Estimation of the Optimum Speed on Urban Residential Streets

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Abstract

The optimum speed is defined as one which balances the social costs and benefits of increased travel time with decreased road trauma, vehicle operating costs, emissions, etc. Three different methods were considered to measure the impact of travel speed on road trauma and/or crash costs. Relationships between cruise speed and average (all) speed were extrapolated to measure the impacts on travel time in residential streets for travel speeds in the range 35 to 85 kmh. The relationship between vehicle operating costs and travel speed was based on two Australian models. Air pollution emission rates at each travel speed were based on European relationships. The project focused on urban residential streets with 60 kmh speed limits because of the availability of a considerable amount of relevant basic data. When the "human capital" valuations of road trauma costs were used, the analysis suggested that the optimum speed on residential streets is 55 kmh. When the analysis was repeated making use of road trauma costs valued by the "willingness to pay" approach, the analysis suggested that the optimum speed on residential streets is 50 kmh. The analysis presumed that it is legitimate to adopt an economic rationalist approach to choose the optimum speed in residential streets. If the value of road trauma was five times the "human capital" costs, a travel speed of 35 kmh would be the maximum speed which could be economically justified. This is close to the maximum speed which has been demanded by societies not wishing to compromise road safety and aiming to prevent all deaths and serious injuries on residential streets (30 kmh).

1 INTRODUCTION

The optimum speed is defined as one which balances the social costs and benefits of increased travel time with decreased road trauma, vehicle operating costs, emissions, etc. A recently completed study in Adelaide has allowed the relationship between road trauma and speeds on 60 km/h roads in Australia to be calibrated for the first time (Kloeden et al 1997). Coupled with information on other social costs and benefits related to speed, the project aimed to estimate the optimum speed by calculating the total social cost for each of a range of travelling speeds.

Previous research in Europe suggested that there is sufficient knowledge relating road trauma, vehicle operating costs, emissions, noise and travel time to vehicle speeds in urban areas to indicate that the project was feasible (Nilsson 1984; Andersson et al 1991; Peters et al 1996; Rietveld et al 1996; Carlsson 1997; Toivanen and Kallberg 1998; Elvik 1998).

Recent research in Australia has provided local information on the relationships between speeds and casualty crash involvement (Kloeden et al 1997) and travel times (SMEC 1998) in urban areas. There is also local information linking speeds with fuel consumption and other operating costs (Thoresen 2000). Other relevant relationships are documented in the European research.

The project focused on urban residential streets with 60 kmh speed limits because of the availability of a considerable amount of relevant basic data provided in the Regulatory Impact Statement recently released by the Victorian Government regarding proposed regulations to reduce the speed limit on those streets to 50 kmh (VicRoads 2000). This focus also made it reasonable to limit the valuation of travel time to private cars on personal business and commuting trips. The study considered travel speeds in the range from 35 kmh to 85 kmh, but findings were considered most reliable in 45-65 kmh range.

The project presumed that it is legitimate to adopt an economic rationalist approach to the choice of travel speeds in residential streets. The appropriateness of such decisions will be covered in the Discussion section.

2 PREVIOUS RESEARCH ON OPTIMUM SPEEDS

Nilsson (1984) reported separate relationships between the increase in the numbers of killed, seriously injured, and slightly injured car occupants, and the increase in the median speed relative to baseline conditions. He built on these relationships to estimate the total injury cost for car occupants per million vehicle kilometres travelled as a function of median speed, for each of six rural road environments in Sweden.

Some roads had much higher median speeds than would be expected if they had the same "accepted" balance between speed and injury cost rate which was displayed on other roads. Nilsson argued that speeds on these roads would need to be reduced (in the order of 5-10 kmh) if the same balance of speed and injury costs were to be achieved on all roads. While Nilsson's proposals may not have achieved the optimum balance, they were aimed in this direction.

Andersson et al (1991) calculated optimal speeds on different classes of Swedish roads on the basis of socio-economic costs. The optimal speed was defined as the speed where the sum of accident costs (injuries and material damage), vehicle operating costs, and travel time costs was lowest. The prices or values used were the same as those normally used in official transport economic calculations.

They found that the optimal speeds on three types of urban roads, presently speed-zoned with 50 kmh limits, was in the range 47-58 kmh. However, in the rural road environments, the optimal speeds were considerably lower than the current mean speeds and the speed limits.

Plowden and Hillman (1996) calculated optimal speed limits for U.K. main roads both outside and inside towns. The calculations took into account the speed-related impacts on and monetary values of fuel, other vehicle operating costs, travel time and accidents. The results were considered to be the upper boundaries of the speed limits because all the impacts left out of the calculations were negative and increase with speed (eg. noise pollution). The calculations were made with and without the assumption of an effect whereby reduced speed limits influence how much road users travel.

