colleagues point out that there is a need for further research into creating mathematical models that focus on predicting risk of fatality for specific types of crashes.

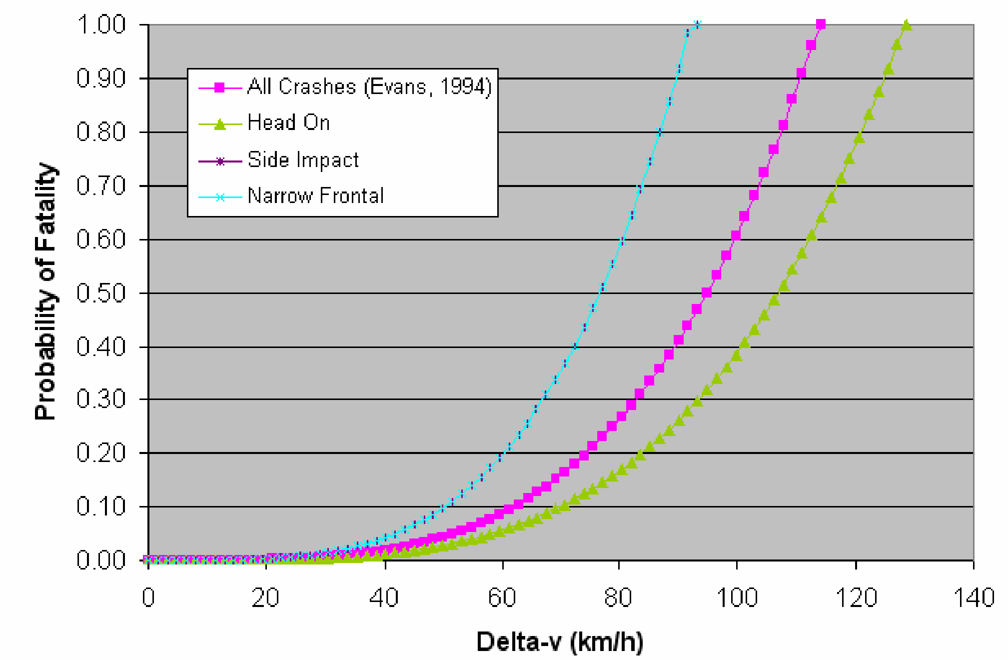

Figure 3. *Consensus view of the relationship between delta-v (and impact speed) and probability of fatality for different crash scenarios (graphs for the Narrow Frontal and the Side Impact scenarios are coincident). (Adapted from Scully et al., 2007).*

2.6 Pedestrian Injury and Crash Risk

While the severity of injuries sustained by vehicle occupants is mitigated by vehicle factors such as energy absorption characteristics and various types and combinations of restraints, the severity of injuries sustained by pedestrians struck by vehicles is more directly related to impact speed. According to Scully and colleagues (2007), studies that use crash databases to estimate risk of death or injury as a function of impact speed are quite rare due to the fact that few databases record the actual impact speed of colliding vehicles. Most databases at best only record pre-impact travel speed using either: speeds estimated by investigating officers, or the speed limit at the crash location. For impacts between vehicles and pedestrians, impact speed is usually measured by estimating the distance over which the pedestrian was thrown (commonly referred to as the *throw distance*). Impact speed can also be estimated by measuring skid marks at the crash scene, if available. Measurement is also made difficult by the fact that many drivers do not brake or swerve before colliding with a pedestrian.

There are number of important studies that have attempted to estimate the probability of a pedestrian being fatally injured given the impact speed of the collision. These studies have all been based on empirical data from one or several sources. Scully and colleagues (2007) have summarised the findings of Anderson and Nilsson (1997); Fildes and colleagues (2004); Ashton (1982) and Ashton and Mackay (1979); and the Transport Advisory Unit (TAU) of the UK Department of Transport (1993) in Figure 4 below.

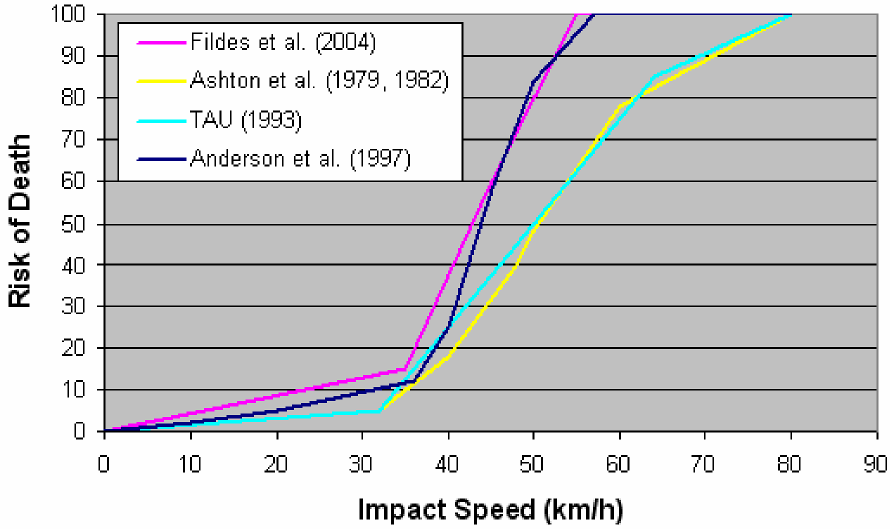

Figure 4. *Comparison of reported estimations of risk of death for pedestrians with respect to impact speeds (from Scully et al., 2007).*

It should be noted that there may be differences in the various sources of data that can be related to population differences and advancements in vehicle design across the time-frame of the different studies. While none of the above studies were based directly on Australian data, the consensus of an expert panel involved in the research conducted by Scully and colleagues (2007) suggests that the risk estimates proposed by Anderson and colleagues are those most suitable for estimating an Australian pedestrian fatality rate with regard to impact speeds.

Predicting the risk of serious injury with respect to impact speed is also difficult for many different reasons. In particular, different studies use different definitions of serious injury. There are however, a number of studies that have attempted to predict serious injury risk for pedestrians based on impact speed. These studies commonly use the Maximum Abbreviated Injury Scale (MAIS) score for a victim of road trauma. A useful study based on this type of data has been conducted by the International Harmonized Research Activities (IHRA, 2001; cited in Scully et al., 2007). This provides one of the most comprehensive estimates of risk of serious injury by impact speed based on a meta-analysis of real-world data of pedestrian crashes from four separate databases. The databases included were from Germany (GIDAS), Japan (Japan Automobile Research Institute and ITARDA), the USA (Pedestrian Crash Data Study) and Australia (Anderson et al, 1997; cited in Scully et al., 2007). Data from the four databases were combined into a single database containing 9,463 separate injuries from 1,605 cases. Each injury was categorised into fields for: case number, age, AIS injury level, body region of the injury, the vehicle impact point and the impact velocity.

The consensus of an expert panel in the research carried out by Scully and colleagues (2007) suggested that injury risk provided by IHRA were the best estimates of injury risk by impact speed for pedestrian crashes and has the advantage of being based on recent data. The risk of serious injury and fatality for pedestrians with respect to the impact speed of the striking vehicle, are shown below in Figure 5.

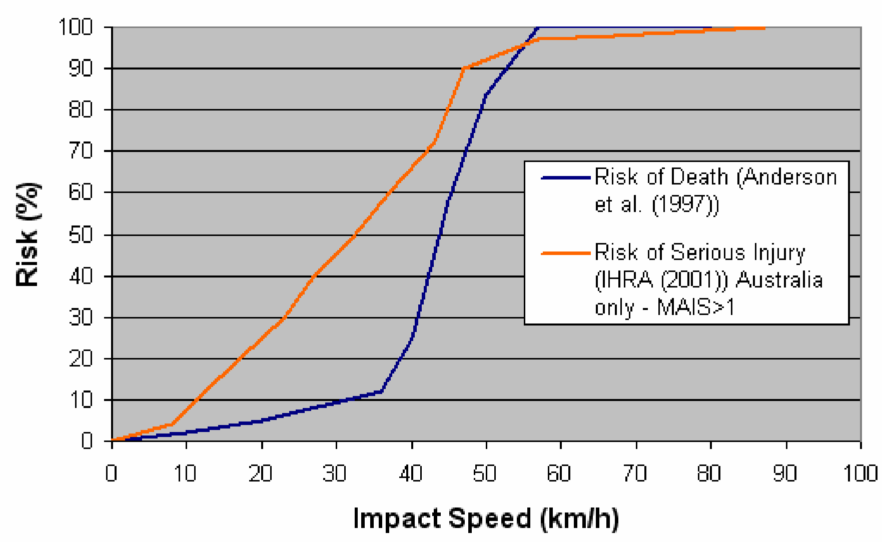

Figure 5. *Consensus view of the risk of death and serious injury with respect to impact speed for pedestrians stuck by a car (from Scully et al., 2007).*

The relationship between driving speed and probability of pedestrian death is a major consideration in setting suitable speed limits and speed measures in the urban environment. For these reasons there has been a move in Australia in more recent years to reduce the default speed limits in urban and built-up areas from 60 km/h to 50 km/h. In many other countries speed limits in urban areas have been 50 km/h for some time, and are often reduced locally to 40 or 30 km/h in residential areas and in the vicinity of schools, age-care centres and shopping precincts where there is a large predominance of vulnerable road users.

In South Australia, the speed limit around some schools has been set to 25 km/h in recognition of pedestrian vulnerability. In some suburbs around Melbourne and Sydney, a 40 km/h speed limit has also been applied. In Stockholm, Sweden, a 30 km/h speed limit on all residential streets in the city area was introduced in early 2007. This represents an important move toward safer speeds on pedestrian streets. Initial indications of the effectiveness of the Swedish 30 km/h speed limit suggest that average speeds and traffic flow remain relatively unaffected while the maximum speed has decreased notably. The issues are related to speed management and are discussed in more detail in the next chapter.

2.7 Speed Limits and Crash Risk

A further approach to understanding and explaining the relationship between speed and crash risk that is relevant to this review is to examine accident rates before and after changes in the speed limit. Some earlier research in this area was conducted in the 1970's following speed limit reductions to counter the oil crisis (TRB, 1998). Other more recent studies around the world have also examined the effects of lowering speed limits, primarily on rural roads and motorways. The findings of many of these international studies were summarized by Fildes and Lee (1994) who reported reductions in road accidents ranging from 8 to 40 per cent in a number of countries including: Belgium, Finland, France, Germany, UK, and South Africa. General conclusions from this study suggested that lower speed limits usually resulted in lower average speeds and corresponding reductions in the numbers of crashes and crash severity. Changes in average speeds were also found to be proportionately less than expected given the actual reduction in the speed limit. While greatly successful in terms of safety impact, this research is based largely on rural and motorway speed limit reductions rather than on roads in urban and metropolitan areas. Consequently, these findings are of less relevance to this report.

Of considerably more relevance are the findings related to the introduction of the 50 km/h default urban speed limit (DUSL) adopted in Australia. The DUSL was applied to many roads that previously had a 60 km/h limit. In New South Wales, the RTA suggested a 25.3% reduction in the risk of being involved in a police reported accident based on 21 months of crash data. An analysis of the data showed that mean travelling speeds dropped by only 0.94 km/h on 50km/h roads (RTA, 2000; in Woolley, 2005). In Queensland, the 50 km/h DUSL is believed to have brought about a reduction in casualty crashes of 8 per cent and an 18 per cent reduction in fatal crashes. A reduction in travel speeds by approximately 5 km/h was also reported (Walsh and Smith, 1999; in Woolley, 2005). In Victoria, Horeau and colleagues (2006) reported that the DUSL had resulted in an overall reduction of 12 per cent in casualty crashes between February 2001 and December 2003, along with a reduction in fatal and serious injury crashes involving pedestrians (approximately 25 to 40 per cent). Average travel speed was reported to be only slightly lower (approximately 1 per cent).

