Economic evaluation of the impact of safe speeds: literature review November 2012

Bill Frith
Central Laboratories
Opus International Consultants

NZ Transport Agency research report 505

ISBN 978-0-478-40701-3 (electronic)
ISSN 1173-3764 (electronic)

NZ Transport Agency
Private Bag 6995, Wellington 6141, New Zealand
Telephone 64 4 894 5400; facsimile 64 4 894 6100
research@nzta.govt.nz
www.nzta.govt.nz

Frith, WJ (2012) Economic evaluation of the impact of safe speeds: literature review. *NZ Transport Agency research report 505.* 38pp.

Central Laboratories, Opus International Consultants, email: william.frith@opus.co.nz

Keywords: emission greenhouse, road, safe, safety, speed, system, time, travel, value

An important note for the reader

Acknowledgements

The valuable contributions of Kathy McKenzie of NZTA and Dr Felicity Powell of Opus International Consultants to this work are acknowledged.

Abbreviations and acronyms

ACTRA	Advisory Committee on Trunk Road Assessment
BITRE	Bureau of Infrastructure, Transport and Regional Economics
DoT	Department of Transport, UK
ECMT	European Council of Ministers of Transport
EEM	Economic Evaluation Manual
ETSC	European Transport Safety Council
EU	European Union
FIA	International Federation of Automobile Clubs
GRSP	Global Road Safety Partnership
HEATCO	Harmonised European Approaches for Transport Costing and Project Assessment
ITF	International Transport Forum
MoT	Ministry of Transport
MUARC	Monash University Accident Research Centre
NMSL	National Maximum Speed Law (USA)
NZTA	New Zealand Transport Agency
OECD	Organisation for Economic Cooperation and Development
ROSEBUD	Road Safety and Environmental Benefit-Cost and Cost-Effectiveness Analysis for Use in Decision-Making
TRB	Transportation Research Board, USA
VOC	volatile organic compound

Contents

Executive summary

The goal of the Safe System approach to road safety is to remove fatal and serious injury crashes from our road network.

This literature review, which relates to speeds under a Safe System approach, addresses the following areas:

1 Alternative ways of classifying roads across the road network, which are compatible with the Safe System approach in relation to speed.

2 The relationship of speed to crashes, fuel consumption and emissions.

3 Key questions relating to economic valuation:

   a What values are currently being placed on the cost of serious and fatal crashes in the developed world?

   b What values are currently being placed on travel time in the developed world?

   c What values are currently being placed on fuel consumption savings in the developed world; and how on a macroscopic scale can these economic values be translated into greenhouse gas emissions savings?

   d How do these values relate in the context of cost–benefit analysis under a Safe System approach to speed?

The speed component of a Safe System involves the development of road typologies to eliminate fatal and serious injury crashes by avoiding speeds above critical thresholds. The thresholds are established according to a specific road situation and are similar to the following:

- 70km/h for head-on collisions
- 50km/h for front impacts with a tree or pole
- 50km/h for vehicle-to-vehicle side-impacts (at intersections)
- 30km/h for side-impacts with trees or poles
- 30km/h for impacts with a pedestrian or cyclist.

There are well attested relationships between increased vehicle speed and decreased safety. The values of safety in the developed world, with a few exceptions where human capital approaches are used, are conservative willingness-to-pay values augmented by damage and treatment costs, etc. This is very similar to New Zealand's approach.

The concept of 'optimal speed' where speed is optimised taking all costs, both safety and non-safety, into account should not be confused with 'Safe System speed' where the only criterion is 'harm minimisation' or total avoidance of fatal and serious injury. The adoption of speed limits based on Cameron's speed optimisation approach, as expounded in his 2003 report *Potential benefits and costs of speed changes on rural roads* has been recommended as a practical interim measure on the way to a full harm minimisation approach under a Safe System strategy

The values of time internationally are similar to New Zealand's values where different multiples of wage rates are used for different types of journey, at a fairly aggregated level. Willingness-to-pay approaches have been researched but there is a reluctance to implement these. Within these aggregations, constant averages are used without any discounting of the values of small lengths of time. The discounting of small lengths of time has been frequently mooted but little has been done, notwithstanding evidence that such discounting might be appropriate in some circumstances. This is linked to difficulties in defining what a short length of time is and in deciding what type of discounting protocol to use from a number available. In particular it is arguable as to whether an approach without any discounting for small time savings properly allows for the interests of vulnerable road users by overemphasising the costs of small time losses associated with slowing for vulnerable road users in urban areas. As discounting may be applicable in some circumstances this is a liberal rather than conservative approach. Thus regarding the economic appraisal of safety projects under a Safe System approach to road safety the review indicated that the wisdom of the use of a conservative valuation of safety along with a liberal valuation of time in economic analysis is arguable.

There is also concern that the aggregating processes used in economic analysis models may not be accurate and that this may be a bigger problem than the actual valuations.

Regarding travel speed, fuel consumption and road traffic emissions there are well defined linkages between the speeds of vehicles on the network and their fuel consumption. These linkages allow macroscopic speed changes (such as those related to adopting a Safe System approach to road safety) to be converted to fuel consumption changes. These can be transformed into greenhouse gas emissions estimates which can then be multiplied by the appropriate unit costs to provide emissions costs to be used in economic analysis. The individual characteristics of the New Zealand vehicle fleet can be allowed for by accessing the comprehensive data from the Motor Vehicle Register.

Abstract

The Safe System approach to road safety implies the goal of removing fatal and serious injury crashes from our road network.

This review addresses:

- alternative ways of classifying roads in relation to speed, across the road network, compatible with the Safe System approach
- how speed relates to crashes, fuel consumption and emissions
- the values currently placed on the costs of serious and fatal crashes, travel time and fuel savings in the developed world
- how on a macroscopic scale these values can be translated into greenhouse gas emissions savings
- how these values relate in the cost–benefit analysis context under a Safe System approach to speed.

Well attested relationships were found between speed and crashes. Safe System road types related to the maximum speeds above which serious or fatal injury would occur in various types of crashes.

Internationally, valuation of crashes is mainly based on willingness-to-pay criteria. The values placed on time are constant unit values which is a less conservative approach as there are strong grounds for sometimes discounting the values of small time periods. Macroscopic fuel savings can be linked to greenhouse gas emissions with costs expressed as unit values per kilogram of emissions.

1 Introduction

The Safe System approach to road safety implies the goal of removing fatal and serious injury crashes from our road network.

This literature review, which relates to speeds under a Safe System approach, addresses the following areas:

1. Alternative ways of classifying roads across the road network, which are compatible with the Safe System approach in relation to speed.
2. The relationship of speed to crashes, fuel consumption and emissions.
3. Key questions relating to economic valuation:
   a. What values are currently being placed on the cost of serious and fatal crashes in the developed world?
   b. What values are currently being placed on travel time in the developed world?
   c. What values are currently being placed on fuel consumption savings in the developed world; and how on a macroscopic scale can these economic values be translated into greenhouse gas emissions savings?
   d. How do these values relate in the context of cost-benefit analysis under a Safe System approach to speed?

2 The Safe System approach

The Safe System approach to road safety focuses on creating safe roads, safe speeds, safe vehicles and safe road use. Under the Safe System approach to road safety, a road system is created in which serious and fatal injuries do not occur. In order for this to happen, all necessary measures must be taken to avoid crashes, and if crashes do occur, the people involved should not be subjected to the sort of trauma that would result in fatal or serious injury. One factor in injury severity is speed. Thus the interaction between the road environment and the speed of vehicles must be such that Safe System compatible injury tolerances are not exceeded.

Speed control measures are an integral part of the Safe System approach. New Zealand's road safety strategy 2010–2020, titled *Safer journeys*, (MoT 2011a) guides New Zealand's efforts towards a Safe System approach to road safety.

2.1 International uptake of the Safe System approach

As well as in New Zealand, the fundamental principles of the Safe System approach to road safety have been adopted by national governments of other countries such as Sweden, Norway, Finland and Iceland, the Netherlands, Switzerland, Australia (OECD/ITF 2008). The International Transport Forum organisation within the Organisation for Economic Cooperation and Development (OECD) encourages all its member nations to also adopt the Safe System approach to road safety, which is endorsed by the Global Road Safety Partnership (GRSP) comprising the FIA, the World Bank and the World Health Organisation.

3 Speed and road safety

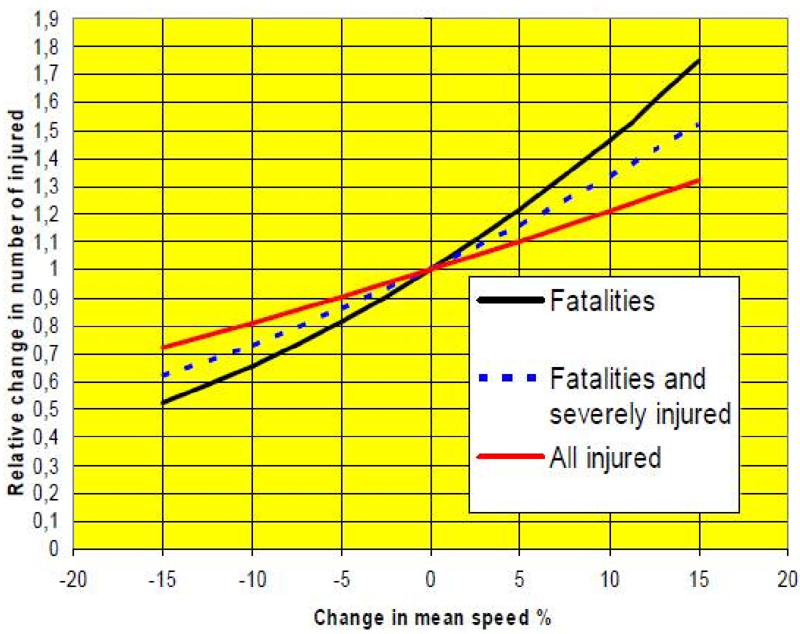
This section looks at the relationship between speed and road crashes, including those involving vulnerable road users, and how this relates to the Safe System approach to speed through changes in the roading infrastructure.

3.1 Travel speed and road-user casualties

It has been well established that highway travel speed is linked to road trauma in such a way that in most circumstances increased travel speed will lead to increased road trauma.

Combining a number of evaluations of speed changes following highway speed limit changes in Sweden, Nilsson (1982) validated a theoretical model for estimating the relationship between speed change and change in casualties. This model predicts a number of power relationships between proportional change in mean travel speed and proportional change in casualties. The exponent ranges from 2 for injury crashes to 4 for fatal crashes. Nilsson (2004) reconfirmed the model, using linear regression results produced by Elvik et al (1997). Elvik et al (2004) also found the model adequately described the relationship between speed and safety. Figure 3.1 from Nilsson (2004, p90) is derived from the model, describing the relationship between speed changes and changes in casualty rates.