For motorways and "A" roads outside towns, in general they found that optimal speed limits were up to 15 mph lower than existing limits, depending on the road class and assumptions on fuel taxation. Their analysis of urban roads had greater difficulties determining the effects of speed changes, but they concluded that the urban speed limit should normally be 20 mph (32 kmh). However, it appears that some of their assumptions may have been extreme, so this figure could be viewed as a lower limit for optimal speeds in urban areas. They made a number of suggestions for further work to refine their calculations.

Rietveld et al (1996) calculated the socially optimal speed for passenger cars on different roads types in the Netherlands, with and without the assumption that total travel is independent of changes in speed. The calculations made a distinction between fatal and other serious accidents, and also included the speed-related impacts on travel time, energy use, and CO_2 and NO_X emissions. Further information on their methods and data is given by Peeters et al (1996) and Coesel and Rietveld (1998).

The researchers had to rely on general estimates of the elasticity between travelling time and vehicle travel when estimating the speed-related impacts. They noted that a full network model would have been necessary to provide a more realistic estimate of the effects of speed changes on travel demand. They also stated that their analysis was incomplete because they were not able to consider the effects on noise pollution and costs.

Rietveld et al noted that vehicles seldom travel at constant speed and that actual average (all) speeds are considerably lower than speed limits and desired speeds, especially in urban areas. On urban roads with a 50 kmh limit, they found that the average speed was 38 kmh on major urban through roads and 27 kmh on other urban roads. The average speed was 15 kmh in residential streets, which have a 30 kmh limit. They also found that the optimal speed on the urban roads/streets was close to (or a little less than) the average speed in each case, whereas on the higher speed limited rural roads the optimal speeds were considerably less than the corresponding averages. In the urban areas in the Netherlands, it appears that desired speed behaviour is generally consistent with the current speed limits and produces average (all) speeds which are close to socially optimal.

Elvik (1998) undertook a similar analysis to calculate the optimal speed in urban areas in Norway, considering in addition the speed-related impacts on noise pollution and feelings of insecurity towards children. He found that the optimal speed on urban main roads was 50 kmh, on collector roads it was 40 kmh, and on residential access roads it was 30 kmh.

Carlsson (1997) calculated the optimum speeds of passenger cars on different types of rural roads in Sweden. The speed-related effects on fatalities, serious injuries, slight injuries, property damage, travel time, fuel consumption, tyre wear, and CO_2 , NO_X and HC emissions were all included. He found that the present travel speeds in Sweden were 15-25 kmh higher than the optimum speed for each type of road.

Kallberg and Toivanen (1998) have described a framework for assessing the impacts of speed, developed as part of the European project MASTER (MAnaging Speeds of Traffic on European Roads). While they do not use this to calculate optimum speeds, the framework was a valuable basis for the project described here. It aims to provide a comprehensive coverage of all the impacts, both direct and indirect, and quantifiable and non-quantifiable.

Kallberg and Toivanen draw an important distinction between the impacts of speed at the level of the individual road section or link, viewed in isolation, and at the level of the transport network. It is possible that changes in speeds or speed limits on individual links can have impacts on perceived accessibility, transport modal split, and broader socio-economic impacts, all of which can have feed-back effects on travel speeds. They also note that speed management can have objectives related to *efficiency* (where socio-economic cost-benefit analysis is an important tool) and *equity* (where the distribution of the costs and benefits of speed needs to be considered). Speeds which are desirable from an efficiency point-of-view may not be acceptable because of real or perceived inequities to some parts of society. However, the inequities are usually difficult to quantify.

The MASTER project has developed a computer spreadsheet to allow all the impacts of a change in speed management policy to be recorded, and analysed where appropriate. Kallberg and Toivnanen (1998) give a detailed description, and illustrate its use by applying it to speed policy issues in Finland, Hungary and Portugal. The spreadsheet provided a useful computational basis (with modifications) for the calculation of the impacts of different travel speeds on urban residential streets.

3 IMPACTS OF SPEED

3.1 ROAD TRAUMA

The most relevant research linking travelling speed with road trauma on urban 60 kmh speed-limited roads in Australia has been carried out by Kloeden et al (1997). They estimated the relative risk of passenger car involvement in a casualty crash[1] for travelling speeds (free speeds, unimpeded by other traffic) ranging from 35 to 85 kmh, in 5 kmh intervals. The risk was estimated relative to the risk at 60 kmh, which was set at a value of 1. Upper and lower 95% confidence limits for the true relative risk at each travelling speed were also provided.