In Western Australia, average travel speeds were found to have decreased by slightly more than 1 km/h as a result of the DUSL. Furthermore, there was a significant reduction in the number of drivers exceeding the speed limit by more than 10 km/h (Kidd and Radalj, 2003; in Woolley, 2005). A metropolitan analysis indicated a 21 per cent net reduction in casualty crashes with a 51 per cent net reduction in crashes involving pedestrians (Horeau and Newstead, 2004). In Australian Capital Territory there was a non-significant 2.1 per cent reduction in police reported crashes in the two years after the introduction of the DUSL, while mean travel speeds (main collector roads) were found to be 2 km/h lower on 50km/h streets. A similar reduction was also observed on unchanged 60 km/h streets, (Green, Gunatillake and Styles, 2003; cited in Woolley, 2005). No analysis was conducted in Tasmania although Woolley (2006) reports that there were 89 fewer casualty crashes in the year following the introduction of DUSL.

Finally, in South Australia the 50 km/h default urban speed limit was estimated to have been responsible for a 20 per cent reduction in casualty crashes. This estimate was based on data from the year prior to the DUSL introduction and data from the year after the 50 km/h limit was imposed. An overall 2.2 km/h drop in average travel speed was found. These results were found to coincide with average travel speed reductions (0.7 km/h) on arterial roads where the speed limit remained unchanged. These changes also brought about a 4.6 per cent reduction in casualty crashes (Kloeden, Woolley and McLean, 2004; cited in Woolley, 2005).

The findings related to the introduction of the 50 km/h DUSL show significant reductions in crashes and crash trauma (and therefore accident risk) despite relatively small decreases in overall average speeds. As Woolley (2006) points out, it is vulnerable road users that gain the most benefit from the DUSL induced speed reductions.

Chapter 3 Speed Management

In the introduction to this report a number of typical speed management measures were listed. These represent different tools or mechanisms that are available to traffic engineers and transport planners to ensure both the safety and performance of the road transport system. Speed management measures include, amongst others, the following:

- Speed limits that are in alignment with the design speed of the road
- Traffic calming (roadway design measures that force drivers to reduce speed e.g. chicanes and speed humps, and which separate different types of road-users)
- Speed enforcement using new and more sophisticated techniques including speed camera
- Driver education and public service announcements
- Traffic signal synchronization to encourage less stops if legal speeds are maintained
- Signs that provide speed feedback to drivers to increase their awareness of speeding
- Infrastructure based intelligent transportation systems such as variable speed signs that attempt to harmonize traffic flow through speed management strategies
- In-vehicle based intelligent transportation systems that provide mandatory or informative speed adaptation support

The various speed management measures are effective in different ways with differing levels of success in terms of effectively reducing vehicle speeds to more suitable levels. A number of important issues related to these measures are described in more detail below.

3.1 Speed Limits

The most elementary method of managing speed is to impose speed limits. To be effective, speed limits should be compatible with the design speed of the road. Research has shown that the design speed (i.e. the speed for which the road is designed) tends to have a greater effect on a driver's choice of speed than the actual speed limit (see e.g. Varhelyi, 1996). Generally, a speed limit increase will result in slightly increased average travel speed. This in turn influences the number of accidents and accident outcome severity. The magnitude of the increase (or decrease) is dependent on the mean speed before the change (TRB, 1998).

The primary purpose of speed limits is to enhance safety by reducing the risks imposed by drivers in their choice of speed. They have both a limiting function by establishing an upper bound on speeds where the objective is to reduce the probability and outcome severity of accidents; and also a coordinating function to reduce dispersion in driving speeds where research has shown that more uniform speeds are associated with better safety. Another function of speed limits, which is related to their coordinating function, is to achieve an orderly flow of traffic and improve traffic flow efficiency. Once established, well-conceived speed limits help to determine a reasonable standard for enforcement. In previous years, speed limits have also been used as a mechanism for energy conservation purposes such as the oil crisis in the early 1970s.

Traffic engineers and transport planners set speed limits to achieve a balance between transport system safety, mobility (and environmental impact). Determining the optimal trade-off between these objectives depends, in part, on the function of the road (Harwood, 1995). Whatever trade-offs are made between safety and mobility in establishing speed limits, the posted limits must also convey information to drivers. According to current practice, the numerical value on the sign advises the motorist of the maximum speed at which a driver can lawfully proceed under favourable conditions (e.g. good weather, daylight, and free-flowing traffic). Drivers are expected to reduce their speeds as these conditions worsen. The maximum speed limit should be related to the actual risk characteristics of the road (e.g. curvature, road and lane width, etc.) and roadside objects (e.g. trees, rocks, etc.) if drivers are to perceive the speed limit as credible and if adequate levels of voluntary compliance are to be achieved (Fildes and Lee, 1993).

There are often differences in driver's perceptions of suitable travel speeds and those speed limits (compulsory or recommended) that are posted in reality. This is why physical barriers and perceptual countermeasures are often used (see e.g. Fildes and Jarvis, 1994). Fixed roadside objects such as trees are often not perceived by drivers as dangerous as a result of them being situated off the main roadway, however, these objects are potentially lethal in the event of a collision as suggested by the high number of serious injury and fatal run-off road accidents (see e.g. Elvik and Vaa, 2004).

3.1.1 Differential Speed Limits

Differential speed limits are used for heavy vehicles on motorways in many European countries, where speed logging devices (tachographs) are required by law as a means of enforcement. According to TRB (1998) differential speed limits are often imposed due to the different vehicle operational characteristics of light passenger vehicles and heavy vehicles such as buses and trucks. Trucks and buses are known to have longer stopping distances than light vehicles due to their greater mass and are often more unstable due to their weight distribution and size, heavy vehicles also have slower acceleration and are less manoeuvrable than lighter vehicles (see e.g. George, 2003). These factors are believed to increase the crash probability of heavy vehicles and increases the outcome severity of those accidents that do occur (see e.g. Brooks, 2002). Implementing differentiated speed limits is believed to resolve some of the problems associated with the different operational characteristics of vehicles and therefore also reduces crash risk. Those who oppose the concept of differentiated speed limits propose that the differences in vehicle speeds are likely to increase the potential for vehicle conflicts that result from the need to change lanes and other passing manoeuvres. To date, however, there is no conclusive research evidence to support or reject the use of differential speed limits for passenger cars and heavy trucks.

In Australia, heavy vehicles are restricted to 100 km/h on open roads where the speed limit may be as high as 130 km/h. This is achieved by the use of speed limiting equipment fitted to all vehicles over a certain weight (12 tonnes gross vehicle mass) in accordance with Australian Design Rule (ADR) 65. Furthermore, road trains are restricted to 90 km/h in some jurisdictions. Despite the use of speed limiters many heavy vehicles are known to exceed the speed limit on the open road, and in urban and metropolitan areas where speed limits are the same for all vehicles. There is no Australian data to suggest that heavy vehicles have a greater crash risk than light vehicles in any speed zones, although it is known that the outcomes of crashes involving heavy vehicles are generally more severe (NTC, 2006).

3.2 Roadway Design to Control Speed

While roadway design leads to a particular design speed and the subsequent posting of speed limits, it is also recognised that the design of the roadway can be actively used as an instrument to achieve suitable speeds. Roadway design is today recognised by transport planners and traffic engineers as a cost effective and sustainable approach to speed control and speed management.

Traditionally, a new road is designed in accordance with the intended function of the facility (e.g. through travel, distribution, access) and its anticipated level of service (see e.g. AASHTO, 2001). These factors guide the choice of a design speed, which subsequently determines design factors such as, for example, sharpness and extent of banking of horizontal curves and rate of grade change of vertical curves, as well as stopping sight distances and intersection sight distances. Geometric design principles in Europe and Australia currently incorporate predicted vehicle operating speeds as an important determinant of roadway design. On existing roads, changes in speed limits are often made in accordance with operational speeds (e.g. 85th percentile speeds), and other operational considerations (e.g. signal coordination etc.) which can lead to inconsistencies between the design speeds, speed limit, and operational speed chosen by a driver. More appropriately, the target speed for a roadway should be reflected through its design in order to be consistent with motorists' expectations and thereby bring about an appropriate operational speed (see e.g. McLean, 1984; Fildes and Lee, 1993; TRB 1998).

On low-speed urban streets where driving speeds often exceed target speeds, research has shown that the driver's choice of speed is influenced by design features such as roadway alignment and lane width. Thus, curving roadways and narrower lane widths can be used effectively to bring about targeted operational speeds and improve safety (TRB, 1998). Traffic safety strategies aimed at reducing speeds in the urban environment have often been based on a combination of different physical measures that fall under the umbrella term '*traffic calming*'. Traffic calming originated in Europe, where the basic objective was to achieve calm, safe, and environmentally improved conditions on local streets (see e.g. Hydén et al., 1995; TRB, 1998; Elvik and Vaa, 2004; Racioppi et al., 2004). Some of the best-known and earliest examples of traffic calming were the Dutch '*Woonerf*' schemes of the early 1970s, which reduced traffic speeds by the use of design treatments that aimed to give equal priority to pedestrians and other non-motorized road users on neighbourhood streets. The concept spread rapidly to other European countries, Australia, and the United States.

The ineffectiveness of speed limits and the high cost of enforcement led communities to adopt traffic calming measures that physically constrained vehicle speeds. Traffic calming treatments include measures to reduce vehicle speeds by narrowing the roadway and changing the path of the vehicle with roundabouts and traffic circles, widened sidewalks, raised median strips, chokers, and chicanes. Similarly, measures that make higher speeds uncomfortable, such as speed humps, raised intersections, and rumble strips were introduced. Traffic calming treatments can be applied singly (e.g. speed humps on individual streets) or in combination as part of an area wide strategy. In many cases the success of traffic calming measures has been enhanced by complementary policies, such as publicity campaigns and increased enforcement. In some countries, the change from more traditional roadway intersections with signal, stop or yield control, to roundabouts that effectively reduce speed and the number of potential conflict points, are considered a useful traffic calming measure (see e.g. Fildes and Lee, 1993; Elvik and Vaa, 2004).

While there is a vast amount of research suggesting the success of traffic calming measures around the world with regard to traffic safety (see e.g. Hydén et al., 1995; TRB, 1998; Fildes and Lee, 1993), many of the measures introduced were not considered suitable for urban arterial streets, which serve commuter and commercial traffic and carry emergency vehicles. A further problem is the diversion of traffic and speeding problems to neighbouring streets.

Other physical design aspects have also displayed an effect on driver's choice of speed. Generally the better the quality of the road, the higher the average speed and the numbers of drivers that exceed the speed limit (Varhelyi, 1996). Specific design aspects that are known to influence driver's choice of speed include road width, road markings, number of lanes, road geometry (bends, curves, hills and raised sections), as well as sight distance and visibility, side friction (presence of cyclists and pedestrians on or near the roadway, and parked vehicles) and forms of traffic control and regulation (see e.g. Elvik and Vaa, 2004). Bearing in mind the many factors mentioned above it is also important to note the influence of time of day (darkness) and weather on driver's choice of speed (see e.g. Triggs and Berenyi, 1982; Fildes and Lee, 1993).

3.3 Traffic Control and Regulation

Operational measures can also be effectively used to slow traffic. In neighbourhoods, multi-way stop or yield signs, traffic signals, turn prohibitions, and one-way streets can be used to manage speed. Mainly because such measures require driver compliance, some operational measures (e.g. yield signs) are found to be less effective than other physical countermeasures in reducing driving speeds. If traffic signal systems are correctly set and coordinated with posted speed limits, they can be a highly effective method for controlling travel speeds, particularly on urban collector and arterial roads (see e.g. Taylor, 1997). The implementation of *'green-waves'* through several sets of traffic signals encourages drivers to adopt a more suitable speed to reduce the need for braking, accelerating and stopping, thereby also having a significant positive impact on the environment in terms of vehicle emissions and noise. Taylor (1997) has also suggested that properly coordinated signals systems as opposed to systems that work in isolation, have the ability to be as effective as a reduction in speed limits, e.g. from 60 to 50 km/h, and have significant advantages for the efficacy of a traffic network in terms of reduced delay caused by queues. A major drawback with traffic signals is that the effects achieved through coordination and optimisations diminish with increasing levels of congestion.

Considerable advances have been made in designing and implementing advanced signal control systems. Advanced forms of traffic signalling are often self-optimising and self-organizing catering for different scenarios in large urban and metropolitan areas where there is a need to control traffic and give priority to public transport, e.g. buses trams and commuter rail traffic (Roozemond, 1998). From a safety perspective, improving signal timing can reduce speed dispersion, reduce the occurrence of rear-end collisions, prevent accidents resulting through red-light violations, and provide added protection to pedestrians and cyclists (see e.g. Taylor, 1997).