Figure 3.1 Relationship between speed changes and changes in casualty rates



Cameron and Elvik (2008) found that Nilsson's model does not apply in urban arterial environments, as these situations involve power relationships of a lower level. This is not surprising as all Nilsson's work involves high-speed roads. The authors estimated a lower power of 1.57 applicable to serious crashes on urban arterials, substantially less than that on rural highways (2.59) which is also substantially less than that on freeways (4.93).

Elvik and Hoye (2004) reported a very detailed study which involved the meta-analysis of a large number of studies of speed changes. Its conclusions were unequivocal:

> *Speed has been found to have a very large effect on road safety, probably larger than any other known risk factor. Speed is a risk factor for absolutely all accidents, ranging from the smallest fender-bender to fatal accidents. The effect of speed is greater for serious injury accidents and fatal accidents than for property damage-only accidents. If government wants to develop a road transport system in which nobody is killed or permanently injured, speed is the most important factor to regulate.*

The meta-analysis of Elvik and Hoye (2004) set out the following inclusion criteria:

1. *Mean speed before the adoption of a measure affecting speed*
2. *Mean speed after the adoption of a measure affecting speed*
3. *The number of accidents, or accident victims, by severity, before the adoption of a measure affecting speed*
4. *The number of accidents, or accident victims, by severity, after the adoption of a measure affecting speed*
5. *An identification of the measure which was introduced.*

Some useful studies on speed and casualty rates were not included in that meta-analysis because of the criteria or because they were not available at the time to the authors. ACC/LTSA (2000) discussed some of the same studies included in the Elvik and Hoye (2004) meta-analysis, and also some other studies that were not included.

These other studies included Kloeden et al (1997) who used a case-control study to quantify the relationship between actual observed[1] free-travel speed and the risk of involvement in a casualty crash in a 60km/h speed limit zone. Kloeden et al (1997) found the risk of involvement in a casualty crash doubled with each 5km/h increase in free-travel speed above 60km/h. In a similar case-control study of crashes on rural roads in Australia with speed limits of 80km/h and above, Kloeden et al (2001) found an increased risk of involvement in a casualty crash for vehicles travelling at speeds above the mean control (non-crash involved) vehicle speed. Specifically, the risk of involvement in a casualty crash was found to be twice as high for vehicles travelling 10km/h above the mean control speeds and nearly six times as high when travelling 20km/h above the mean speed. The Kloeden studies were not included in Elvik and Hoye (2004), not because they breached the inclusion criteria but because of doubts the authors had about the estimates of impact speeds used by Kloeden et al (see Elvik and Hoye (2004, p44).

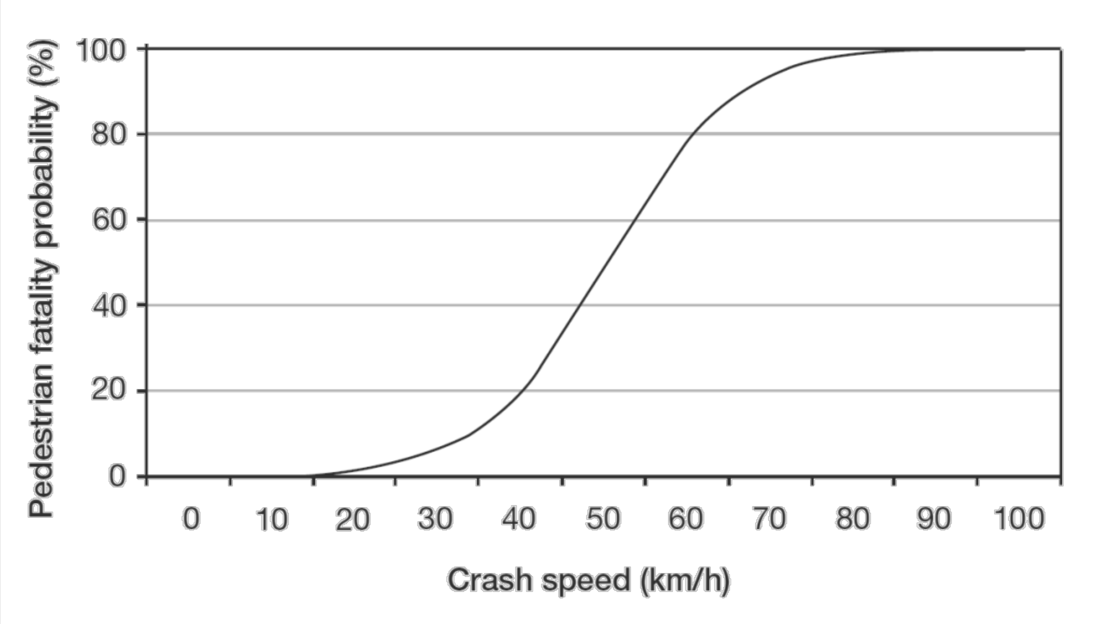
There have also been a number of studies of the deleterious impact of upward speed limit changes in the USA. An example is Patterson et al (2002), who examined the effect the 1995 repeal of the 65mph speed limit had on the occurrence of US rural interstate highway fatalities. Fatalities between 1992 and 1999 were modelled against the size of the change introduced by the post-1995 speed limit (65mph being no change, 70mph being a change of 5mph, and 75mph being a change of 10mph). Two periods were modelled: 1992 to 1995 before the repeal, and 1996 to 1999 after the repeal. Fatalities in the states that raised their speed limits to 75mph and 70mph were 38% and 35%, respectively, higher than expected compared with fatalities in the states that did not change their speed limits. Some of the states that raised their speed limits to 75mph had a higher rural interstate fatality rate than other states even before the speed limit was changed. Paterson et al (2002) estimated that, overall, an extra 1900 people died in association with the 1995 repeal, with the increased speed limit considered the most likely causal factor.

[1] Free-travel speed is the speed of a vehicle unimpeded by other traffic.

3.2 Travel speed and vulnerable road-user casualties

Accepting that increased travel speed will lead to increased road trauma, the extent of trauma varies with the participants in the crash. Vulnerable road users, ie pedestrians, cyclists and motorcyclists, can withstand only relatively gentle impacts as figure 3.2 shows (Wegman and Aarts 2006, p36). This forms a basis for the recommendation mentioned in some literature to restrict travel speed to 30km/h in the presence of pedestrians. Figure 3.2 shows the fatality risk for pedestrians increases sharply when travel speed is beyond 30km/h.

Figure 3.2 Probability of pedestrian fatality versus travel speed of the crash



3.3 Safe System approach to travel speeds

Accepting that crashes will occur, the Safe System approach to road safety addresses controlling speed in such a way that crashes do not cause fatal or serious injury. This involves taking measures to reduce the maximum impact speeds in crashes so that fatal and serious injuries are avoided.

This approach, where serious injury is not tolerated, is commonly referred as a harm minimisation approach to speed (Fildes et al 2005). This is a different approach from the speed optimisation approach used in a number of analyses by Cameron (2000, 2003 and 2009) and is described by Fildes et al (2005, pI) as:

> *Economic optimisation – in practice, a collection of approaches whereby dollar values are set to all the costs associated with travel and to the burden of injury and death from motor vehicle crashes. The posted speed limit becomes that speed which provides the minimal total cost:*

Referring to Cameron (2000), Fildes et al (2005, p18) describe Cameron's speed optimisation approach as relating to 'the travel or cruise speed which leads to the total cost of road trauma, travel time, vehicle operating costs and air pollution emissions being at a minimum'.

Fildes (2005) recommends the adoption of speed limits based on Cameron's speed optimisation approach as a practical interim measure on the way to a full harm minimisation approach, under a Safe System strategy. An example of this approach is Cameron (2009) who applied a speed optimisation approach to Tasmanian rural roads as part of a government push towards eventual Safe System speeds.

Harm minimisation is defined in Fildes et al (2005, pl) as:

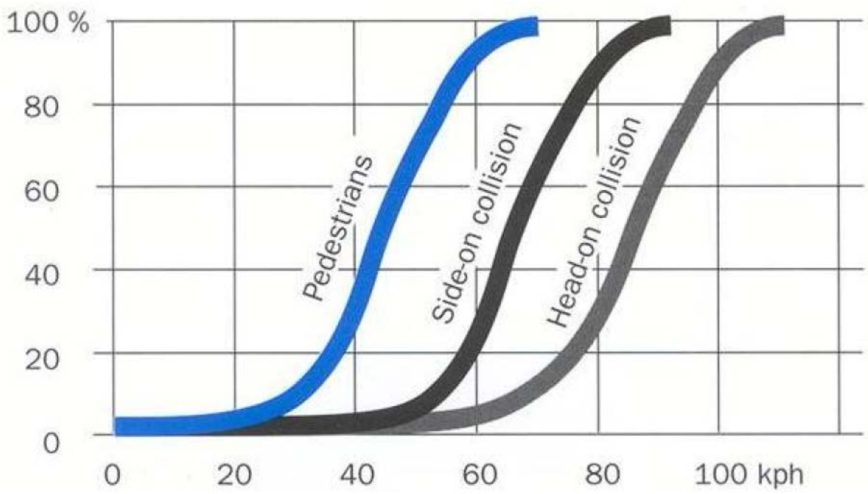
> *Harm minimisation – whereas economic optimisation approaches assume that it is legitimate to put a fiscal cost on human trauma, these approaches commonly contend that life and health cannot be measured or traded in terms of monetary costs. Rather, they aim to create transport systems that do not accept fatalities or other serious casualties as an inevitable cost of mobility.*

Austroads (2008) categorises the maximum impact speeds compatible with Safe System human injury tolerance principles for various common crash types as:

- pedestrian struck by vehicle: 20km/h to 30km/h
- motorcyclist struck by vehicle (or falling off): 20km/h to 30km/h
- side impact vehicle striking a pole or tree: 30km/h to 40km/h
- side impact vehicle to vehicle crash: 50km/h
- head-on vehicle to vehicle (equal mass) crash: 70km/h.

Corben (2011) illustrates these tolerances for collisions with pedestrians, and for side-on collisions and for head-on collisions with the chart shown in figure 3.3.

Figure 3.3 Fatality risk as a function of impact speed



Various authors have used these maxima to evolve speed limit maxima, for compliance with a Safe System approach to road safety. Langford (2006, p6) states:

> *where infrastructure improvements cannot be made in the short term, a possible starting point to considering [safe system] speed limits would be not the road design features, but foreseeable types of crashes likely to occur along different types of streets and roads. Speed management could then be used as a primary (but not exclusive) factor in either preventing the main and most damaging crash types or reducing the severity of those crashes which do occur.*

Archer et al (2008, p24) point out that restricting travel speeds below specific threshold levels, relative to the types of crashes that could occur, is beginning to be recognised in Australia. They quote the speeds as:

> *70km/h for head-on collisions; 50km/h for front impacts with a tree or pole; 50km/h for vehicle-to-vehicle side-impacts (at intersections); 30km/h for side-impacts with trees or poles; and 30 km/h for impacts with a pedestrian.*[2]

The OECD and the International Transport Forum included table 3.1 in a joint publication (OECD/ITF 2008, p113). The table was sourced from the Netherlands Institute for Road Safety Research report *Advancing sustainable safety* (Wegman and Aarts (2006).

Table 3.1 Safe speed thresholds for different road types

Road types combined with allowed road users	Safe speed (km/h)
Roads with possible conflicts between cars and unprotected users	30
Intersections with possible side-on conflicts between cars	50
Roads with possible frontal conflicts between cars	70
Roads with no likelihood of frontal or side-on conflicts between road users	≥100

Beer (2011) generally agrees with table 3.1, but adds a travel speed of 30km/h to 40km/h for a road where impacts with fixed poles or trees could occur.

GRSP (2008), in its speed management manual, has similar sentiments, giving the following examples of appropriate actions to control speeds under a Safe System approach to road safety:

- *In built-up areas where there is a mix of vulnerable road users and motor vehicle traffic, a 30km/h speed limit [should be imposed].*
- *Limit intersection approach speeds to less than 50km/h and consider roundabouts instead of traffic lights to achieve reduction in the likelihood of side-impact crashes.*
- *Reduce the likelihood of head-on crashes on two-way single carriageway roads by using median barriers .or keeping speed limits below 70km/h.*
- *Where speeds cannot be restricted to lower than 50km/h, remove roadside hazards such as poles and trees.*

[2] Impacts with cyclists would have a similar speed threshold to those with pedestrians.

4 Valuing reductions of crashes and casualties

This section looks at how the valuation of crashes and casualties is carried out in New Zealand and internationally.

4.1 In New Zealand

The value of reducing crashes and casualties is often expressed as a social cost. In New Zealand, the social cost of a crash and the associated injuries include the following components:

- loss of life and life quality (value of statistical life or VOSL)
- loss of output due to temporary incapacitation
- medical costs
- legal costs
- property damage costs (MoT 2011b).

The Ministry of Transport (MoT 2011b) explained how the 'loss of life and life quality' component, which in the case of a fatality is much larger than the other components, is a willingness-to-pay value provided by a stated preference survey. The survey estimated the amount of money the New Zealand population would be willing to pay for a safety improvement that resulted in the expected avoidance of one premature death. The VOSL was established at $2 million in 1991 based on a 1989/1990 stated preference survey. Over time, this value has been indexed to the average hourly earnings (ordinary time) to express the value in current dollars. At June 2011 prices, the social cost of a fatality was $3,693,000.

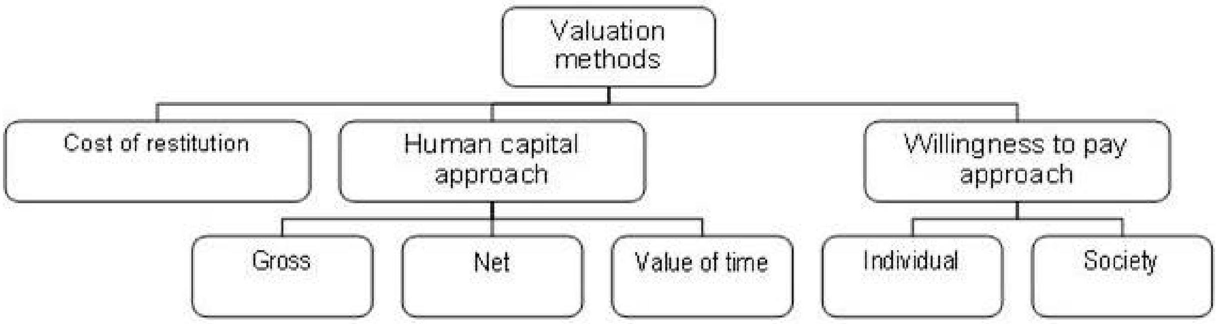
Following the findings of a 1997/1998 stated preference value of safety survey, the average loss of life quality due to permanent impairments from a serious injury was estimated at 10% of VOSL and 0.4% for a minor injury (MoT 2010). At June 2011 prices, the Ministry of Transport (2011b) gave the average social cost per serious injury as $390,400 and the average social cost per minor injury as $20,700 (excluding adjustments for the level of non-reporting of crashes of these severities).

New Zealand's introduction of this system of valuation obviously preceded the Safe System approach to road safety, which began in 2010.

4.2 Internationally

Outside New Zealand, across other countries which practise the Safe System approach to road safety, there is no fully consistent approach at present to the valuation of safety although most include a willingness-to-pay component in their values. The range of methods used historically for valuing safety is shown in figure 4.1 from the European Commission (undated).

Figure 4.1 Methods used historically for valuing safety



The European Commission (undated) explains terms used in figure 4.1 as:

- *'Costs of restitution' are the direct costs generated by road accidents (for example, medical costs, property damage or administrative costs).*
- *The 'human capital approach' is used to estimate the value of lost productive capacity due to a traffic fatality.*
- *The willingness-to-pay approach is used to estimate the value of lost quality of life. Two varieties of the willingness-to-pay approach are normally used:*
  - *the individual willingness-to-pay approach where information is obtained from individuals, by studying behaviour in situations where risk is traded against other commodities or information can be obtained via questionnaires*
  - *the social willingness-to-pay approach where society's willingness-to-pay for reduced risk is inferred from the valuation implicit in public decisions like setting speed limits.*

From the above it may be gauged that New Zealand has a social willingness-to-pay approach.

The European Commission (undated) further states that:

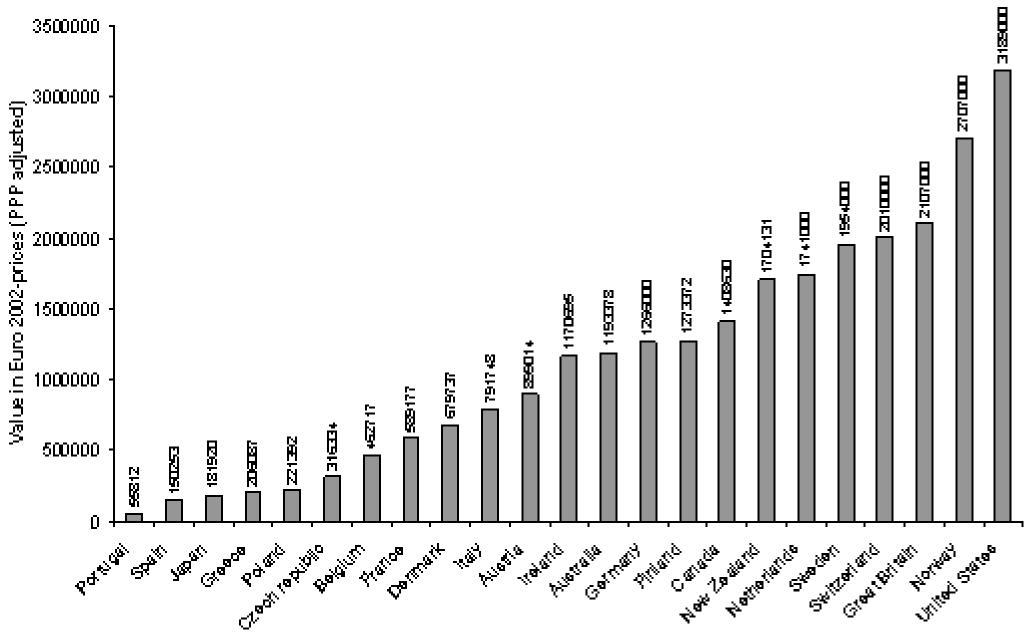
> *... in many European countries, studies have been made to assess willingness-to-pay (WTP) for improved road safety. The results of these studies are, however, not always strictly applied in the official monetary valuation of road safety in all countries. Thus, [willingness-to-pay]-studies have been made in Belgium, Denmark, France, Great Britain, Greece, the Netherlands and Sweden all showing considerably higher figures for the willingness-to-pay for road safety than the official valuations used in these countries. Although the official valuations of road safety in most of these countries are based on the willingness-to-pay principle, the valuations represent a very conservative interpretation of the results of the studies that have been made.*

In New Zealand, values used reflect a conservative interpretation of study results. Thus, for those countries and for New Zealand, it would be expected that all things being equal, more road safety measures would pass benefit–cost analysis if less conservative interpretations of the willingness-to-pay study results were used.

The main argument given for conservatively interpreting willingness-to-pay studies is that many error sources may lead to inflated valuations. To counter this view, there are well proven techniques to minimise the chances of this happening. An excellent discussion of willingness-to-pay methods to value safety is available in Jones-Lee and Loomes (2003).

A survey was made as part of the European ROSEBUD-project (see de Blaeij et al 2004). The survey looked at methods used in estimating the costs to society of traffic injury, then presented recent cost estimates for selected countries. These are shown in figure 4.2 from the European Commission (2004, p31).

Figure 4.2 Values of avoiding a road-fatality in euros purchasing power parity (PPP) adjusted



The seven countries with the highest fatality valuation all use willingness-to-pay based values and of those all except the USA are known to have a Safe System approach to road safety. Of course it can be expected that there will be a large variation between countries in the level of conservatism in the use of the values.

One would expect as a corollary that countries that have embraced a Safe System approach to road safety place a high value on safety. Thus one would expect higher willingness-to-pay values to be the norm in those countries. However, this is not always the case.

HEATCO[3] (2006, pS15) recommends that European countries value safety as follows:

- *Value of safety per se: willingness-to-pay values based on stated preferences studies carried out in the country for which they are applied.*
- *Direct and indirect economic costs: cost values for the country under assessment.*
- *Material damages from accidents with material damage only: cost values for the country under assessment.*

This is broadly similar to the New Zealand approach.

[3] The acronym of an EU project to develop harmonised European approaches for transport costing and project assessment.

5 Valuing travel time savings

This section looks at how travel time savings are valued in New Zealand and internationally and in particular discusses the treatment of the values of smaller time savings.

5.1 The New Zealand approach

At present in New Zealand, in the analysis of road network projects, the NZTA uses unit values of time which are applied to time savings or losses on an aggregated basis. The process for this is established in the NZTA's (2010) *Economic evaluation manual volume 1* (EEM). While there are various classes of time savings, as detailed below, the unit values are constant. This is called the constant unit value approach, and is the dominant approach worldwide.