3.3.1 Advisory Speed Signs

In addition to speed limits, advisory speed signs are also used to provide speed information to drivers. This type of speed information is often posted at hazards such as narrow curves or steep inclines as a warning mechanism. As the name suggests, these signs are advisory and not mandatory. Research suggests that the presence or absence of these signs has little influence on driver's speed choice, particularly for drivers who are familiar with the road. In effect, these signs are no more effective than for example a curve warning sign on its own (TRB, 1998, Varhelyi, 1996). The poor compliance associated with these signs is believed to be due to the fact that they are often based on engineering criteria rather than on human factors knowledge.

A more recent technological development that falls into this category is the use of mobile roadside speedometers that measure a vehicle's speed and then display the speed back to the driver on a variable message sign. In some instances these roadside signs also display information regarding whether or not the prevailing speed limit is exceeded. These signs have become popular in Europe and Australia and are often used along residential streets and outside schools where there are reduced speed zones. Unfortunately, their effectiveness is rarely studied scientifically.

3.3.2 Variable Message Signs and Variable Speed Limit Systems

In many countries, including Australia, new infrastructure based technologies such as variable message signs are often used to inform drivers of crashes, adverse road conditions such as queues, road works, adverse weather conditions, or other factors requiring an increase in awareness and a reduction in speed. These signs are often automated or semi-automated in conjunction with a traffic management and control strategy and can provide timely information as and when it is needed (TRB, 1998).

A form of variable message sign, which has received a great deal of attention by researchers in recent years, concerns those that display variable speed limits. Variable speed limits offer drivers guidance on appropriate maximum (and sometimes also minimum) speed limits following the dynamic real-time monitoring of various conditions that are deemed to require a reduction of the default speed limit. Factors that can influence the speed limit displayed include: the time of day; weather conditions such as fog, rain, ice or snow; the level of congestion; downstream traffic disruptions; and other such variables. This dynamic information is displayed to motorists to inform them of the appropriate speed limit (Parker and Tsuchiyama 1985). Less dynamic forms of variable speed limits are time-based or traffic flow-based. These systems involve changing the speed limit between a default value and a predetermined lower value. This simpler type of system is used on many arterial roads in metropolitan areas in Australia.

More dynamic variable speed limit systems are now commonplace in Europe and the United States, most often as part of a larger motorway control system, but also in urban and metropolitan areas to control the flow of traffic on arterial roads. Germany in particular has an extensive system of dynamic variable speed limits to manage traffic flow under adverse environmental conditions on the autobahns. These systems are reported to be highly successful in reducing crash rates. The Dutch (Van den Hoogen and Smulders, 1994) and, more recently the British (TRL, 1997), have introduced dynamic variable speed limits on their major motorways. The primary purpose of these systems is to improve traffic flow in congested conditions by equalizing speeds in all lanes to achieve speed harmonization. Results from these and other studies indicate that when the variable speed limits are in effect, traffic speeds are more uniform thereby reducing vehicle crashes and their severity. Variable speed signs are well suited to address temporal changes in traffic volumes, speed, and density. More research and knowledge is needed, however to determine the efficiency gains and safety benefits of these systems, particularly on urban arterial roads. A major drawback with these systems is their high cost and maintenance.

3.4 Speed Limit Compliance

Drivers continually make choices about appropriate driving speeds, making their own assessment concerning the amount of risk they are willing to bear. Because drivers have a strong incentive to complete their trips safely, one could ask why they should not be left to choose their own travel speeds.

According to TRB (1998) there are three principal reasons for regulating drivers' speed choices:

- Externalities i.e. the imposition of risks and uncompensated costs on others because of inappropriate speed choices made by individual drivers
- Inadequate information that limits a motorist's ability to determine an appropriate driving speed
- Driver misjudgement of the effects of speed on crash probability and severity

Regulatory intervention is often needed in situations where drivers do not take into account the risks imposed on others by their choice of driving speed. For example, drivers who choose to drive very fast relative to other traffic, or very fast for the prevailing road conditions in exchange for a shorter trip time, may accept the higher risk of death or injury for themselves, but their choice almost certainly increases the risk of death and injury for other road users. Even a single-occupant, single-vehicle crash imposes medical and property damage costs that are not entirely covered by the driver. Other costs in the form of higher fuel consumption or higher emissions resulting from higher driving speeds are not directly paid for from current fuel or vehicle operating taxes. Externalities such as these are often considered to be the major theoretical justification for the imposition of speed limits.

Given that drivers choose their own speed based on their perceptions of relative safety on a stretch of road in conjunction with the posted speed limit, some attempt has been made to influence perceived safety to enhance actual safety. Research to date has however, been contradictory with their effectiveness being dependent on levels of perceived lack of safety (Fildes, Leening and Corrigan, 1989). A typical example is a patterned road surface (transverse road marking) that gives the appearance that one is travelling much faster than would be the case without the treatment. A range of other measures is available, including centre and edge-line treatments; lane-width reductions; curvature enhancements; and delineators, guideposts, and chevrons. Most of these measures are low in cost, although some require continued maintenance to be effective. Thus, they may be appropriate in locations where more expensive treatments cannot be justified. However, their long-term effectiveness in reducing speeds is not well established and often appears to be site dependent (Fildes and Lee, 1993).

3.5 Speed Enforcement

According to TRB (1998), compliance with any regulation such as a speed limit requires that it represents a reasonable constraint on behaviour. It is believed that public support (i.e. willingness to obey) is closely linked with the requirement of '*reasonableness*' of speed limits. For compliance with speed limits to be high, the majority of the driving public must perceive them to be legitimate and comply with them voluntarily. Otherwise they are likely to be disregarded. If attempts are made to enforce unreasonable speed limits, large numbers of violations will result and law enforcement will provide little help in controlling speeds. Further, without strong public support, law enforcement agencies may themselves be reluctant to attempt to enforce the speed limits. A combination of better adapted speed limits, sustained enforcement and education may help to change driver behaviour toward better speed compliance, however this requires a community perception that speeding is a safety problem and a long-term effort to attempt to change attitudes and behaviour towards speeding.

Speed enforcement is probably the most common mediator between a speed limit and driver's choice of speed. There is evidence that drivers respond to perceived enforcement by adjusting their behaviour, most notably by reducing their speed (see e.g. Shinar and McKnight, 1985; cited in TRB, 1998). The effect of enforcement is typically maximal at the site of the perceived enforcement although '*halo effects*' relating to both time and place have been reported. The link between enforcement and crash reduction has been examined by Elvik (1997), who conducted a meta-analysis of studies that evaluated automated speed enforcement in several countries including England, Germany, Sweden, Norway, Australia, and the Netherlands. Elvik concluded that, overall, automated enforcement yielded a 17 percent reduction in injury crashes (16 to 19 per cent at a confidence level of 95 percent). The difference in effectiveness at different locations suggests that it is most effective at crash '*Blackspots*' (i.e. high-crash locations). The issue of whether crashes migrate elsewhere as a result of Blackspot treatments is one that is greatly debated (see e.g. Kloeden et al., 1997).

Generally, the enforcement of speeding laws is based on the assumption that a driver chooses the speed at which to travel through a process of weighing up the perceived advantages and disadvantages of exceeding the speed limit (Fildes and Lee, 1993). The perceived advantages may include such factors as time savings and thrill gains, while the 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 therefore to deter the driver from driving too quickly by increasing one of the disadvantages of speeding, primarily the perceived likelihood of getting caught. Enforcement is also used to detect and apprehend the drivers for whom the increased risk of apprehension alone does not act as a sufficient deterrent.

Australia is one country where speed camera programmes have been used extensively. In New South Wales speed cameras have been associated with a 22 per cent reduction in crashes at speed camera locations. Similarly, in Victoria, the number of speeding motorists was reduced from 24 per cent to 13 percent in the first year of operation. A 32 per cent reduction in crashes on Melbourne's arterials roads was also found during times of the day when alcohol consumption was low, following the introduction of speed cameras, as well as a reduction in the severity of casualty crashes across Victoria of between 28 and 40 per cent, during the early 1990s. Furthermore, a significant reduction was found in casualty crashes within a 1 km radius of the speed camera sites (Rogerson et al., 1994).

In summary, speed enforcement plays an important role in ensuring driver's compliance with posted speed limits and is essential in helping to achieve a safe and sustainable traffic system in the future.

3.6 Vehicles and Speed Limiting Devices

It is important to note that considerable progress has been made in reducing the risk of injury and fatality through vehicle design. Vehicle engineering and technology has come a long way in mitigating the influence of speed in traffic accidents through the introduction of active protection devices such as Dynamic Stability Control and Advanced Collision Warning systems, and passive occupant protection devices such as seat belts and airbags. More recently design attention has also been paid to compatibility between different vehicle types (heavy vehicles, four-wheel drives and passenger vehicles of varying size and weight), and *'pedestrian friendly'* vehicles with sloping fronts to reduce the injuries sustained by pedestrians in collisions with vehicles.

On a more negative note it has been found that improved vehicle design has insulated vehicle drivers from the perception of speeding given better engineering that reduces vibration and the masking of engine and external noise (Varhelyi, 1996). This has led some drivers to report '*subconscious*' speeding as a result of increased comfort. Modern vehicles are also designed to travel much faster than the speed limit although both performance and safety are key objectives of modern vehicle design. Modern vehicles now have passive and active safety features that not so long ago were only found on luxury vehicles. Research suggests that the adoption of such devices in new vehicles (particularly fleet owned vehicles) has risen dramatically in Australia during the recent years.

One of the most direct means of reducing vehicle speed and crash risk is through the introduction of speed limiting devices and intelligent speed adaptation (ISA) devices. Speed limiters (designed to limit maximum speed) are often used to control the maximum speed of heavy vehicles and are common in European countries and Australia. ISA devices have the ability to physically limit the speed of a vehicle in accordance with any predefined speed limit, or alternatively to provide information regarding inappropriate speed and provide warnings when a speed limit is exceeded. ISA is a sophisticated technological system that usually relies on GPS and a digital map containing speed limit information for a particular stretch of road or network area.

Many field and simulation studies have been conducted to examine the effectiveness and acceptability of ISA systems, particularly in Europe. Hjälmdahl (2004) examined the use of ISA in passenger vehicles in urban areas in Sweden with 30, 50 and 70 km/h speed limits. The speed reductions with the device were actually quite small (corresponding perhaps with a generally good compliance with the speed limits or high levels of congestion so that the limit was not often reached anyway). Interestingly, there was a small but overall *decrease* in journey times (0.6 per cent) that was assumed to be due to smoother driving with lower top speeds resulting in less stopping and waiting at traffic lights (Varhelyi, Hjälmdahl, Hyden and Draskoczy, 2004).

The UK External Vehicle Speed Control (EVSC) project made predictions of the injury and fatal accident savings associated with various types of intelligent speed adaptation (ISA) systems, and estimated the costs and benefits of national implementation (Carsten and Tate, 2005). The ISA systems tested included an advisory system, a voluntary ('driver select') system that allowed the driver to deactivate the system, and a mandatory system that could not be overridden. For each of these there were also three variations including: a 'fixed' standard system that uses only speed limit information; a 'variable' system that also took into account sharp horizontal curves; and a 'dynamic' form of ISA that could also respond to factors such as: darkness, wet or icy driving conditions, and traffic conditions in the current network. The predictions for injury and fatal accident reduction for each of these system combinations are shown below in Table 1.

Table 1. *Best estimates of injury and fatal accident savings by ISA system combination (adapted from Carsten and Tate, 2005).*

System type	Speed limit type	Best Estimate of Injury accident reduction (per cent)	Best Estimate of Fatal accident reduction (per cent)
Advisory	Fixed	10	18
	Variable	10	19
	Dynamic	13	24
Voluntary	Fixed	10	19
	Variable	11	20
	Dynamic	18	32
Mandatory	Fixed	20	37
	Variable	22	39
	Dynamic	36	59

As the data in Table 1 indicates, the best prediction of accident reduction was found for the variable mandatory system. According to the Carsten and Tate's (2005) calculations this system could save up to 36 per cent of all crashes involving injury and up to 59 per cent of fatal crashes. The best prediction of accident reduction for the fixed advisory system (such as that used in the various ISA trials in Australia) was a saving of to 10 per cent of all crashes involving injury, and a saving of up to 18 per cent of fatal crashes.