The basis for the values used is not clear in the EEM, in particular whether or not they are based on a willingness-to-pay like the values of crash savings (discussed in the previous section). To the casual observer it would seem sensible for such values to be calculated using similar premises to the safety values used in the same analyses. Hensher (2000) indicated that values in 2000 were related to percentages of the hourly wage rate.

In valuing time savings, the EEM considers various classes of time savings based on:

- whether the person involved is a pedestrian, cyclist, motor vehicle driver or passenger
- whether the time is considered 'work time' or 'non-work time'
- whether on public transport a passenger is seated or standing
- time of day (considered as during peak, shoulder, or off-peak traffic conditions)
- location (considered as metropolitan/city, town, or rural)
- whether travel is in congested conditions.

5.2 Travel time savings and total travel time

The list above summarised from the EEM excludes any relativity between the change in travel time and the total travel time. This means, for instance, that a second saved in a 10-hour journey is valued the same as a second which is part of a 10-minute saving on what was previously a half-hour journey.

Some studies show that the value of time saved on a journey is a function of the total travel time of that journey. Tsolakis et al (2011), after reviewing the literature, considered the literature evidence regarding the valuation of small time savings 'mixed' and the recommended levels of threshold uncertain. They found evidence for valuing such savings as a percentage of journey time but also found that the variations in the values of such savings over the total length of journey were uncertain. A key input to their view was a US Department of Transport review (DoT 1997) in which the following statement was made.

> *Although economic theory provides some support for the idea that the hourly value of small travel time savings should differ from average values per hour over larger changes in trip duration, it provides insufficient guidance for estimating the magnitude of any such differences, or even for anticipating their direction. At the same time, empirical evidence on the relative unit valuations of large and small time savings implied by traveller behaviour is*

mixed, and the lower hourly values for small time savings that appear to be supported by a few early studies are no longer believed to be reliable (DoT 1997, p6).

5.3 Constant unit value of time approach versus a discounting approach

There was discussion in the literature as to whether savings of small time intervals (in the range up to about five minutes) were worth as much as similar intervals which were part of a larger tranche of savings.

Jones et al (1984) argued that some small time savings had zero or low value because they were not large enough to be either perceived and/or put to some alternative higher-valued activity. This implies a threshold, or threshold function, the lower end of which could vary from seconds to a number of minutes depending on the view of what constitutes a useful packet of time. It also supports a discounting approach, rather than a constant unit value of time approach.

There was also concern (see Tsolakis et al 2011; Welch and Williams 1997) about the possibility of large errors in aggregating the values of very small lengths of time, depending on the types of models used. These errors could overshadow the impact of the actual values given to the time units if they are not formulated carefully.

Studies (such as Welch and Williams 1997; Hensher 2001; Metz 2004) showed that in road schemes time savings benefits often accounted for large shares of total project benefits (on average 60% to 90%).

Welch and Williams (1997) quoted results from a survey of some local authorities in the UK which indicated that for a series of road schemes the average time savings were in the range of one to three minutes, suggesting that the savings of many road users were small. In an economic analysis of these road schemes, the time savings were aggregated using the constant unit value of time approach; however, if a discounting approach was used, the aggregate and by implication the results of the economic analysis, could be substantially less.

Welch and Williams (1997) quoted a number of studies to illustrate the impact of a constant unit value of time approach versus a discounting approach. They quoted Sharp (1973) as finding that for a road scheme in Leicester, UK, if the unit values of time periods less than or equal to three minutes were discounted by 75%, the estimated first year rate of return would have been 5.3% compared with 19.7% if a constant unit value of time approach was used. They also quoted Waters et al (1992) who referred to a Canadian Highway appraisal where an illustrative calculation showed that removing small time savings from the calculation reduced the benefits of time savings from 80% of the total to 33% of the total. Assuming the underlying constant unit values had cogency, as Welch and Williams (1997) remarked, the constant unit value approach provided the upper bound to benefit estimates derived from transport improvements.

The arguments for a constant unit value of time approach put up by the UK's Department of Transport in a 1970s review were discussed by Powell and Bowers (1996) quoting ACTRA (1978). They listed them as:

- The majority of benefits come from small time savings and it would be inconsistent to value the total differently from the individual parts. This is acceptable because empirical measures of the value of non-work time are based on studies in which people face small time savings.
- The majority of transport projects have been accepted historically despite the fact that journey time savings were small.

In a second major review (MVA et al 1987), according to Powell and Bowers (1996), the constant unit value approach was questioned more thoroughly. Notwithstanding some existing behavioural evidence and the study's own empirical work that suggested small time savings were valued at a lower rate than large time savings, the review upheld the constant unit value approach for three reasons:

1 Although the evidence suggested a smaller value of time for small savings compared with large savings, that evidence was considered weak.

2 There were practical concerns. Abandoning the constant unit value of time approach would mean that the value of a major scheme would vary depending on whether it was appraised as one large scheme or several smaller ones, creating inconsistency.

3 The reviewers were of the view that sometimes the time saved would not aggregate to generate a useful amount of spare time. The total amount of time converted into useful time, on average, would be the same as the sum of actual time saved. (This is the theoretical basis of the constant unit value of time approach to aggregation today.)

Both O'Fallon and Wallis (2012) and Victoria Transport Policy Institute (2012) took the matter further by suggesting that in some cases travel time could have utility to the traveller, in particular that commuters might have minimum travel time thresholds under which they were reluctant to go, implying that some of their commute time might have utility rather than disutility. This could be due to the commuters' ability to use the time to advantage as long as they had sufficient of it.

With regard to our understanding of the different values of time disbenefits on long and short journeys that might accrue with slower speeds, it is questionable whether the discounting or non-discounting of small periods of time would have much effect. The effect of that discounting or non-discounting is more likely in the trade-off between safety-oriented investment and time-saving investment where the value of time saved may be in small questionable chunks to the user.

ACC and LTSA (2000) dealt with the question of time disbenefits on longer journeys. People may assume that the faster the speed on a journey the shorter the time it will take to complete. However, this is not always true. If the speed of travel causes a crash the journey may not be completed at all. Also in urban environments where journeys are often interrupted by waits at delay points, such as traffic signals, a faster travel speed between obstructions may lead to longer waiting time at the obstruction rather than reaching the destination faster. However, in less impeded environments a faster travel speed may lead to shorter journey times.

A National Maximum Speed Law (NMSL) setting a maximum speed limit of 55mph for rural roads was introduced in the USA in 1974 as a fuel saving measure. It was also accompanied by a large safety gain. TRB (1984) compared data gathered in 1982, after this speed limit change, with data from 1973 when states set their own speed limits, which although covering a range tended to be higher than 55mph. The TRB found that motorists (mainly in personal vehicles) spent one billion extra hours travelling the same distance under the 1982 mean speed than the 1973 mean speed, notwithstanding that most of the trips were relatively short. These billion hours would have had a large cost under present costing regimes, but would not have created great distress to many motorists as individually their extra time on the road would have been small as their total journey was short. Even when a longer trip is involved, the travel time savings from increased speed are small. For example, a driver travelling consistently at 120km/h for 100km compared with another driver travelling at 100km/h for 100km would save only 10 minutes (ETSC 1995).

After analysing trip chains using the New Zealand Household Travel Survey, O'Fallon and Sullivan (2009) found that of trip chains with main mode 'vehicle driver' only 21.3% were over 20km in length. Similarly, a study in Germany found that 80% of journeys were shorter than 10km, cited in Ward et al (1998).

Ward et al (1998, p9) referring to the use of lower values for smaller time savings stated that:

> *Where the latter approach is adopted in relation to speed management, it will be necessary to estimate the distribution of the incidence of travel- time changes in order to know for how many journeys the changes exceed the threshold and by how much.*

This would require models with the capability to carry out the estimation, adequate data to feed into the models and agreed threshold protocols built into the models.

Cameron (2003) estimated optimum speeds for different types of Australian rural roads, using a variety of time and safety valuations. Cameron's basic scenario was to value leisure travel time and road trauma by the 'human capital' approach. Compared with that scenario, giving no value at all to reduced travel time cut the optimal speeds on freeways and divided roads from 120km/h to 100km/h and from 110km/h to 105km/h respectively.

5.4 Models for a discounting approach

An unspoken reason for the lack of change to a discounting of shorter periods of time is likely to be difficulties in deciding on the appropriate discounting model (or models) to use. There are a number of choices as can be seen from the literature and it could be expected that any choice would be controversial and difficult to implement.

In New Zealand, Hensher (2000, p34) made the point that 'The theoretical literature makes no judgement about whether values of time savings should be point estimates or distributions'. He then went on to promote the idea of a valuation function to enable the valuation of travel time savings to vary by the preferred criteria and suggested that functions for the valuation of time could deliver adjustments for, inter alia, size of time savings. This would mean they could deliver discounts or loadings to the unit value of time depending on the circumstance. Hensher (2000) considered that these models could use both the stated and revealed preferences of people and suggested further work on this topic (to the author's knowledge, this further work has not been undertaken).

Welch and Williams (1997) examined six different discounting models for the value of small time periods including different methods of modelling thresholds. Though six models were examined, there is no reason to believe this range of models covered all the options.

The alternative of discounting in some way small time savings (called discounted unit value) has been frequently discussed over the last few decades with much controversy but used little. As in New Zealand, Australia and the USA, all the EU-25 countries except Germany and Switzerland, use a constant value no matter the size of the time saving. The Germans discount the value of small time savings on non-work trips by 30%, similar to what used to be the case in The Netherlands, France and the USA where a constant value is now used (Welch and Williams 1997). Notwithstanding this, HEATCO (2006) finally recommended a constant value be retained with the proviso that given the errors associated with small time savings 'the proportion of the economic benefits derived from time savings attributable to small time savings (less than three minutes)' should be identified. It was not stated how this information should be used.

HEATCO (2006) grappled both with the problem of whether time values varied the sign of travel time savings (ie whether time had been lost ((sign negative)) or gained ((sign positive)) and the size of travel time savings). Its context was savings within the range 0 to 20 minutes which it stated as a typical range for changes associated with European transport schemes. With regard to the sign of the savings in time HEATCO quoted Bates and Whelan (2001) who found no evidence for distinguishing between time gains and losses (within the range of +/- 20 minutes) from the analysis of two value of time studies. A weakness in the work of Bates and Whelan is that they did not consider time periods of less than three minutes.

Victoria Transport Policy Institute (2012) reviewed methods of valuing travel time in use now, and for possible use in the future. Values used elsewhere while differing in detail would appear to be similar in principle to those used in New Zealand. This is irrespective of whether or not the country involved is wedded to the Safe System approach to road safety.

6 Balancing valuation of travel time savings with valuation of safety under a Safe System approach

How the valuations of time and safety would affect safe speed under a Safe System approach is an interesting question. A major part of any road-related benefit–cost analysis is the balancing of travel time benefits and safety benefits. The main item of discussion is the values used in the cost–benefit analyses. Do the safety and time values used provide a level playing field for the analysis? This would be the case if the values were based on similar premises and were similarly conservative. From the point of view of the Safe System approach to safety it is important that these values are in tune. If the values given to time savings were overstated, this could result in biases away from expenditure on primarily safety benefits to expenditure on primarily time saving benefits which might provide little benefit in terms of road user journey times.

For the case of a Safe System approach to road safety, a willingness-to-pay method, as is used for safety valuations, would seem appropriate for the valuation of time. This method would ascertain how travellers themselves (or their employers) value various tranches of time savings or time delay, while also providing a time valuation method consistent with the willingness-to-pay safety valuation methods currently used. The reliability of travel time would also be addressed by considering the values placed upon the ‘expectedness’ of delay (Tilahun and Levinson 2007). There is discussion of various approaches to time valuation in the context of safety projects in HEATCO (2006). HEATCO (2006) recommends valuing non-work time savings using a willingness-to-pay approach while using methods discussed in Hensher (1977) to value working time. This allows for the fact that not all travel time is unproductive and not all savings are transferred to extra work.

In terms of lower speeds in areas where vehicles potentially conflict with vulnerable road users, these lower speeds over finite lengths of road would be expected to result in only small time losses which arguably may be of little consequence and could be discounted, while the safety benefits to the vulnerable road users are demonstrably real. Cameron (2000) quoted in Fildes et al (2005) noted earlier work indicating that urban travel speeds were, on average, well below posted speed limits. One example is Rietveld et al (1996) who found that for some Netherlands major urban through roads with a 50km/h limit, average speed was 38km/h and 27km/h on other urban roads. The work quoted indicated that reductions in the speed limit in urban areas may contribute comparatively little if anything in terms of increased travel times.

7 Fuel consumption and road traffic emissions

This section looks at the linkages between travel speed, fuel consumption and greenhouse gas emissions, particularly in relation to estimating the costs of greenhouse gas emissions from macroscopic changes in fuel use related to changes in travel speed.

Whatever the motivations for their introduction, highway travel speed reductions have led to both safety improvements and improvements in fuel consumption with the corollary of improvements in many road-traffic emissions. In complementary effects, history shows experiences where speed reductions introduced with the motivation of reducing fuel consumption have also led to good safety outcomes. For example, in response to the oil crisis of the early 1970s, in December 1973 New Zealand imposed a change in open-road speed limit, from 60mph (100km/h) down to 50mph (80km/h) as a fuel-saving measure. Frith and Toomath (1982) reported positive road safety outcomes following the speed reduction. In a similar example, as a fuel-saving measure, in 1974 the USA imposed a maximum speed limit of 55mph (89km/h) on interstate highways; and the TRB (1984) reports the positive road safety outcomes that followed.

7.1 Travel speed and fuel consumption

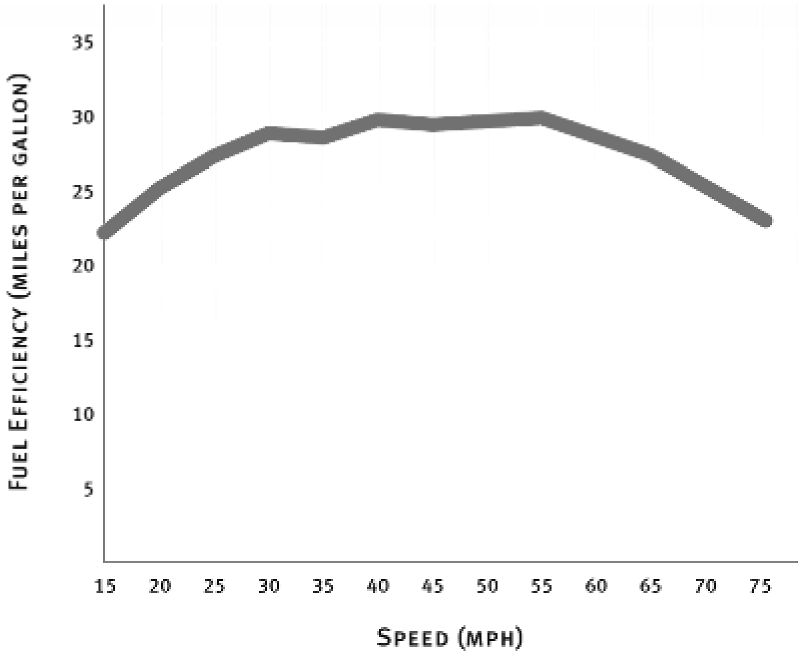
ACC and LTSA (2000) pointed out that the relationship between fuel use and vehicle speed has been well known for some time (see figure 7.1). The European Conference of Ministers of Transport (ECMT 1996) reported several studies relating to fuel consumption and speed. Though the dates and details of some of these studies are not completely clear, relevant findings include:

- ‘Various studies estimate that, for a car fleet of the type found in Germany, a reduction of *x* percent in average driving speeds on rural road networks can reduce fuel consumption by 0.8*x* percent.’ (p17)
- One study estimated if the speed limits existing in France at that time were strictly complied with, there would be a saving of 1.4% of oil consumed annually by car drivers (being 350,000 tonnes saved from the 25,000,000 tonnes consumed annually).
- In the Netherlands, improved enforcement on motorways with speed limits of 100km/h reduced average speeds on those motorways from 111km/h to 104km/h; and this resulted in energy savings of 40 million litres of petrol, 40 million litres of diesel fuel and 15 million litres of LPG.
- ‘With respect to energy savings, it has been calculated in the USA that increasing a steady driving speed from 55mph (89km/h) to 70mph (113km/h) increases fuel consumption by 17%.’

In New Zealand, Waring (1996) estimated that an increase in speed limits from 100km/h to 110km/h would increase fuel consumption by about 10%.

These changes relate to variation in fuel efficiency with speed and are illustrated by figure 7.1, reproduced from ACC and LTSA (2000).

Figure 7.1 Fuel efficiency as a function of speed – model year 1988–1995, automobiles and light-duty trucks



Source: Davis (1997, pp3–51, cited in TRB, 1998, p69). Note: 1mph = 1.609km/h; 1 gal = 3.8L.

Figure 7.1 shows fuel efficiency peaks at about 55mph (89km/h). The drop in fuel efficiency after 55mph is due primarily to the effect of aerodynamic drag. The lower fuel efficiency at lower speeds occurs because of engine friction, tyres and accessories (such as power steering) (TRB 1998).

7.2 Vehicle technology and fuel consumption, and the New Zealand fleet

It is important to investigate how advances in vehicle technology have impacted on fuel consumption so that reported findings from previous studies can be placed in the context of New Zealand's existing vehicle fleet. This will ensure vehicle operating costs and crash benefits assigned to slower speeds are not overstated. Of recent years, the fuel economy of vehicles with internal combustion engines has improved for a given engine size. This has been achieved by a variety of means including:

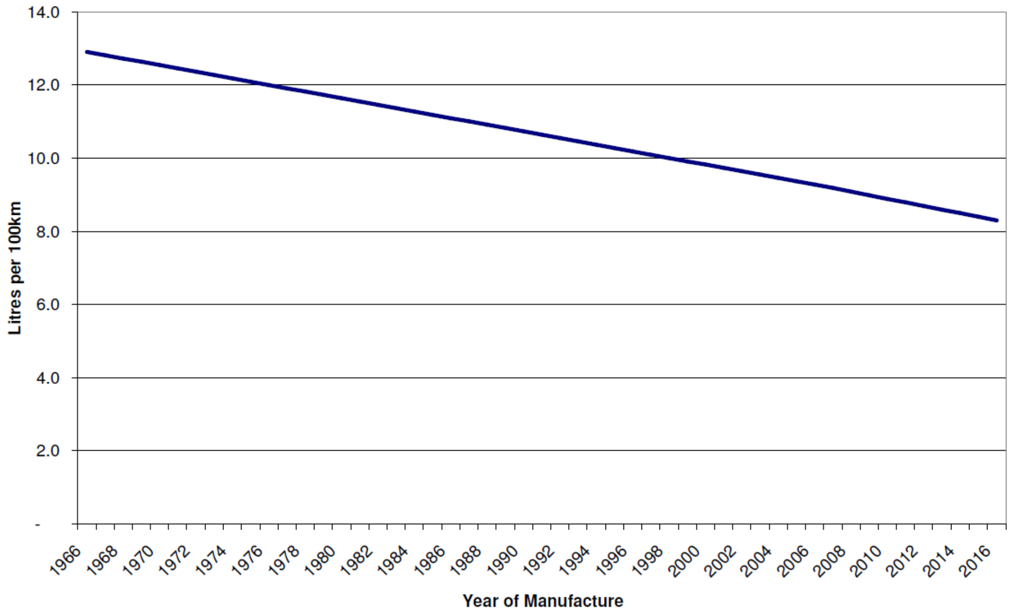
- improving vehicle aerodynamics
- reducing vehicle weight
- improving engine efficiency
- improving the efficiency of gear changes, such as via continuously variable transmission
- stop-and-go technologies where the engine stops when the vehicle stops
- the introduction of hybrid technologies.

The improvements have come about both by public demand attached to increased fuel prices and also mandatory fuel economy standards promulgated by vehicle-producing countries and picked up in their overseas markets. These standards have been motivated by a desire to limit the emissions of greenhouse gases and other pollutants by motor vehicles.

Of course, these changes do not flow through into a vehicle fleet immediately, and there are confounding factors, as in New Zealand, where an increase in the average size of a car has to some extent cancelled out fuel economy improvement along with lags associated with used vehicle imports (see MoT 2011c). In particular, there tend to be large blocks of vehicles imported at times immediately prior to changes in requirements, thus producing clumps of similarly aged vehicles working their way through the remainder of their life-cycles. This is well documented in the official Motor Vehicle Register so that allowance for these impacts can be made with reasonable ease.