A strategy for ISA implementation was proposed by Carsten and Tate (2005) as part of the work on this project. This took into consideration: the need for further research; decisions by stakeholders and authorities to move forward; legislation and standards development; manufacturing and production; and the establishment of the supporting infrastructure. The proposed strategy would lead to compulsory usage of ISA by earliest 2019 for the more advanced forms of mandatory ISA. This included a period of voluntary usage between years 2013 and 2019. Strategies for the advisory and voluntary types of ISA system were not suggested as the authors considered the mandatory system to be most advantageous from a cost-benefit perspective.

The cost–benefit analyses calculated by Carsten and Tate (2005) indicated a benefit–cost ratio for dynamic mandatory system and suggested implementation strategy of between 12.2 and 16.7 depending on economic growth. In other words, the payback for this system could be up to 16.7 times the cost of implementing and running it. Initial cost–benefit calculations for the simpler fixed advisory system analyses indicated a benefit–cost ratio of between 5.0 and 6.9.

The European PROSPER project has attempted to predict the network impacts of Intelligent Speed Adaptation (Carsten, Tate and Liu, 2006). The broad conclusions from this work are that ISA generally produced small but perceptible benefits in the networks studied. The benefits were limited in some cases due to the fact that the networks were congested. The stronger (mandatory) form of ISA substantially out-performed the softer (voluntary) system although there are clear benefits achieved by both types of systems. In terms of safety and the cost benefit relationship, there was found to be a convincing case for ISA (both for mandatory and advisory systems) despite the extensive time period before ISA was expected to reach a high level of penetration. The authors state that for ISA to achieve its full potential there is a need for a commitment by the various national and European authorities to promote and encourage implementation.

In Australia, significant work in relation to advisory ISA was undertaken as part of the TAC sponsored SafeCar project (Regan et al., 2006). This project evaluated the potential road safety benefits of various in-vehicle Intelligent Transport Systems. Results from this project suggested that ISA has a positive effect in promoting safer driving performance. In particular, ISA was found to reduce the mean, maximum and 85th percentile speeds of drivers as well as speed variability in most speed zones. The ISA system also reduced the percentage of time driver spent travelling above the speed limit, but importantly was not found to significantly increase travel times. Predictions of the potential safety impact of ISA suggested that this system (in isolation of the other systems tested) could reduce the incidence of fatal crashes by up to 8 per cent and serious injury crashes by up to 6 per cent. The advisory ISA system that was trialled proved to be well accepted by drivers. Research into levels of acceptance with different types of ISA systems suggest that advisory systems are generally preferred over mandatory systems, although the mandatory systems usually have a better effect on speed compliance (see e.g. Myhrberg, 2005).

It is also interesting to note that ISA simulator studies conducted as part of the TAC SafeCar project revealed that an informative (advisory) system was slightly more effective in reducing speed than an actively supporting (semi-mandatory) system. Unfortunately, the actively supporting system was not tested as part of the field trial.

3.7 Speed Management as an Integral Part of the Road Safety Strategy

Some years ago the Swedish Parliament took an important step in sanctioning the development of '*Vision Zero*'. In a conference paper concerning the Vision Zero and its potential application in Australia, Tingvall and Haworth (1999) envisaged the end-product of an inherently safe system, which does not generate any serious or fatal injuries, and which should be the ultimate goal of any speed management strategy. The key issue is that the strategy is sustainable and allows substantial investments that will not be obsolete over any foreseeable time-frame. This approach is based on the assumption that there will be a continuing development in vehicle safety and the use of in-vehicle restraints in order to provide the maximum benefit. It is also assumed that road users will be encouraged or forced to use the system in the intended way.

In Sweden, Vision Zero clearly points out that no single factor has as great an impact on safety as speed. It is stated that if everyone were to keep to the speed limit 100 lives would be saved each year. Similarly, each reduction in average speed of 1 km/h is believed to save 25 lives. Of the safety targets stated in mid-2006, a reduction of 4 km/h on municipal streets is believed to save as many as 40 lives and a 6 km/h reduction on national roads as many as 60 lives. The measures to achieve greater speed compliance include the use of: information in relation to speed and road safety, leadership in the private and public sectors, increased use of automated traffic cameras, increased police presence, lower tolerance and higher fines for speeding, the increased use of Intelligent Speed Adaptation and other technologies such as dynamic variable speed limits.

In relation to the Vision Zero philosophy, the concept of maximum tolerable impact speeds for different types of infrastructure facilities has been suggested (Tingvall and Haworth, 1999). It has previously been mentioned that speed limits need to reflect a speed that is considered safe depending on: the function of the road; the composition of the traffic flow (e.g. mixture of pedestrians and motorized traffic); the characteristics of the traffic situation (e.g. the density of at-grade intersections); and the road design characteristics related to design speed, such as horizontal alignment (e.g. road width, obstacle free zones) and vertical alignment (e.g. type of curves, gradients, design consistency).

The traffic system (i.e the interplay between the road, the driver and the environment) should operate such that, in the event of a collision, the forces are not exerted on vehicle occupants or other road users. According to the table, this implies that vehicle speeds should be no higher than 30 km/h where pedestrians are present. Where vehicle to vehicle impacts occur they should be at speeds below the impact speeds at which cars can be shown (through the relevant New Car Assessment Programme) to safeguard occupant life. The speeds suggested by Tingvall and Haworth (1999) are shown in Table 2 below. Maximum tolerable impact speeds in specific common crash types is beginning to be recognised and accepted within Australia. Basically this reasoning is based on the fact that with impact speeds above the specific threshold levels for several important crash categories, the risk of severe injury in the event of a crash rises rapidly. The generally accepted values in Australia are: 70 km/h for head-on collisions; 50 km/h for front impacts with a tree or pole; 50 km/h for vehicle-to-vehicle side-impacts (at intersections); 30 km/h for side-impacts with trees or poles; and 30 km/h for impacts with a pedestrian.

Table 2. *Suggested maximum tolerable impact speeds related to the infrastructure, given best practice in vehicle design and 100% restraint use (from Tingvall and Haworth, 1999).*

Type of infrastructure and traffic	Maximum tolerable impact speeds (km/h)
Locations with possible conflicts between pedestrians and cars	30
Intersections with possible side impacts between cars	50
Roads with possible frontal impacts between cars	70
Roads with no possibility of a side impact or frontal impact (only impact with the infrastructure)	100+

Scully and colleagues (2007) point out that these maximum tolerable impact speeds should be interpreted as indicative only, given that there are many variables that influence the level of risk in a crash (e.g. the age of the pedestrian or vehicle occupants, the design features of the vehicles involved, the specific points of impact, and the types and properties of the roadside objects struck). These threshold impact speeds also appear to have been adopted by the SWOV Institute of Road Safety Research in the Netherlands (Wegman and Aarts, 2005).

The Australian Safe System approach follows to a large extent the Vision Zero philosophy as part of a conceptual framework for road safety management. The Safe System approach assumes that accidents will happen and therefore the road system should be designed and built to protect road users and reduce the number of deaths and serious injuries. This approach aims to create a safer road environment in which responsible and alert road users should not lose their lives or be permanently disabled as a result of a crash in the road system.

The key elements of the Safe System approach are:

- Safer road and roadsides - improving the infrastructure of Australian roads and roadsides to reduce the likelihood of crashes, and the likelihood of death where a crash does occur
- Safer vehicles – increasing the proportion of vehicles on Australian roads with high standard safety features to reduce risks for all road users
- Safer road users - increasing the safe behaviour of road users by tackling areas such as speeding, drink driving, fatigued driving and driver distraction, and by focusing on particular groups of road users

The Victorian Government has for the first time formally incorporated the Safe System approach into its ten year (2008-17) *arrive alive* road safety strategy named. The a*rrive alive* strategy recognises that road safety is a shared responsibility and that all road users in Victoria must play their part in reducing road trauma. A key goal of the a*rrive alive* strategy is to reduce deaths and serious injuries by 30 per cent during the ten year period (2008-17). By the end of 2017 it is envisaged that the strategy will save an additional 100 lives per year, prevent over 2,000 serious injuries, and reduce the severity of serious injuries sustained by road-users (see: www.arrivealive.vic.gov.au).

The first of several *arrive alive* action plans sets out a comprehensive range of initiatives designed to address the key elements in the Safe System approach. The *First Action Plan (2008-2010)* has been developed in consultation with the Victorian community and is delivered in partnership with road-users, state government agencies, 'RoadSafe' community road safety councils, professional organisations, community groups and others. The action plan includes new campaigns, projects and investments delivered across eight areas of action, including: public education, enforcement, infrastructure, technology, legislation, licensing, occupational health and safety, and research and data.

The Victorian Government recognise the problem of speeding and inappropriate travel speeds, which are believed to directly contribute to at least 30 per cent of the fatalities on Victoria's roads each year. The *First Action Plan* introduces a number of different activities and actions including new public education campaigns and tougher enforcement activities to reduce speeding and the number of fatalities and serious injuries caused by speeding in Victoria. The planned activities and actions are listed below:

- **Public education** - Undertake media and targeted campaigns to: increase road user understanding of how and why speed limits are set; encourage travel speeds that are appropriate to the conditions, not necessarily the posted speed limit; raise awareness of Victoria Police enforcement activities; and encourage consumer take up of vehicles with intelligent speed assist (ISA) and top speed limiting ignition systems.
- **Enforcement** - Improve road user compliance with speed limits by: targeting heavy vehicle speed limiter compliance; targeting high crash risk locations through increased use of marked and unmarked police patrols; introducing new technology in police vehicles to detect speeding vehicles (on-coming and following) while the police vehicle is in motion; reviewing and considering potential new speed management technologies; implementing police vehicle video technology to record speeding behaviour and assist enforcement; and redeploying existing cameras to emerging high risk locations to ensure maximum benefit from available camera technology.
- **Infrastructure** - Increase the conspicuousness of speed zones. This includes: expanding the use of specific speed zones (such as 40 km shopping strips) to protect vulnerable road users such as pedestrians; installing electronic speed limit signs at selected sites around schools; and undertaking trials of electronic warning signs at hazardous locations.

- **Technology** Implement systems that will allow intelligent speed assist technology to function across Victoria. Intelligent speed assist (ISA) automatically warns a driver when they intentionally or inadvertently travel over the speed limit. Most ISA systems establish the position of the vehicle on the road, and compares the current speed of the vehicle with the speed limit at that location. The system then issues audible and visual warnings if the vehicle exceeds this limit.
- **Legislation** Review penalties for speeding to ensure that penalties more accurately reflect the risk to the community (such as tougher penalties for repeat speeding offenders) and ensure that the sole objective of these penalties is aimed at, and is recognised by the community as, achieving improved road safety. This involves: a review the Road Safety Act and Regulations to simplify and clarify road safety laws; implementing a trial of a driver general road safety awareness course that would remove three demerit points from a driver's licence; and implementing a trial of a scheme that would enable drivers to cancel demerit points for speed offences through voluntary installation of an intelligent speed assist (ISA) system in their vehicle at the driver's own cost.

Chapter 4 Changes in Speed Limits and the Impact on Mobility and the Environment

4.1 Factors that Influence the Speed – Mobility Relationship

A general and often misleading assumption made by drivers is that an increase in speed will lead to a proportionate decrease in travel time. Particularly in the urban environment however, drivers must frequently stop or slow down for different forms of regulatory control at intersections (traffic signals, stop signs or yield signs), pedestrian crossings, rail crossings and reduced speed areas near schools and shopping zones. Researchers have commonly found factors such as a lack of traffic signal coordination and critical lane volume to capacity (V/C) ratios to play an important role in explaining delays and travel time variations (see e.g. Levinson, 1998). Particularly in urban and metropolitan areas, drivers are affected by congestion where preceding vehicles do not allow the adoption of a discretionary free-flow speed. Furthermore, the prevalence of intersections and multitude of other types of road-users in the urban environment causes large variance in individual speeds, even during off-peak periods.