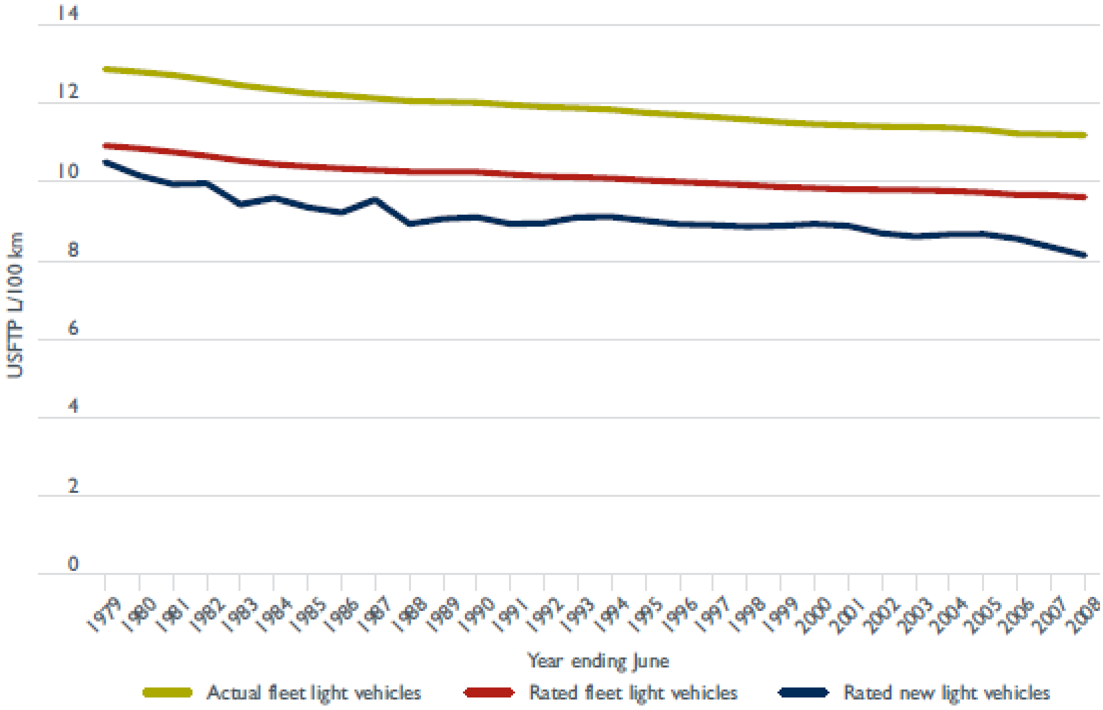
MoT (2011b) also looked at and modelled future scenarios for our light vehicle fleet. These show the considerable level of future uncertainty. At any particular moment the fuel efficiency of our fleet can be estimated from the composition of the fleet and the standards to which the vehicles in it were manufactured with allowance for changes with age of vehicle. This type of analysis has been previously carried out making use of MoT's Vehicle Fleet Emissions Model (see Covec 2007, p16) which contains estimates for New Zealand (see figure 7.2). The straight-line form of the relationship is an artefact of the use of previous MoT estimates of fuel economy and the future estimates (as at 2007) assume no further action to improve fuel economy.

Figure 7.2 Estimated average fuel economy of light petrol vehicles in the New Zealand fleet



The Australian Bureau of Infrastructure, Transport and Regional Economics (BITRE) (Cregan and Gargett 2009) has compared average light vehicle fleet fuel economy with average new vehicle fuel economy, as shown in figure 7.3. The reason for the difference between the 'actual' and 'rated' fleet figures is explained as the 'rated' value of the fleet intensity is based on a 55/45 estimate of the percentage split between driving on city/highway roads, whereas this split in reality is closer to 85/15.

Figure 7.3 Historic trend of Australian light vehicle fuel economy



Source: BITRE estimates

Notes: Estimates based on drive cycle test values as opposed to on-road fuel use values.

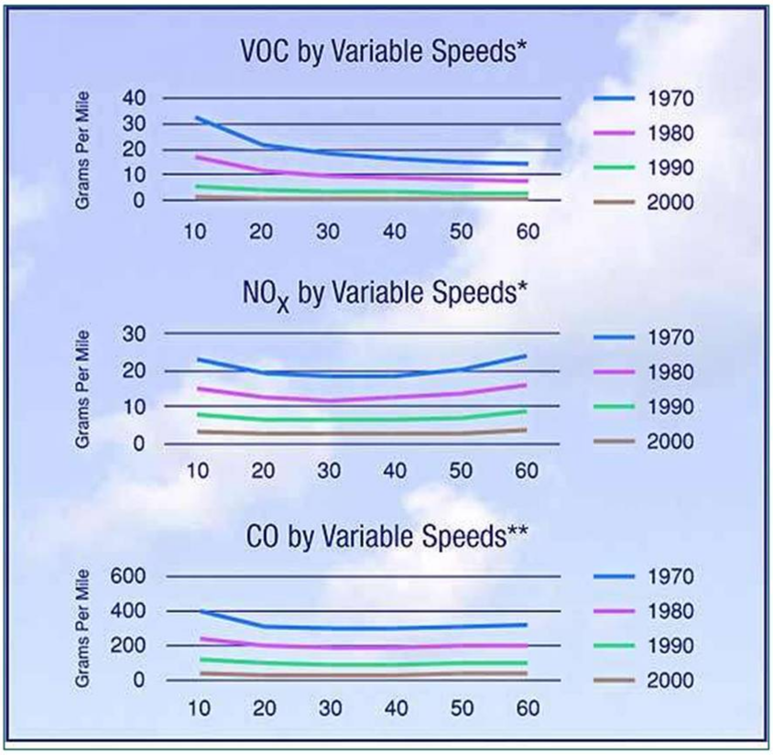
7.3 Travel speed and emissions from road-traffic

'A clear link exists between high vehicle speeds and the volume of gaseous emissions from vehicles' (ECMT 1996, p17). Vehicle emissions typically relevant to consideration of the environment and greenhouse gases include carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (CH_x) and oxides of nitrogen (NO_x). These pollutants are produced in different quantities at different speeds.

The link between speed and emissions of carbon monoxide, oxides of nitrogen and volatile organic compounds (VOCs) is quantified in figure 7.4.[4] This indicates an approximately u-shaped curve for NO_x and CO emissions with increases beginning between roughly 30mph and 50mph depending on the emission type. VOC emissions flatten with increased speed and all emissions have reduced considerably over time. Carbon dioxide emissions, which are not shown, relate to fuel use.

[4] From www.fhwa.dot.gov/environment/air_quality/publications/fact_book/page15.cfm (accessed 22 June 2012)

Figure 7.4 Per mile emission rates versus vehicle speed (mph)



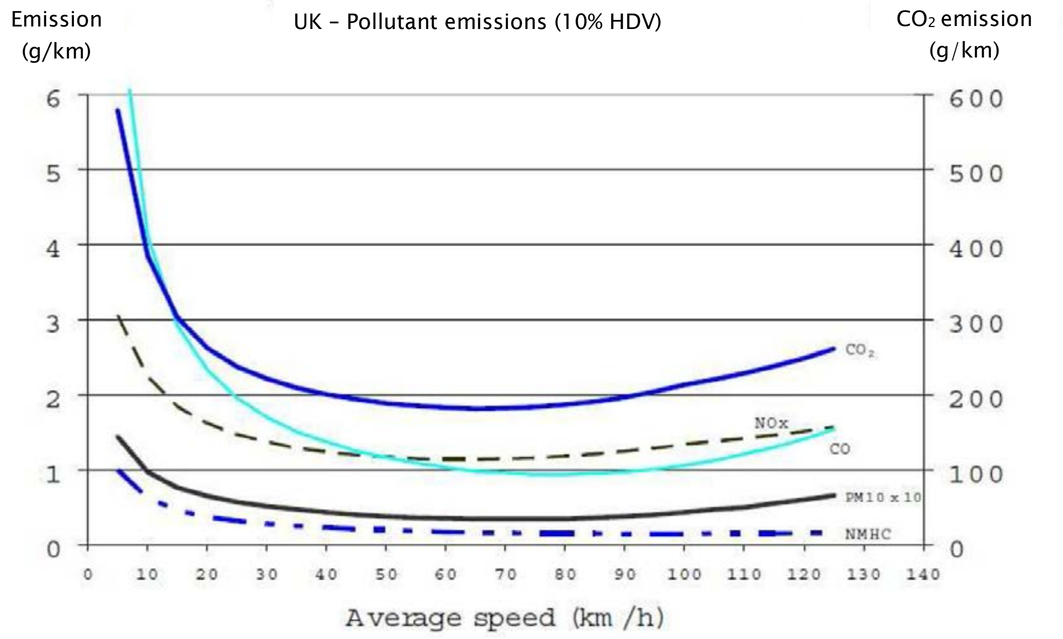
*Note: summer, freeway assumption used.
**Note: winter, freeway assumption used.

ECMT (1996) cited some studies relating changes in emission rates to changes in speed limits or mean speeds. For example, when the speed limit was lowered from 130km/h to 100km/h in Austria, there was a 17% reduction in oxides of nitrogen emissions and a 25% reduction in carbon dioxide emissions. In another example, similarly, when the mean speeds on motorways in the Netherlands decreased from 111km/h to 104km/h, there was a 5% reduction in oxides of nitrogen emissions and a 34% reduction in carbon dioxide emissions.

OECD/ITF (2008) cited a Netherlands initiative to reduce air pollution, particularly from oxides of nitrogen emissions, by reducing speeds on motorways. In 2002, a zone was introduced on the motorway between The Hague and Rotterdam, where the speed limit was reduced from 100km/h to 80km/h and strictly enforced. This pilot project recorded the reduction in oxides of nitrogen emissions from vehicles was about 13% and, in addition, injury accidents decreased by more than 50%.

ECMT (2006, p43) features the chart shown in figure 7.5 which looks at the variation in pollutant emissions with average speed of traffic. It is apparent that optimal speed varies with the pollutant.

Figure 7.5 UK pollutant emissions assuming 10% heavy vehicles by average speed



TRB (1998) quoted TRB (1995) that for light vehicles, according to models current at the time, VOCs and carbon monoxide emission rates were high at very low speeds associated with heavily congested stop-and-go traffic. Emission rates of these VOCs and carbon monoxide were also high with open road driving because of the increased power demands at high speeds, but at exactly what speed this occurred and the extent of the increase were unclear. Oxides of nitrogen emission rates were thought to increase gradually at speeds well below open road speed, but there was some uncertainty as to the details of the increase.

Heavy vehicles followed broadly similar patterns to the patterns from light vehicles, but the data available on heavy vehicles was much more limited.

7.4 Macroscopic fuel consumption and greenhouse gas emissions

This review looks at means to quantify and value changes in emissions of carbon dioxide, and other greenhouse gases pollutants by relating fuel consumption changes to emissions. In New Zealand, the EEM, appendix 9 has a value only for carbon dioxide emissions (12 cents per litre of fuel at 2004 prices based on updating values from the MoT (1996) *Land transport pricing study*.