It is widely assumed that changes in speed limits affect travel times through changes in mean speed. However, the TRB (1998) states that travel time is more dependent on congestion and roadway design and geometry factors than on the posted speed limits. This is exemplified by earlier research that indicated that the National Maximum Speed Limit in the United States during the oil crisis in the early 1970s had a greater effect on travel time on rural interstate highways than on urban collector roads. Similarly, a greater impact on travel time was experienced by commuter drivers and commercial truckers with longer trip distances as a result of congestion on rural interstate roads and greater levels of exposure compared to other drivers.

Congestion or high traffic volume is known to play an important role in determining speed. Fundamental traffic engineering literature suggests that as traffic volume and density increases, the travel speed decreases (see e.g. May, 1990). Traffic safety research also suggests that accident rates tend to increase with increasing traffic volume, although there is generally a threshold effect at higher volumes due to the fact that traffic flow becomes severely restricted and eventually limits the speed at which vehicles can travel. The safety benefit of increasing traffic volume is often demonstrated in relation to multi-lane highways, where flow rates over 1,400 passenger cars per hour/lane have been shown to result in speed decreases (Highway Capacity Manual, 1985; cited in Várhelyi, 1996).

During times of congestion, posted speed limits are often believed to have little effect on driving speed in urban or metropolitan areas, except during the build-up of queues and their later dispersion. It can therefore be argued, that reducing a speed limit by 5 or 10 km/h during peak hours when and where the level of congestion is high is unlikely to result in any significant safety benefit (see e.g. Noland and Quddus, 2005). Reduced speed limits are likely to have their greatest safety impact at low to medium levels of traffic density where traffic is periodically able to travel at or near the speed limit. At traffic density levels where a flow can be maintained, it is theoretically possible that lower speed limits could actually bring about a reduction in overall travel time through a smoother and more harmonic traffic rhythm. For such an effect to be achieved, however, it is likely that the traffic regulation system (e.g. traffic signals and variable speed limits) would need to be adapted accordingly.

There are few practical field studies reported in the literature to support the notion that reduced speed limits in urban or metropolitan traffic networks actually can reduce travel time or improve network efficiency. Traffic simulation work in relation to ISA in the EU PROSPER project has, however, shown indications that travel times remain relatively unchanged (Carsten et al., 2006) when speeds are restricted to the speed limit (and average speeds are reduced), and work by Taylor (1997) in relation to reductions in urban speed limits in Adelaide has shown evidence of reduced delays that are believed to be due to a smoothing effect on traffic flow and speed.

A harmonisation of traffic flow is usually one of the goals of advanced motorway control systems that incorporate a dynamic variable speed control system, such as that on the M25 ring road in London, UK (Highways Agency, 2006). While the impact of lowering speed limits on travel times remains questionable, there is good evidence to suggest that they are likely to generate less lane-changing friction, less speed dispersion, and greater headways which consequently result in less shock-waves and therefore fewer accidents on urban motorways and urban arterial roads (see e.g. Shafer and Rietveld, 1997; Matsuki et al., 2002, Noland and Quddus, 2005).

Congestion problems in urban and metropolitan areas can be relieved to some extent through suitable traffic management and control strategies that often utilize new technology, including advanced forms of signal control. If implemented correctly, traffic management and control strategies can improve traffic network performance and mobility without having a negative effect on safety (see Taylor, 1997; 2000). Taylor also suggests that the effects of well-coordinated signals can encourage the adoption of travel speeds that correspond more closely to the speed limit. This may also have the effect of generating a smoother traffic flow which can reduce travel times. The effects of such measures are believed to be as effective as lowering speed limits. Signal coordination optimization can be difficult to achieve and often provides little advantage during peak hours. Traffic signal coordination may also require some adjustment following the introduction of lowered speed limits if there is a resulting impact on design speed and saturation flow.

It is interesting to note that the presence of other road users such as pedestrians and cyclists on the roadside has generally been found to have little effect on driver speed. For example, the presence of children on the roadside was found to have little or 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). Várhelyi (1996) conducted a review of vehicle speeds at zebra crossings when pedestrians were present (waiting to cross) and found that this had little or no influence on the speed of approaching vehicles. Presently, there is a move in many European countries such as Sweden, the UK and the Netherlands to design the roadway to suit the needs of all road-users, particularly in the urban environment. The need for a sustainable road transport system in the future has brought about an understanding of the fact that roads with different functions should have different priorities for different road user classes (TRB, 1998).

Other research has also shown that maintaining short headways, changing lanes and other aggressive behaviours such as accelerating hard from traffic lights and other stops are often exhibited by drivers in the erroneous belief that they will reduce their journey time (RACV, 1990). The differences in travel time between aggressive and non-aggressive drivers in motorway conditions were also compared in a recent experiment conducted by the University of Queensland, (Panwai and Dia, 2006). In this study, aggressive drivers were found to reduce travel time by as little as one minute for a 44 km journey. In addition, the fuel consumption and CO_2 emissions from aggressive driver's vehicles increased by as much as four times that of non-aggressive drivers (RACV, 1990).

The insight that travel speed is dependent on factors such as road type, levels of congestion, and driver's personal speed preferences, suggests that the relationship between speed limits and travel time is relatively complex. Given that average trip distances in metropolitan areas are relatively small (see e.g. Robertson and Ward, 1998), it is interesting to see how much additional time is needed for a 10 kilometre journey when the average speed is reduced by 5 km/h. Figures to this effect are presented in Table 3 below.

Table 3. *Extra travel time on a journey of 10 km when average speed is reduced by 5 km/h.*

Original Speed (km/h)	35	45	55	65	75	85
Reduced Speed (km/h)	30	40	50	60	70	80
Travel Time Difference (mins:secs)	*2:51*	*1:40*	*1:05*	*0:46*	*0:34*	*0.26*

The data shows that the effects of a 5 km/h reduction in travel speed are greater at lower speeds. When average speed is reduced from 55 to 50 km/h there is a difference of only 6.5 seconds per kilometre (i.e. additional travel time). It is also important to note that reductions in travel speeds over 60 km/h bring about dramatic decreases in crash risk.

4.2 Rezoning Speed in Urban/Metropolitan Australia

In 1996 in Australia a decision was reached by the federal government not to reduce the current default urban speed limit (DUSL) from 60 km/h to 50 km/h. However, the 50 km/h DUSL was trialled in New South Wales in 1997, and soon thereafter by all other States with the exception of Northern Territory. In the lead up to re-zoning many 60 km/h residential zones to 50 km/h zones, Cairney and Donald (1996) suggested that any journey time increases due to lowered speed limits would be negligible. Their argument was that the main source of delays on such roads relate to intersections, traffic hold-ups and negotiating corners – all situations generally unaffected by the prevailing speed limit. Reviewing the Unley (South Australia) experience of setting a city-wide 40 km/h speed limit (the Lower Urban Speed Limit or LUSL project), Dyson, Taylor, Woolley and Zito (2001) noted that travel times increased only by a small degree and not in proportion to the reductions in the posted speed limits. It was also proposed that smoother traffic flow may have served to minimise the losses in travel time.

In research reported by SMEC and Nairn (1999), the effect of reducing cruising speed on travel time was simulated for Melbourne traffic during morning peak hours. Results indicated that reducing the speed limit on all roads by 10 km/h would, in the short term, result in an increase in travel time of up to 5 per cent (reducing down to 1 per cent in the long term due to behavioural adaptation), but also bring about a 13.5 per cent decrease in accidents. With a reduction of 10 km/h for roads other than freeways, travel time was found to increase by only 3 per cent (reducing to 0.6 per cent in the long term), with a 10.3 per cent decrease in accidents.

Taylor (2000) has also used a simulation approach to study urban traffic under a number of different scenarios including varying speed limits and different congestion levels. The model was used for examining the potential outcomes of engineering modifications to the actual network. Although there was no direct measure of safety, the lowering of speed limits represents implicit safety reductions given known speed-risk relationships such as that described by Nilsson. Taylor found that regardless of congestion level and speed limit (40, 50 or 60 km/h), and whether traffic signals were coordinated or un-coordinated, predicted mean travel speeds were always less than the posted speed limit. Further, increases in the speed limits from 40 to 50 to 60 km/h produced proportionate increases in average journey speed. As congestion increased, delays at signalised intersections were lengthened and the opportunities to accelerate to the posted speed limit were reduced.

Taylor (2000) also found a reduction in delays at lower speed limits that were believed to be due to smoother flowing traffic. Interestingly, overall fuel consumption and emissions were found to be higher for the lower speed limits. Of the three speed limits, 60 km/h (with coordinated traffic signals) resulted in the best overall system performance outcomes. This work confirmed some of the earlier findings of Cairney and Donald (1996) for Austroads who had investigated the effects of imposing a 50 rather than 60 km/h speed limit for local streets.

In a report prepared for the National Road Transport Commission, Haworth, Ungers, Vulcan and Corben (2001) modelled the travel times costs associated with a national decrease in the general urban speed limit from 60 to 50 km/h. They found that a 50 km/h default urban speed limit on local streets, collector roads and arterial roads would, on the assumption of a 5 km/h reduction in travel speed, result in the prevention of an estimated 3,000 casualty crashes and an increase in average travel time per trip of less than 10 seconds. Further, they found that a 10 km/h reduction in average cruise speed would prevent over 8,000 casualty crashes per year while at the same time increasing average travel time by less than 26 seconds per trip.

The actual effects of the lowered default urban speed limits (DUSL) in different Australian States were mentioned briefly in Section 2.2 in relation to potential safety impact. This information is reiterated here with more detail regarding impact and levels of community support. In New South Wales the RTA predicted a 25.3% reduction in the risk of being involved in a crash based on 21 months of crash data. This corresponded to 262 fewer crashes. Perhaps not surprisingly, pedestrians and cyclists were found to benefit most from the new 50 km/h DUSL. An analysis of the data also showed that mean travelling speeds dropped by only 0.94 km/h on 50km/h roads, and that there was a high level of community support for the lower speed limit with 75 per cent approval among 6,814 respondents (RTA, 2000; cited in Woolley, 2005).

Similar levels of community support were also found in Queensland where the effects of the 50 km/h DUSL were believed to have brought about a reduction of 8 per cent in casualty crashes and an 18 per cent reduction in fatal crashes. A reduction in travel speeds by approximately 5 km/h was also reported (Walsh and Smith, 1999; cited in Woolley, 2005). Woolley points out that the findings from Queensland were reported relatively soon after the introduction of the DUSL and therefore should be treated with caution. More recent findings suggest a 23 per cent yearly reduction in casualty crashes and an 88 per cent reduction in fatal crashes with significant reductions in travel speed and the proportion of excessive speeds.

In a recent report by Horeau and colleagues (2006) the effects of the DUSL were estimated for Victoria. An overall reduction of 12 per cent in casualty crashes was suggested between February 2001 and December 2003 along with what was described as a sustained reduction in fatal and serious injury crashes involving pedestrians (approximately 25 to 40 per cent). Average travel speed was reported to be only slightly lower (approximately 1 per cent).

In Western Australia, average travel speeds were found to have decreased as a result of the DUSL by slightly more than 1 km/h. Furthermore, there was a significant reduction in the number of drivers exceeding the speed limit by more than 10 km/h (Kidd and Radalj, 2003; in Woolley, 2005). A metropolitan analysis indicated a 21 per cent net reduction in casualty crashes with a 51 per cent net reduction in crashes involving pedestrians (Horeau and Newstead, 2004). In Australian Capital Territory there was a non-significant 2.1 per cent reduction in police reported crashes in the two years after the introduction of the DUSL, while mean travel speeds (main collector roads) were found to be 2 km/h lower on 50km/h streets (a similar reduction was also observed on unchanged 60 km/h streets). Community support for DUSL remained high at 70 per cent (Green, Gunatillake and Styles, 2003; cited in Woolley, 2005). No analysis was conducted in Tasmania although Woolley (2006) reports that there were 89 fewer casualty crashes in the year following the introduction of DUSL.

Finally, in South Australia the 50 km/h default urban speed limit was estimated to have been responsible for a 20 per cent reduction in casualty crashes. This estimate was based on data from the year prior to the DUSL introduction and data from the year after the 50 km/h limit was imposed. An overall 2.2 km/h drop in average travel speed was found. These results were found to coincide with average travel speed reductions (0.7 km/h) on arterial roads where the speed limit remained unchanged. These changes also brought about a 4.6 per cent reduction in casualty crashes (Kloeden, Woolley and McLean, 2004; cited in Woolley, 2005).

The findings related to the introduction of the 50 km/h DUSL show significant reductions in crash trauma despite relatively small decreases in overall average speeds. Furthermore, it appeared that there was a high level of community support in the years following the introduction of the 50 km/h DUSL. Woolley (2006) points out that it is vulnerable road users that gain most benefit from the speed reduction. Adapting speed to suitable levels in areas where there are large numbers of vulnerable road users was one of the main reasons for the introduction of DUSL. Woolley (2006) suggests that the reduction in average travel speed on other non-DUSL roads found in Australian Capital Territory and South Australia is an added benefit that hopefully will be retained in the future.

A recent paper by Langford and Fildes (2007) used urban crash data to estimate the possible benefits of an 'across-the-board' 50 km/h speed limit for all undivided urban streets and roads with a present speed limit of 60 km/h. Based on various assumptions (e.g. that two-thirds of all casualty crashes on urban arterials occurred on undivided roads) the authors suggest that an extension of the 50km/h default urban speed limit to all 60km/h undivided streets would result in an overall 12% reduction in casualty crashes and a crash reduction of 6% for all urban crashes. The estimated changes in casualty crashes were made using Nilsson's formula where a reduction in average travel speeds of 5 km/h to 45 km/h on residential streets and 50 km/h on urban arterial roads was used. Given the larger number of casualty crashes on urban arterials (including state roads and arterials), this category of road produced by far the greatest saving.

Langford and Fildes conclude with recommendations regarding proposed changes in speed limits in urban areas in accordance with Tingvall and Haworth's (1999) suggestions (see Section 3.7) in order to meet the needs of the Australian Safe System approach.

4.3 Environmental Impact

4.3.1 Energy Efficiency

At the Australasian Road Safety Conference in Melbourne 2007, guest speaker Claes Tingvall of the Swedish Road Administration (SRA) presented a number of future trends in traffic safety that were also corroborated by the SRA Safety Director Anders Lie (Tingvall, 2007). One of the most important questions for debate raised by Tingvall concerned whether or not energy efficiency would take over as the main issue for speed management in the future. The reasoning behind this predicted shift in importance among transport system objectives is due to the increasing awareness of climate changes and increased fuel prices that are anticipated to have a profound impact in terms of travel patterns, road design, traffic management, speed, vehicle design, etc. Tingvall points out that future transport system targets will also refer to energy efficiency, which in the future must involve renewable sources.

4.3.2 Fuel Use and Vehicle Operating Costs

There are a number of studies that have been conducted to estimate the reduction in fuel consumption following a reduction in vehicle speed. Many of these studies from different European countries are included in a report by the OECD/ECMT (1996). In France, for example, it was concluded that there would be a saving of 350,000 tonnes of oil (1.4 per cent) by car drivers if the speed limits were fully complied with. Similarly, in the Netherlands, when speeds on motorways were heavily enforced bringing about a drop in mean speed from 111 to 104 km/h, there was a saving of 40 million litres of petrol and a similar amount of LPG. In New Zealand in 1996, it was estimated that an increase in speed limits from 100 to 110 km/h would increase fuel consumption by around 10 per cent (Waring, 1996).

In 1990 the Royal Auto Club of Victoria (RACV) conducted a study looking at the effect of driving styles on fuel consumption. The testing took place over a 61 kilometre course along a range of Melbourne road types. Using a new set of vehicles, they repeated the test in 2000 (RACV 2000). They found a difference of less than five minutes in journey time between aggressive (but not speeding) driving, which included behaviours such as accelerating quickly away from traffic lights, and smoother driving. Using three different light vehicle classes, they found up to a 30% difference in fuel consumption for the trip in a large passenger car. In fact, a large car driven smoothly achieved better fuel economy than a small car driven aggressively. They also found that there was no significant journey time increase related to smoother driving.

Besides the cost of increasing fuel, there are a number of other operating costs such as tyre wear and mechanical wear that tend to increase with increasing speed. These costs are most significant for truck fleets such as those of logistics companies where the heavy vehicles cover a high mileage each year. Generally, however, the increased costs of fuel consumption with higher speed far outweigh other operating costs (TRB, 1998). Small changes in vehicle operating costs other than fuel are less likely to be noticed by private vehicle drivers and thereby are unlikely affect speed choice. There appear to be few studies in the literature that suggest how the cost of fuel (petrol) for private individuals might influence individual's speed behaviour. Considerably more is known about how transport costs can influence people's choice of transport modality.

4.3.3 Emissions

Motor vehicles are reported to be the largest single contributor to urban air pollution in Australia's major cities. The Australian Government has launched the "Green Vehicle Guide" as an initiative to promote more environmentally friendly forms of motorised transport (see www.greenvehicleguide.gov.au). On the Green Vehicle Guide website, it is reported that cars contributed 41.7 million tonnes of carbon dioxide or equivalent greenhouse gases in Australia in 2004. Further, trucks and light commercial vehicles contributed 26.2 million tonnes. In total, vehicle emissions represent 12% of Australia's total air-pollutant emissions including hydrocarbons, nitrous oxides and fine particles. The emissions statistics show a 25 per cent increase since 1990. There are two major concerns associated with car exhaust emissions:

- Air-pollutant emissions such as: carbon monoxide, nitrogen oxides, particulate matter, volatile organic compounds, benzene that contribute to urban air pollution. Air pollutants such as these can contribute to urban air quality problems and can adversely affect human health and the health of other living things.
- Greenhouse gases, primarily CO_2, that contribute to climate change, but are not recognised as air-pollutants *per se*. Other greenhouse gases besides carbon dioxide include nitrous oxide and methane. The level of CO_2 emission is known to be directly related to the amount of fuel consumed by the vehicle, and the type of fuel used.

There are large differences in the air pollutants and greenhouse gases emitted by motor vehicles. A key objective of the Green Vehicle Guide is to provide advice on more environmentally friendly vehicles. This is done through a rating system that assigns a value to different vehicles that takes into consideration both air pollutants and greenhouse gas emissions. The vehicle ratings displayed in the Green Vehicle Guide (GVG) are based on the results of testing conducted in accordance with current standards including ADRs for emissions and fuel consumption labelling.

Vehicle emission standards are of great importance for minimising air pollutants and greenhouse gas emissions. Before a road vehicle can be registered for the first time in Australia it must comply with the Motor Vehicle Standards Act 1989. The Act applies to new and used imported vehicles and locally manufactured vehicles. The Act requires vehicles to meet national standards covering safety and environmental requirements. The present emissions standard for new cars in Australia is ADR (Australian Design Rule) 79/01. This standard replaced the previous emissions model in 2005 for lighter vehicles. Similarly, the current standard for heavy vehicles is ADR 80/01, which replaced the earlier standard in 2006. The Australian standards are harmonised with the vehicle standards developed by the UN Economic Commission for Europe (European emissions standards Euro 2, 3 and 4). More stringent UN standards (Euro 4) have been developed and may come into effect in Australia from mid-2008.

All new vehicle models up to 3.5 tonnes gross vehicle mass sold in Australia are also tested to determine both the fuel consumption and the level of CO_2 emissions. This is currently done in accordance with ADR81/01 Fuel Consumption Labelling for Light Vehicles. A new standard, ADR81/02 has currently been drafted which prescribes the requirements for the measurement of vehicle fuel consumption and carbon dioxide (CO2) emissions, and the design and application of fuel consumption labels to vehicles. This revised ADR is expected to be introduced in 2008-2009.

All vehicles are tested to the same test procedure under carefully controlled conditions in specialised vehicle emission laboratories in accordance with the ADRs. This means that comparsions, such as those in the Green Vehicle Guide, can be made. The test methods adopt internationally recognised United Nations ECE Regulations (ECE R83 and ECE R101). It is recognised however, that no test can simulate all possible combinations of conditions that may be experienced on the road in real-world emissions where fuel consumption may vary depending upon a number of factors including driving and road conditions, driver behaviour and the condition of the vehicle. Fuel consumption and emissions levels depend greatly on the mode of the vehicle throughout a journey; in other words, the proportion of time and/or distance spent idling, accelerating, decelerating or cruising. The speed profile is therefore a more important factor in determining fuel consumption and emissions levels than, for example, measures of average speed. Research shows that the effects of travel speed on fuel consumption and emissions are often distorted by incomplete descriptions of what is actually being measured (see e.g. Haworth and Symmons, 2001).

Generally, higher speeds result in higher emission levels although this is not necessarily true for the individual pollutants (ECMT1,996). Research in this area has produced a number of emissions models to describe the interaction between various types of emissions and varying speed levels. One such model is VETO (see Figure 6 below). According to VETO, carbon monoxide (CO) and the oxides of nitrogen (NOx) are at a minimum around 40 km/h, while particulates are minimal at around 50 km/h. Hydrocarbons appear to remain relatively stable showing a slight decrease with higher speeds

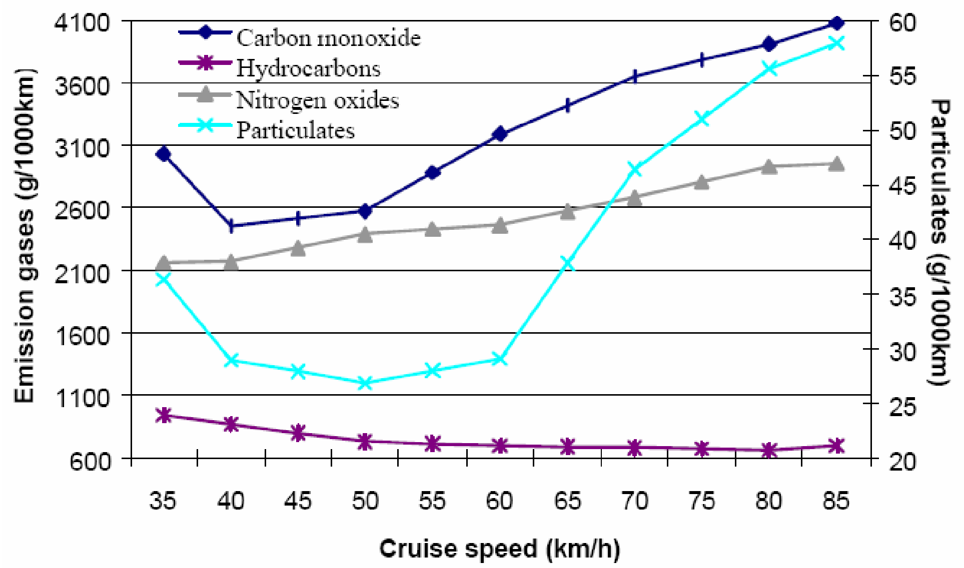

Figure 6. *Gaseous emissions as a function of speed (from Haworth and Symmons, 2001, based on Ward et al., 1998).*

The data shown in Figure 6 is from Europe and is now over 10 years old. Due to the changes in emissions standards (in Europe) during the past 10 years these average emissions curves presented originally by Ward and colleagues may no longer be representative of present day vehicles. They do, however, demonstrate general trends relating to the speed-emissions relationship. It is also noteworthy that carbon dioxide (CO_2) is not included in this diagram. This is due to the fact that CO_2 is not recognised as an air pollutant (as mentioned earlier), and perhaps also the fact that climate change and greenhouse gases have become a more accentuated problem in recent years. A number of curves relating emissions to constant vehicle speeds have been generated in other research although many differ significantly to those presented by Ward and colleagues (see e.g. Andre and Hammarstrom, 2000; cited in Haworth and Symmons, 2001).

There are a number of studies that have examined the relationship between changes in speed limits or mean speeds and vehicle emissions. In Austria, when the speed limit was lowered from 130 to 100 kph, there was a 17 per cent reduction in NO*x* emissions and a 25 per cent reduction in CO2 emissions (OECD/ECMT, 1996). Similarly, when the mean speeds on motorways in the Netherlands decreased from 111 to 104 km/h, CO2 emissions decreased by 34 per cent and NO*x* emissions by 5 percent. Research from Germany has also shown some interesting results. The implementation of traffic calming in German residential areas was found to actively reduce vehicle idle times by 15 per cent, gear changing by 12 per cent, braking by 14 per cent and fuel use by 12 per cent, thereby having a significant positive environmental effect (Newman and Kenworthy, 1999). Other research in Germany has also indicated a 10 per cent reduction for hydrocarbons and a 32 per cent reduction for NOx emissions when aggressive driver's average speed is lowered from 31 to 19 mph. Furthermore, reductions of 22 per cent were noted for hydrocarbons as well as a 48 per cent reduction for NOx emissions, when average speeds were reduced for drivers who adopted a calmer driving style. There is also research from several countries, including Australia, which suggests that improved traffic regulation (mostly better signal coordination) can have a significant positive impact on emissions (see e.g. Newman and Kenworthy, 1999; Frey et al., 2000; Taylor 2000; Rakha et al., 2000; Ahn et al., 2002).