The Australian Government, however, has gone into the area of greenhouse gases in a detailed manner (Department of Climate Change and Fuel Efficiency 2011). This document provides tables of fuel combustion emission factors for carbon dioxide, methane (CH_4) and nitrous oxide (N_2O) which are considered the vehicle emissions significant to greenhouse impacts. A number of other gases, including other oxides of nitrogen and carbon monoxide, are emitted by vehicles, along with particulate matter, but these are notable for environmental and health impacts other than their greenhouse impacts. Estimates of emissions from the burning of any given quantity of fuel can be made for each vehicle emission by simply multiplying the physical quantity of fuel combusted by a fuel-specific energy content factor and also a fuel-specific emission factor.

In terms of an equation, the Department of Climate Change and Energy Efficiency (2011), depicts this relationship as:

$$E_{ij} = \frac{Q_i \times EC_i \times EF_{ijoxec}}{1{,}000}$$

Where: E_{ij} is the emissions of gas type (j), carbon dioxide, methane or nitrous oxide, from fuel type i (equivalent tonnes of CO_2 (CO_2-e tonnes))

Q_i is the quantity of fuel type i (kilolitres or gigajoules) combusted for transport energy purposes

EC_i is the energy content factor of fuel type i (gigajoules per kilolitre or per cubic metre) used for transport energy purposes — see table 7.1. (If Qi is measured in gigajoules, then ECi is 1).

EF_{ijoxec} is the emission factor for each gas type j (which includes the effect of an oxidation factor) for fuel type i (kilograms CO_2-e per gigajoule) used for transport energy purposes.

Total emissions are calculated by summing the emissions of each fuel type. Table 7.1 reproduces results from the Department of Climate Change and Energy Efficiency (2011).

Table 7.1 Fuel combustion greenhouse gas emission factors for transport fuels

Fuel combusted	**Energy content factor (GJ/kL unless otherwise indicated)**	**Emission factor kg CO_2-e/GJ (relevant oxidation factors incorporated)**		
		CO_2	**CH_4**	**N_2O**
Transport equipment type: general transport				
Gasoline (other than for use as fuel in an aircraft)	34.2	66.7	0.6	2.3
Diesel oil	38.6	69.2	0.2	0.5
Gasoline for use as fuel in an aircraft	33.1	66.3	0.04	0.7
Kerosene for use as fuel in an aircraft	36.8	68.9	0.01	0.7
Fuel oil	39.7	72.9	0.06	0.6
Liquefied petroleum gas	26.2	59.6	0.6	0.6
Biodiesel	34.6	0.0	1.2	2.2
Ethanol for use as fuel in an internal combustion engine	23.4	0.0	1.2	2.2
Biofuels other than those mentioned in items above	23.4	0.0	1.2	2.2
Natural gas (light duty vehicles)	39.3 × 10-3 GJ/m^3	51.2	5.5	0.3
Natural gas (heavy duty vehicles)	39.3 × 10-3 GJ/m^3	51.2	2.1	0.3
Liquefied natural gas (light duty vehicles)	25.3	51.2	5.5	0.3

Fuel combusted	Energy content factor (GJ/kL unless otherwise indicated)	Emission factor kg CO_2-e/GJ (relevant oxidation factors incorporated)		
		CO_2	CH_4	N_2O
Liquefied natural gas (heavy duty vehicles)	25.3	51.2	2.1	0.3
Post-2004 vehicles				
Gasoline (other than for use as fuel in an aircraft)	34.2	66.7	0.02	0.2
Diesel oil	38.6	69.2	0.01	0.6
Liquefied petroleum gas	26.2	59.6	0.3	0.3
Ethanol for use as fuel in an internal combustion engine	23.4	0	0.2	0.2
Heavy vehicles conforming to Euro design standards				
Euro iv or high, diesel oil	38.6	69.2	0.05	0.5
Euro iii, diesel oil	38.6	69.2	0.1	0.5
Euro I, diesel oil	38.6	69.2	0.2	0.5

Source: National Greenhouse and Energy Reporting (Measurement) Determination 2008 (Schedule 1).

Note: All emission factors incorporate relevant oxidation factors (sourced from the DCCEE 2011).

The Department of Climate Change and Energy Efficiency (2011) provides the following practical example to illustrate the process:

A freight company consumes 10 million litres of automotive diesel for transport purposes. Emissions of greenhouse gases (carbon dioxide, methane and nitrous oxide) in tonnes of CO_2-e are estimated as follows:

- emissions of carbon dioxide = (10,000 x 38.6 x 69.2)/1000= 26,711 t CO_2-e
- emissions of methane= (10,000 x 38.6 x 0.2)/1000= 77 t CO_2-e
- emissions of nitrous oxide= (10,000 x 38.6 x 0.5)/1000= 193 t CO_2-e
- total GHG emissions = 26711 + 77 + 193= 26,981 t CO_2-e

These emissions are direct emissions from fuel use.

Note, the information used in developing the methods and providing the factors in DCCEE (2011) comes from a wide variety of sources listed in that document.

The Intergovernmental Panel on Climate Change website[5] provides similar factors for other gases associated with social costs, such as carbon monoxide and oxides of nitrogen. The information allows calculation of appropriate unit costs per kg of gas emissions, and so allows estimates of how changes in fuel consumption can affect these emissions and costs.

[5] www.ipcc-nggip.iges.or.jp/EFDB/find_ef_ft.php

8 Conclusions

8.1 Safe System speed and road typologies

The speed component of a Safe System involves the development of road typologies to eliminate fatal and serious injury crashes by avoiding speeds above critical thresholds. The thresholds are established according to a specific road situation and are similar to the following:

- 70km/h for head-on collisions
- 50km/h for front impacts with a tree or pole
- 50km/h for vehicle-to-vehicle side-impacts (at intersections)
- 30km/h for side-impacts with trees or poles
- 30km/h for impacts with a pedestrian or cyclist.

8.2 Safe System speed and optimal speed

The concept of 'optimal speed' where speed is optimised taking all costs, both safety and non-safety into account should not be confused with Safe System speed where the only criterion is 'harm minimisation' or total avoidance of fatal and serious injury. The adoption of speed limits based on Cameron's (2003) speed optimisation approach has been recommended as a practical interim measure on the way to a full harm minimisation approach under a Safe System strategy

8.3 Travel speed and valuation of safety

There are well attested relationships between increased vehicle speed and decreased safety. The values of safety in the developed world, with a few exceptions where human capital approaches are used, are conservative willingness to pay values augmented by damage costs treatment costs etc. This is very similar to New Zealand's approach.

8.4 Travel speed and time savings and valuation of time savings in economic analysis

The values of time internationally are similar to New Zealand's values where different multiples of wage rates are used for different types of journey, at a fairly aggregated level. Willingness-to-pay approaches have been researched but there is a reluctance to implement such approaches. Within these aggregations, constant averages are used without any discounting of the values of small lengths of time. The discounting of small lengths of time has been much mooted but little has been done notwithstanding evidence that such discounting might be appropriate in some circumstances. This is linked to difficulties in defining what a short length of time is and in deciding what type of discounting protocol to use from a number available. In particular it is arguable as to whether an approach without any discounting for small time savings properly allows for the interests of vulnerable road users, as it may overemphasise the costs of small time losses associated with slowing for vulnerable road users in urban areas. There is also concern that the aggregating processes used in economic analysis models may not be accurate and that this may be a bigger problem than the actual valuations. As discounting may be applicable in some circumstances this is a liberal rather than conservative approach.

Thus regarding the economic appraisal of safety projects under a Safe System approach to road safety the review indicated that the use of a conservative valuation of safety along with a liberal valuation of time in economic analysis is arguable.

8.5 Travel speed and fuel consumption and road-traffic emissions

There are well defined linkages between the speeds of vehicles on the network and their fuel consumption. These linkages allow macroscopic speed changes (such as those related to adopting a Safe System approach to road safety) to be converted to fuel consumption changes. These can then be transformed in to greenhouse gas emissions estimates which can then be multiplied by the appropriate unit costs to provide emissions costs to be used in economic analysis. The individual characteristics of the New Zealand vehicle fleet can be allowed for by accessing the comprehensive data from the Motor Vehicle Register.

9 References

ACC and LTSA (2000) *Down with speed, a review of the literature and the impact of speed in New Zealand.* Accessed 11 June 2012. www.transport.govt.nz/research/documents/acc672-down-with-speed.pdf.

ACTRA (1978) *Report of the Advisory Committee on Trunk Road Assessment* (ACTRA). London: HMSO.

Alfaro, JL, M Chapuis and F Fabre (Eds) (1994) Socio-economic cost of road accidents: final report of action COST 313. Commission of the European Community, Brussels. Accessed 5 December 2012. http://ec.europa.eu/transport/road_safety/specialist/knowledge/measures/monetary_valuation_of_road_safety/ index.htm

Archer, J, N Fotheringham, M Symmons and B Corben (2008) The impact of lowered speed limits in urban and metropolitan areas. *MUARC report no.276*. Accessed 19/6/2012. www.monash.edu.au/miri/research/reports/muarc276.html

Austroads (2008) *Guide to road safety, part 3: speed limits and speed management*. Sydney: Austroads.

Bates, J and GA Whelan (2001) *Size and sign of time savings*. Working paper 561. Leeds: Institute for Transport Studies, University of Leeds.

Beer, K (2011) Striving for Safe System speeds. *Paper presented at Australasian College of Road Safety Conference – A Safe System: Making it Happen!* Melbourne, 1–2 September 2011.

Cameron, M (2000) *Estimation of the optimum speed on urban residential streets (draft report). Melbourne, Victoria: Monash University Accident Research Centre*. Accessed 22 June 2012. www.monash.edu.au/miri/research/reports/other/optspeed.pdf

Cameron, MH (2003) Potential benefits and costs of speed changes on rural roads. *Road safety research report CR216*. Canberra: Australian Transport Safety Bureau.

Cameron, MH and R Elvik (2008) Nilsson's Power Model connecting speed and road trauma: Does it apply on urban roads? *Paper presented the Australasian Road Safety Research, Policing and Education Conference*. Adelaide, 2008.

Cameron, MH (2009) *Economic evaluation of the introduction of lower rural default and national highway speed limits in Tasmania*. Report to the Department of Infrastructure, Energy and Resources, Hobart.

Corben, B (2011) Safe roads and roadsides. A glimpse into the future. *Paper presented at Australasian College of Road Safety Conference – A Safe System: Making it Happen!* Melbourne, 1–2 September 2011.

Covec (2007) *Update and extension of vehicle emissions modelling*. Prepared for Ministry of Transport. Accessed 6 June 2012. www.covec.co.nz/sites/covec.tst/files/Vehicle%20Fleet%20Emission%20%20Final%20Report.pdf

Cregan, M and D Gargett (2009) *Bureau of Infrastructure, Transport and Regional Economics (BITRE) Information sheet 30: Fuel consumption by new passenger vehicles in Australia 1979–2008*. Accessed 7 June 2012. www.bitre.gov.au/publications/2009/is_030.aspx

Davis, SC (1997) *Transportation energy data book: edition 17*. ORNL-6919. Oak Ridge, Tennessee: Oak Ridge National Laboratory.

de Blaeij, A, M Koetse, YY Tseng, P Rietveld and E Verhoef (2004) *Valuation of safety, time, air pollution, climate change and noise; methods and estimates for various countries*. Report prepared for ROSEBUD. Amsterdam: Department of Spatial Economics, Vrije Universiteit.

Department of Climate Change and Energy Efficiency (DCCEE) (2011) *National greenhouse accounts factors.* Canberra. Accessed 12 March 2012. www.climatechange.gov.au/~/media/publications/greenhouse-acctg/national-greenhouse-accounts-factors-july-2011.pdf

Department of Transportation (DoT) (1997) *Departmental guidance for the valuation of travel time in economic analysis*. Washington DC: Office of the Secretary of Transportation, US Department of Transportation. Accessed 5 July 2012. http://ostpxweb.dot.gov/policy/Data/VOT97guid.pdf

European Conference of Ministers of Transport (ECMT) (1996) *Road safety: speed moderation*. Paris: Organisation for Economic Co-operation and Development. Accessed 11 June 2012. http://internationaltransportforum.org/pub/pdf/96Speed.pdf

European Conference of Ministers of Transport (ECMT) (2006) *Speed management*. Paris: OECD. Accessed 13 March 2012. www.internationaltransportforum.org/Pub/pdf/06Speed.pdf

Elvik, R, T Vaa and AB Mysen (1997) *Traffikksikkerhetshandbok.* Oslo: Institute of Transport Economics. Pp313–316 (in Norwegian).

Elvik, R and A Hoye (2004. *The handbook of road safety measures*. Amsterdam: Elsevier.

Elvik, R, P Christensen and A Amundsen (2004) *Speed and road accidents. An evaluation of the power model*. Institute of Transport Economics (TOI). Accessed 11/6/2012. www.trg.dk/elvik/740-2004.pdf

ETSC (1995) *Reducing traffic injuries resulting from excess and inappropriate speed.* Brussels: European Transport Safety Council.

European Commission (Undated). Monetary valuation of road safety. Accessed 22 June 2012. http://ec.europa.eu/transport/road_safety/specialist/knowledge/measures/monetary_valuation_of_road_safety/index.htm

European Commission (2004) Road safety and environmental benefit–cost and cost-effectiveness analysis for use in decision making – WP 3 –the use of efficiency assessment tools: solutions to barriers.

Fildes, B, J Langford, D Andrea, and J Scully (2005) Balance between harm reduction and mobility in setting speed limits: a feasibility study. *Austroads report AP-R272/05*. Sydney: Austroads.

Frith, WJ and B Toomath (1982) The New Zealand open road speed limit. *Accident Analysis and Prevention 14,* no.3: 109–218.

GRSP (2008) *Speed management: a road safety manual for decision-makers and practitioners*. Geneva, Switzerland.

HEATCO (2006) *Developing harmonised European approaches for transport costing and project assessment, specific support action PRIORITY SSP 3.2: the development of tools, indicators and operational parameters for assessing sustainable transport and energy systems performance. Deliverable 5, proposal for harmonised guidelines*. European Commission.

Hensher, DA (1977) Value of business travel time. Oxford: Pergamon Press.

Hensher, DA (2000) Travel time values theoretical framework and research outline. *Transfund NZ research report 138*.

Hensher, DA (2001) Measurement of the valuation of travel time savings. *Journal of Transport Economics and Policy 35*, no.1: 71–98.

Jones, P, P Goodwin and T Whiteing (1984) *Constraints, thresholds and alternative uses of time: review of activity-based research*. Value of time study, working paper 4. London: Department of Transport.

Jones-Lee, M and G Loomes (2003) Valuation of safety. Chapter 24 in Handbook of Transport and the Environment. Edited by D. A. Hensher and K. A. Button. Elsevier Science, Oxford.

Kloeden, CN, AJ McLean, VM Moore and G Ponte (1997) Travelling speed and the risk of crash involvement. Volume 1 – findings. *Road safety report CR172*. Australian Federal Office of Road Safety.

Kloeden, CN, G Ponte and AJ McLean (2001) Travelling speed and the risk of crash involvement on rural roads. *Road safety report CR204*. Australian Transport Safety Bureau.

Langford, J (2006) *Setting speed limits for a safe system*. Monash University Accident Research Centre. Viewed 11 June 2012. www.whiteandblack.co.nz/wp-content/uploads/2010/06/9._Setting_speed_limits__ 16_Nov_06_.pdf.

Metz, D (2004) Travel time – variable or constant? *Journal of Transport Economic and Policy 38*, no.3: 333–344.

Ministry of Transport (MoT) (1996) *Land transport pricing study – environmental externality*. Wellington MoT.

Ministry of Transport (MoT) (2010) *The social cost of road crashes and injuries*. June 2010 update. Wellington: MoT.

Ministry of Transport (MoT) (2011a) *Safer journeys. New Zealand's road safety strategy 2010–2020.* Accessed 13 March 2012. www.transport.govt.nz/saferjourneys/Documents/SaferJourneyStrategy.pdf

Ministry of Transport (MoT) (2011b) *The social cost of road crashes and injuries,* June 2011 update. Accessed 11 June 2012. www.transport.govt.nz/ourwork/land/landsafety/thesocialcostofroadcrashesandinjuries/

Ministry of Transport (MoT) (2011c) The aging of the New Zealand light vehicle fleet. Accessed 6 June 2012. www.transport.govt.nz/ourwork/climatechange/Documents/Light-vehicle-sector-report-aging-of-the-fleet-June-11.pdf

MVA Consultancy, ITS University of Leeds, TSU University of Oxford (1987) *Value of travel time savings*. Policy Journals, Newbury, Berks.

New Zealand Transport Agency (2010) *Economic evaluation manual volume 1*. Accessed 13 March 2012. www.nzta.govt.nz/resources/economic-evaluation-manual/volume-1/docs/eem1-july-2010.pdf

Nilsson, G (1982) The effects of speed limits on traffic accidents in Sweden. Pp 1–8 in *Proceedings of the international symposium on the effects of speed limits on traffic accidents and transport energy use.* Dublin, 6–8 October 1981. Organisation for Economic Co-operation and Development (OECD) Paris.

Nilsson, G (2004) *Traffic safety dimensions and the power model to describe the effect of speed on safety*. Lund Bulletin 221. Lund: Lund Institute of Technology. Accessed 28 November 2011. www.lub.lu.se/luft/diss/tec_733/tec_733.pdf

OECD/ITF (2008) *Towards zero: ambitious road safety targets and the safe system approach*. Paris: OECD/International Transport Forum (ITF). Accessed June 2012. www.internationaltransportforum.org/Pub/pdf/08TowardsZeroE.pdf

O'Fallon, C and C Sullivan (2009) Trends in trip chaining and tours: analysing changes in New Zealanders' travel patterns using the ongoing New Zealand household travel survey. *NZ Transport Agency research report 373*.

O'Fallon, C and I Wallis (2012). A wider look at how travellers value the quality and quantity of travel time. *NZ Transport Agency research report 469.*

Patterson, TL, WJ Frith, LJ Povey and MD Keall (2002) The effect of increasing rural interstate speed limits in the United States. *Traffic Injury Prevention 3:* 316–320.2.

Powell, M and J Bowers (1996) *Aggregating small time savings in trunk road scheme appraisals*. Accessed 7 June 2012. www.docstoc.com/docs/25879293/Small-Time-Savings-and-Trunk-Road-Scheme-Appraisal

Rietveld, P, A van Binsbergen, T Schoemaker and P Peeters (1996) *Optimum speed limits for various types of roads: a social cost-benefit analysis for the Netherlands*. Amsterdam: Tinbergen Institute, Free University Amsterdam.

Sharp, CH (1973) *Transport economics*. London: Macmillan.

Tilahun Nebiyou, Y and DM Levinson (2007) *Value of time comparisons in the presence of unexpected delay.* Minneapolis: Department of Civil Engineering, University of Minnesota. Accessed 30 October 2012. http://nexus.umn.edu/Papers/UnexpectedDelay.pdf

Transportation Research Board (TRB) (1984) F-55 A decade of experience. *Special report 204*. Washington DC: National Research Council.

Transportation Research Board (TRB) (1995) Expanding metropolitan highways: implications for air quality and energy use. *Special report 245.* Washington DC: National Research Council.

Transportation Research Board (TRB) (1998) Managing speed: review of current practice for setting and enforcing speed limits. *Special report 254*. Washington DC: Transportation Research Board. Accessed 13 March 2012. http://onlinepubs.trb.org/onlinepubs/sr/sr254.pdf

Tsolakis, D, J Shackleton and T Makwasha (2011) *Small travel time savings: treatment in project evaluations.* Austroads Publication No AP–R392-11. Sydney: Austroads.

Victoria Transport Policy Institute (2012) *Transportation cost and benefit analysis techniques, estimates and implications.* [2nd ed], chapter 5.2. Victoria, BC: Travel Time. Accessed 13 March 2012. www.vtpi.org/tca/

Wallington, TJ, JL Sullivan and MD Hurley (2008) Emissions of CO_2, CO, NOx, HC, PM, HFC-134a, N_2O and CH_4 from the global light duty vehicle fleet. *Meteorologische Zeitschrift 17*, no.2: 109–116. Accessed 13 March 2012. www.schweizerbart.de/resources/downloads/paper_free/56618.pdf

Ward, H, S Robertson and R Allsop (1998) Managing speeds of traffic on European roads-non-accident external and internal effects of vehicle use and how these depend on speed. *Paper presented at the 9th Road Safety in Europe Conference*. Germany.

Waring, P (1996) Vehicle safety standards. In Land Transport Safety Authority, 110km/h speed limits. Internal document, 27 August 1996.

Waters, WC, J Evans, C Leung, B Stefiuk and C Wong (1992) *The value of time savings for the economic evaluation of highway investments.* Vancouver: Centre for Transportation Studies.

Wegman, F and L Aarts (Eds) (2006) *Advancing sustainable safety: national road safety outlook for 2005–2020*. Leidschendam: SWOV. Accessed 11 June 2012. www.swov.nl/rapport/DMDV/Advancing_Sustainable _Safety.pdf

Welch, M and H Williams (1997) The sensitivity of transport investment benefits to the evaluation of small travel-time savings. *Journal of Transport Economics and Policy 31*, no.3: 231–254.