A project carried out by the Department of Civil Engineering at North Carolina State University looked at, amongst other things, the modal distribution of travel time, travel distance, fuel use and emissions for a sample commuter trip (the project is reported in Frey et al., 2001; and on the website: www4.ncsu.edu/~frey/emissions/measurements.html). The data for this 10 mile (16 km) commuter trip is summarised in Figure 7 below. The trip included 20 signalised intersections. It is also reported that vehicle cruising speed varied between approximately 20 and 30 mph (30-50 km/h) on city streets, and between approximately 40 and 50 mph (65-80 km/h) on primary arterials.

The data shown in Figure 7 indicates that 20 per cent of the total time spent on the trip was associated with idling (with no distance travelled). This resulted in less than 10 per cent of the total amount of emissions. In contrast, acceleration occurred for 18 per cent of the total time of the trip (and coincidentally 18 percent of the total distance travelled). However, the time spent accelerating also accounted for the largest proportion of the total air pollutants (35-55 per cent). Furthermore, with the exception of carbon dioxide, emissions during cruising were far less than during acceleration despite the fact that cruising amounted to 70 per cent of the distance travelled and 35 per cent of the total time.

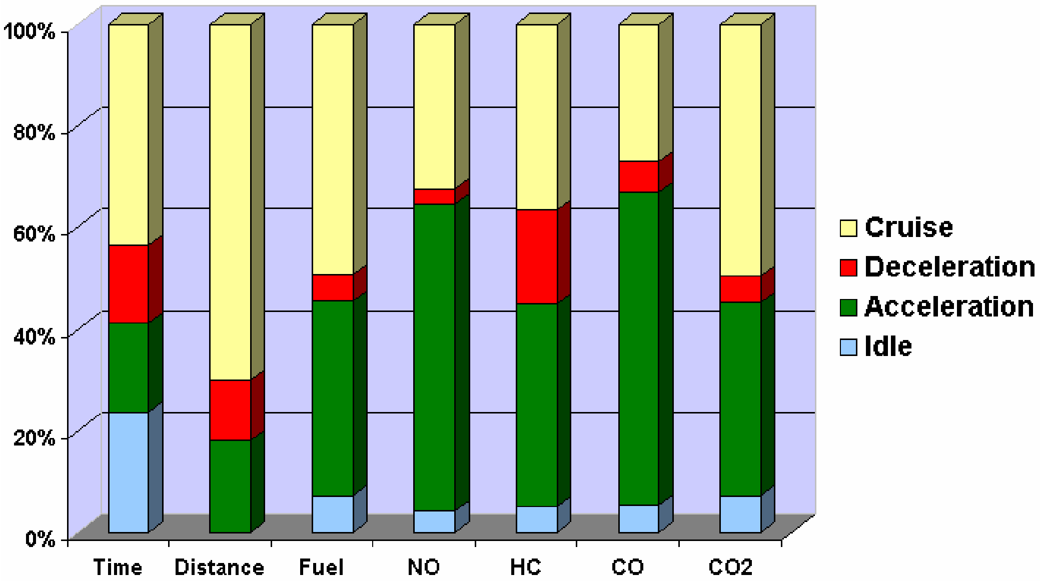

Figure 7. *Distribution of travel time, distance, fuel usage and emissions during a sample commuter trip (from website: www4.ncsu.edu/~frey/emissions/measurements.html)*

There is often concern that lower speed limits will result in less fuel-efficient driving and greater levels of emissions as a direct result of more idling, more stop-and-go traffic, and more gear changes. Although dated, there is some evidence to suggest that constant speeds of 40 km/h use less fuel than constant speeds of 50 km/h; and similarly that constant speeds of 50 km/h use less fuel than 60 km/h. On the basis of these findings Haworth and Symmons (2001) suggest that lower residential speed limits with well-placed traffic-calming measures may discourage drivers to accelerate, thereby providing better fuel efficiency and generating fewer emissions.

Swedish research has shown that constant speeds of 30 km/h tend to use more fuel than constant speeds of 50 km/h (Ministry of Transport and Communications, 1997; cited in Haworth and Symmons, 2001). However, this research also indicated that vehicles travelling at speeds of around 30 km/h use less fuel in starting and stopping conditions than vehicles travelling in similar conditions at around 50 km/h. Other earlier research suggests that the widespread use of traffic-calming measures such as speed humps may have negative impacts on emissions, while street or area-wide reductions in speeds (e.g. reduced speed zones) often have a more positive effect (see e.g. Haworth and Symmons, 2001). This corresponds with the concept that engineering and enforcement measures that generate slower, smoother and more uninterrupted traffic flows are likely to have a positive overall impact on emissions (see e.g. Newman and Kenworthy, 1999).

There is also a wealth of research to suggest that driver training can be effectively used to improve fuel economy and reduce emissions both in urban areas and on rural roads and motorways (see e.g. Haworth and Symmons, 2001). Using positive kinetic energy as an indicator of the smoothness of driving (Nairn et al., 1994; cited in Haworth and Symmons, 2001) estimated the likely reductions in fuel consumption and emissions, as well as fatal crashes, in and around the Melbourne CBD area (see Table 3, below).

Table 3. *Fatality and CO_2 savings from road safety programs in Queensland 1998-2000 from Meers and Roth (2001; presented in Haworth and Symmons, 2001).*

Road safety program	Fatal crashes saved per annum	CO_2-e reduction factor	CO_2-e saved per annum (k tonnes)
Random road watch	80	More consistent driving behaviour, lower speeds	40
Random breath testing	210 [1]	More consistent driving behaviour	40
Speed cameras	82	10% average speed reduction	400
50 km/h local street speed limit	19	10% average speed reduction on 50km/h routes	33
Fatal 4 public education campaign	20 [2]	More consistent driving behaviour	67

1 includes injuries
2 1997/98 data

Differences in fuel consumption and emissions have also been demonstrated in relation to the adoption of slow, conservative driving in comparison to aggressive driving (Dyson et al., 2001; cited in Haworth and Symmons, 2001). Findings such as these have led to the introduction of what is commonly referred to as '*EcoDriving*'. The EcoDriving concept has been widely adopted in Europe and the United States and has been shown to result in considerable savings in fuel economy and emissions (Haworth and Symmons, 2001). The key principles of EcoDriving are now suggested as "Tips for greener motoring" on the Green Vehicle Guide website supported by the Australian Government.

Alternative Fuels

In some jurisdictions such as NSW the use of alternative forms of energy are sought (RTA website: www.rta.nsw.gov.au/environment/vehicleemissions/alternativefuels.html). This includes bio-diesel that is produced from domestic, renewable resources such as vegetable oils that can be used directly in any existing, unmodified diesel engine and Hybrid electric/petrol cars which use up to 50 per cent less fuel than conventionally powered vehicles and produce up to 80 per cent less exhaust emissions. A key advantage of hybrid-electric technology is '*regenerative braking*'. As the name suggests, regenerative braking implies that an electric motor can use electricity to create torque to drive its wheels or reverse the process and use torque to create electricity. Hybrid-electric vehicles with regenerative braking are reported to be particularly advantageous in stop-and-go driving. When a hybrid-electric vehicle slows down, lifting the accelerator or applying the brake causes the system to use the vehicle's momentum to generate electricity so that there is no waste that occurs through a transfer of energy into heat or friction.

4.3.4 Noise

A further environmental effect of higher speed is noise. Australia's cars, vans, trucks, buses and other vehicles are also a major source of noise (and waste). In Australia the need to control noise is recognised by most jurisdictions and there has been a move to better control road traffic noise by: establishing criteria that define acceptable noise levels; establishing standardised methods for assessing and measuring noise levels; and identifying useful strategies that can be adopted to reduce traffic related noise. In Victoria, road traffic noise is recognised as a significant environmental problem, particularly in residential areas. VicRoads has a Traffic Noise Reduction Policy and is committed to reducing overall levels of traffic noise emitted by vehicles and road surfaces by: supporting stringent noise standards in Australian Design Rules for motor vehicles and by encouraging compatible land use next to major roads; limiting traffic noise from new arterial roads and roads upgraded to carry significantly more traffic; and retrofitting noise barriers on older freeways. Other jurisdictions have similar policies, for example, the RTA in New South Wales has a Noise Abatement Program and Environmental Noise Management Manual.

Research in relation to traffic noise suggests that it is produced by two main sources: the power unit of vehicles and the interaction between vehicle tyres and the road (Ward et al., 1998). Generally, the noise from the tyre-road interaction tends to increase with increasing speed, whereas the power unit noise remains reasonably constant across speeds. It has been found that, the noise from the tyre-road interaction dominates the noise from the power unit of the vehicle above the speed range 20 to 40 km/h in newer passenger vehicles. In new trucks, this occurs between 30 and 60 km/h. For older vehicles the tyre-road noise dominates at about 10 km/h higher, due to the higher power unit noise (Ward et al., 1998). The levels of noise emanating from vehicles at speeds of 50 km/h and below is around 80 dB on average, reaching 85 dB at 70 km/h, and increasing to nearly 90 dB at speeds of approximately 90 km/h.

Overall, lower speeds are conducive to lower levels of vehicle noise, particularly if there is a high proportion of heavy vehicles in the traffic composition. It is also important to note that there have been advances in the levels of noise generated by modern vehicles due to new standards and advancements in vehicle and tyre technology since the work of Ward and colleagues.

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Chapter 5 Attitudes toward Road Safety Policy and Speeding

5.1 ATSB Surveys

The Australian Transport Safety Bureau (ATSB) publishes an annual report on community attitudes to road safety, the most recent of which was based on a 2004 survey (Pennay, 2005). There seems to be a general and increasing awareness of the dangers of driving at increased speeds, with 96 per cent of respondents agreeing that a crash at 70 km/h will be more severe than one at 60 km/h (up from 80 per cent in 1995). Additionally, 73 per cent of respondents agreed that if speed was increased by 10 km/h they would be more likely to be involved in a crash, (55% in 1995, and 70 per cent in 2003). Furthermore, 83 per cent of respondents believed that speed limits were generally set at reasonable levels. Somewhat inconsistent with these more positive views regarding speed, was the proportion of respondents who thought that it was okay to speed as long as one drives safely. This figure remained constant at approximately 32 per cent.

For the Victorians surveyed, 31 per cent believed it was okay to speed if driving safely, 79 per cent thought speed limits were generally reasonable, 81 per cent believed that a crash was more likely if they increased their speed by 10 km/h, and 98 per cent thought that a crash at 70 km/h would be more severe than a crash at 60 km/h. There was general support in Victoria for 50 km/h residential speed limits, with about 76 per cent of respondents agreeing that they were "*about right*" (20 per cent believed that there should be more roads set at less than 60 km/h, while 19% said there should be fewer). In 1995, 60 per cent of respondents believed that drivers should be allowed to travel at 65 km/h or more in 60 km/h speed zones, with 26 per cent suggesting 70 km/h as acceptable. In 2004 these rates had declined to 49 per cent and 8 per cent, respectively.

The survey suggests that there is a general awareness regarding the importance of road safety and the fact that increased speed is more dangerous. This is particularly the case in Victoria where only 3 per cent of survey respondents admitted to always, nearly always or mostly driving at 10 km/h over the speed limit, compared with 7 per cent nationally. Additionally, 33 per cent of Victorian respondents stated that their driving speed had decreased over the last two years (3% stated an increase and the remaining 61 per cent stated that it remained the same).

5.2 Surveys in Victoria

TAC speed survey data is presented below in Table 4. The Table shows that approximately 10 per cent of those surveyed in Victoria reported exceeding the speed limit most or all of the time. Importantly, the number of people who report regular speeding shows a positive reduction in 2006 compared to previous years. The data also shows that the majority of people consider 5 km/h over the speed limit as speeding, although there is a tendency for this opinion to diminish in relation to 100 km/h zones. The trend over the past 6 years appears to indicate that there is a heightened awareness of exceeding the speed limit by 5 and 10 km/h. While 76 per cent of those surveyed in 2006 suggest that they would drive at the limit even if there was no risk of getting caught, the number of respondents who correctly regard speed limits as a maximum rather than a guide is only 63 per cent. Of those surveyed, one in four had been caught for speeding in the past two years.

Table 4. *TAC speed survey data.*

Measure	2001	2002	2003	2004	2005	2006
Exceed the speed limit all or most of the time	25%	16%	14%	16%	16%	10%
Define 5km/h over the limit as speeding in:						
50km/h zone	n/a	85%	82%	83%	86%	87%
60km/h zone	n/a	72%	71%	71%	84%	84%
100km/h zone	n/a	53%	56%	57%	71%	66%
Caught speeding in last 2 years	26%	30%	37%	35%	24%	25%
10km/h over the speed limit is speeding	69%	85%	79%	82%	84%	84%
10km/h over the speed limit is unsafe	59%	71%	72%	67%	73%	76%
Drive at limit even if know wouldn't get caught speeding	67%	73%	71%	68%	68%	76%
Speed limits are a maximum not a guide	50%	55%	61%	60%	63%	63%

5.3 The Speed Paradox

A study in Queensland by Flieter and Watson (2006) examined the misalignment between driver attitudes and actual speeding behaviour. The researchers found, on the basis of self-reported behaviour and attitudinal measures, that such a '*speed paradox*' actually existed and believed this to highlight the need for a better understanding of the factors that contribute to speeding behaviour. While two-thirds of the participants agreed that exceeding the speed limit is not worth the risks and that it is not okay to exceed the posted speed limit, more than half of the participants (58.4 per cent) reported a preference to actually exceed the 100 km/h speed limit. Mean speeds on urban and rural roads were also found to suggest a perceived enforcement tolerance level of 10 per cent. Factors that significantly predicted the frequency of speeding included: exposure to role models who speed; experience of avoiding punishment, and the perceived certainty of punishment for speeding.

There are also a number of international studies that confirm the findings of Australian surveys (see e.g. Leonard and Wasielewski, 1983; Rothengatter, 1990; Jorgensen and Polak, 1993; Kanellaidis et al., 1995). In particular, a Dutch study suggests that at least on motorways, the relationship between speed and safety is a major consideration for most drivers. However, it is pointed out that the relationship between speed and psychological factors such as, personal freedom and the sensation of driving fast are also important considerations, while environmental externalities are perceived to be less important (Rienstra and Rietveld, 1996).

Chapter 6 Costs and Benefits of Lowering Speed Limits in Urban and Metropolitan Areas

6.1 Traffic Safety Philosophies and the Cost Benefit Approach

Studies and research in Europe and Australia have suggested ways in which the social costs and benefits of increased travel time, decreased road trauma, vehicle operating costs, emissions, noise, etc. resulting from reductions in posted speed limits and their estimated influence on travel speed can be assessed using a common monetary unit (see e.g. Kallberg and Toivanen, 1998, Cameron, 2000). In most cases, these studies suggest significant overall benefits to society as a result of lowering speed limits, although there is some controversy over the different methods used to calculate costs and their compatibility for comparison purposes. Similarly, there are questions related to how appropriate and meaningful it is to aggregate small increments in travel time and whether individual's tasks or activities will be noticeably affected by increases of only a few seconds.

It is important to point out that contemporary traffic safety philosophies, such as the Vision Zero in Sweden and the Safe System in Australia, suggest that no monetary value should be placed on a life and that all measures, such as lowering speed limits, should be taken to ensure sustainability in the transport system with the ultimate goal of preventing all serious injuries and fatalities. In relation to the potential application of Zero Vision in Australia, Tingvall and Haworth (1999) state that the key issue is to ensure the sustainability of the strategy, which should allow substantial investments that do not become obsolete over any foreseeable period. While there is great controversy surrounding the valuation of human life in relation to infrastructure investment, it continues to be used in practice by most road authorities and local councils around the world as a method to prioritise the finite resources that are made available for transport system maintenance and improvement. Achieving a balance among key transport system objectives often involves making difficult prioritisations based on conflicting monetary values for mobility and safety. This is a practice that is widely adopted in many countries including Australia.

6.2 Cost Benefit Analysis and Speed Limit Reductions

In a report written for the National Road Transport Commission, an evaluation was made of the impact of lowering the national default urban speed limit of 60 km/h to allow for a reconsideration of the adoption of a 50 km/h default limit in the Australia Road Rules (Haworth et al., 2001). One of the main considerations for approving the development of this proposal was the influence of speed on the severity of injuries sustained by pedestrians and cyclists, and the need to give higher priority to non-motorized forms of transport. The methodology adopted by Haworth and colleagues (2001) included a review of local and overseas research on the relationship between speed and crashes and the impact of lowering speed limits in urban areas, as well as a consolidation of available information on the implementation and trials of 50 km/h limits. The analysis of costs and benefits used a modified computer spreadsheet that had been developed as part of the European MASTER (MAnaging Speeds of Traffic on European Roads) project to estimate the impact of speed management policies.

As a basis for the various analyses, the reduction in the speed limit was assumed to bring about a reduction in average travel speed (referred to as cruise speed) of 5 km/h. This was based on earlier findings by the BTE (2000; cited in Haworth et al., 2001). The values assigned to travel time costs were adjusted from the Austroads values to be comparable with the method of calculating accident costs. Among the other scenarios that were examined was an assumed 10 km/h reduction in travel speed along with higher and lower monetary values assigned to accidents. There were also a number of other assumptions that led to the estimation of benefits being overly conservative. In particular, some of the emissions and noise data were not included in the calculations, neither were the possible benefits of improved speed compliance on collector and arterial roads, or the benefits of unreported accidents. The associated costs of the reduced travel speeds were however, overestimated due to the fact that route or destination substitution effects and trip suppression effects were not considered.

Haworth and Colleagues (2001) identified a fundamental problem in comparing the costs of travel time for private and business travel by car and other vehicle types, and the cost of crashes at varying levels of severity provided by the Bureau of Transport Economics based on a '*human capital*' approach. The problem is related to the fact that the time lost as a result of lower travel speeds is valued at a higher rate than the time lost as a result of crashes. This problem is well recognised in the research literature. A further dilemma among previous analyses of travel time effects related to reduced speed limits is that related to the meaningfulness of valuing very small changes in travel time across large numbers of vehicles (Hauer, 1994; VicRoads, 2000; cited in Haworth, 2001).

The results of Haworth and colleagues (2001) study suggested that implementing the lower urban speed limit (50 km/h instead of 60 km/h) on local streets, collector roads and arterials would result in an estimated increase in travel time of 9 seconds per trip and per head of population assuming a 5 km/h reduction in average travel speed. Further, if these travel time impacts were acceptable, it was estimated that approximately 2,900 casualty crashes would be prevented per year. The estimated saving in casualty costs was between $12 million and $25.8 million, and the saving in property damage only costs was $22.4 million giving a total safety benefit of between $34.4 million and $48.2 million. Further, the value of reduced emissions was estimated to be in the region of $421,000. In terms of costs, implementation was estimated to cost approximately $2.8 million including signage and media campaigns, while travel time was estimated to cost around $20.3 million per year. Only negligible effects were presumed for commercial vehicles and public transport. The resulting net benefit in the worst case scenario was therefore calculated at $14 million per year, with a best case scenario of up to $34 million.

Haworth and colleagues (2001) point out that the estimated net outcome was dependent on the extent to which it was meaningful to value and aggregate very small increases in travel times at the individual level. If these *are* valued then the default limit of 50 km/h could only be justified for urban arterial roads that previously had a 60 km/h limit. If on the other hand, the smaller increases in travel time *were not* valued (but were subject to exclusion according to minimum threshold level) then all classes of road could be economically justified.

Other cost benefit analyses related to reductions in speed limits have also been carried out. A SMEC analysis from 1999, involving the use of traffic simulation in relation to the morning peak hour, indicated that reducing the speed limit by 10 km/h on all roads across Melbourne or applying the reduction only to non-freeway roads would result in an economic benefit of more than $60 million despite the economic losses due to travel time. They pointed out, however, that a comprehensive review of modelling approaches was needed along with a critical analysis of the variables to be included and excluded.

Other research has also addressed many of the dilemmas involved in these types of analyses. One of the most debatable issues in valuing road trauma and calculating cost benefit analyses for infrastructure projects concerns the mechanism for assigning a value to the loss of a life. In the human capital approach the value of a life saved is derived from the present value of the income they would have earned had they not been killed. Rather than putting a price on a life it is argued that the focus should be placed on reductions in the probability of a fatality, i.e. in the value of preventing a statistical fatality. This relates to the substitution between income and risk, and the willingness-to-pay for all users who would benefit (see e.g. Cameron, 2000).

Arguably, the costs due to loss of life are likely to be significantly outweighed by any economic benefits of travel time savings. Noland and Quddas (2005) attempted to test this hypothesis for London traffic but found only weak support. However, they conceded the results may be different for different (higher) speeds, such as those often experienced on arterials and collector roads in Australian capitals outside peak times. According to Lushkin (1999), time savings generally account for as much as 80 per cent of the estimated benefits when calculating cost benefit analyses for road projects. These calculations are made based on average trip times that remove the randomness due to congestion and incidents. Lushkin also suggests that people are unlikely to use or even properly perceive the small amounts of time they may save on a journey; but that in practice: "*many drivers risk serious accidents for savings of only a few seconds (by weaving between lanes, for instance)*". Other research has also shown that drivers significantly overestimate total trip savings (Matsuki et al., 2002).

Chapter 7 Conclusions and Future Research

On the basis of the literature reviewed, the most important conclusions in relation to the potential impact of lowered speed limits in urban and metropolitan areas are summarised below:

- Lowered average travel speeds brought about by a reduction in speed limits in urban and metropolitan areas will bring about considerable reductions in road trauma
- A relatively minor impact on average travel times (mobility) is likely to occur at the individual level; at the societal level there are likely to be overall benefits depending on how values are assigned to travel time increases
- Achieving community acceptance and support for speed limit reductions is critical as is the need to encourage better safety awareness by changing attitudes toward speeding and giving greater consideration to the needs of less prioritized road users
- Vulnerable road users (pedestrians and cyclists) are likely to benefit most from reductions in average travel speeds
- Lowered speed limits encourage better and safer forms of interaction between different types of road users which in turn should lead to a more attractive and liveable environment
- Lowered average travel speeds should bring about an increase in energy efficiency with a corresponding reduction in fuel consumption and vehicle running costs, and a reduction in vehicle emissions (Greenhouse gases) and noise; for this to be achieved it is important to maintain road transport system efficiency, e.g. through the better use of coordinated or self-optimized signalling and other infrastructure and vehicle-based ITS
- Lowering speed limits, where circumstances permit, can prove to be a highly effective way of achieving and sustaining the long-term goals and intermediate targets proposed in traffic safety strategies and action plans

A number of areas requiring further research have been identified by this review. Most importantly, there is a need for more detailed travel surveys in Metropolitan areas, such as Melbourne, that can serve as a basis for research. Given the increasing emphasis on energy efficiency, these travel surveys should facilitate macroscopic modelling that can assess the impact of alternative forms of transportation. More research is also required into the use of new technology to provide, for example, dynamic variable speed limits in the metropolitan network on all types of roads. Other technologies include dynamic forms of intelligent speed adaptation that also consider prevailing road conditions. Furthermore, given the introduction of 30 km/h default speed limits on residential roads in some European cities, it would be of value to investigate, trial and evaluate the same approach in designated metropolitan residential areas to gain insight into the potential of this concept for Australia. Finally, a program of research also needs to be undertaken to find ways of providing useful information and changing the attitudes of motorists in relation to the risks associated with excessive speeding and the minimal gains in travel time.

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More information regarding Australian VicRoads “arrive alive!” road safety strategy can be found at the website: www.arrivealive.vic.gov.au.

More information regarding the Green Vehicle Guide can be found at the website: www.greenvehicleguide.gov.au.