The estimated relative risk for a car travelling at 65 kmh was 2.0, with confidence limits ranging from 1.17 to 3.43. The estimated relative risk and its confidence limits increased rapidly for speeds above 65 kmh. However, the estimated risks for speeds below 60 kmh did not decrease substantially and each of the upper confidence limits included the value of 1, indicating that the risks at the lower speeds were not significantly different from that at 60 kmh. Each of the lower confidence limits generally decreased as the speed reduced, as could be expected for the low-speed risks given the substantial increases in the high-speed risks.

Kallberg and Toivanen (1998) considered that a correct assessment of the effects of speed on road trauma requires that the impacts on crash injury severity, as well as crash frequency, be addressed. This is because of findings that, for a given increase in the speed of traffic, the effect on the risk of fatal and serious injury crashes is greater than the effect on injury crashes in general. Thus it is possible that in the crashes analysed by Kloeden et al (1997), the proportion of the casualty crashes resulting in death or serious injury may have decreased for travelling speeds below 60 kmh. This was not apparent from their analysis, which provided the relative risks of involvement in any form of casualty crash.

Nilsson (1984) developed relationships of the following form linking changes in mean or median speeds with the number of crashes:

$$\mathbf{n_A = (v_A/v_B)^p * n_B}$$

where $\mathbf{n_A}$ = number of crashes after the speed change

$\mathbf{n_B}$ = number of crashes before the speed change

$\mathbf{v_A}$ = mean or median speed after

$\mathbf{v_B}$ = mean or median speed before

$\mathbf{p}$ = exponent depending on the injury severity of the crashes:

?? $\mathbf{p}$ = 4 for fatal crashes
?? $\mathbf{p}$ = 3 for serious injury crashes
?? $\mathbf{p}$ = 2 for minor injury crashes

These relationships were based on research linking changes in median speeds (free speeds measured in traffic surveys) with changes in crash frequencies at various injury severities, as a result of a large number of changes in speed limits on Swedish rural roads. A potential problem with the fatal crash relationship is that a poor estimate of the fatal crash frequency before the speed change can give an inaccurate estimate of the impact on fatal crash costs, due to the fourth-power effect of the exponent in this case, and the relatively high unit costs normally attached to fatal outcomes.

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[1] Crashes in which at least one person was transported from the crash scene by ambulance. The injury may have been more severe than one requiring any form of medical treatment, the usual minimum criterion for defining a casualty crash resulting in death or injury.

The MASTER spreadsheet uses the above relationship, with $\mathbf{p} = 2$, as the impact function linking casualty (fatal and injury) crashes with mean speeds, based on Andersson and Nilsson (1997). In recognition that this function does not capture the effects of changing injury severity distribution resulting from changes in speed, the MASTER spreadsheet uses a development of this function to calculate speed-related changes in accident costs:

$$\mathbf{C_A = [k*((v_A/v_B)^2-1)+1]*C_B}$$

where $\mathbf{C_A}$ = crash costs after

$\mathbf{C_B}$ = crash costs before

$\mathbf{k}$ = a constant depending on the actual unit costs of fatal, serious and minor injuries and the average number of each in casualty crashes of various severities (Kallberg and Toivanen found that $\mathbf{k} = 2$, approximately, applied in most European countries, and adopted this value in the spreadsheet)

Given the critical role of the impact function linking travelling speeds with road trauma, all three of the above relationships were considered in this study. However, it should be noted that the function for the change in accident costs breaks down when $\mathbf{v_A/v_B} < 0.707$. For changes in mean speed in this range, it was decided to modify the formula to $\mathbf{k} = 1$ during this study. This problem did not arise when the analysis was conducted using Nilsson's (1984) relationships in their original form.

3.2 VEHICLE OPERATING COSTS

Thoresen (2000) summarises two models for calculating vehicle operating costs as a function of travel speeds in urban areas. For speeds less than 60 kmh, he proposes that the following "Urban Stop Start Model" model be used:

$$c = A + B / V$$

where c = vehicle operating cost (cents/km) and V = journey speed (kmh). The values of constants applicable to private (used) cars have been used in this study, namely A = 23.10 and B = 71.48.

For speeds in excess of 60 kmh, Thoresen proposes that the "Freeway Model" be used:

$$c = C_0 + C_1V + C_2V^2$$

The values $C_0 = 25.56$, $C_1 = -0.061$, and $C_2 = 0.00043$, applicable to private (used) cars, have been used here.

The Urban Stop Start Model has been used for speeds up to 60 kmh, and the Freeway Model has been used for speeds greater than 60 kmh. There is little discontinuity in vehicle operating costs between the two models around a speed of 60 kmh.

3.3 TRAVEL TIME

It is well known that travel time = link length / speed of traffic flow. However, Kallberg and Toivanen (1998) noted that, especially in urban conditions, a considerable part of the travel time may be spent not moving at all or moving at very low speeds. Thus the average of all actual speeds may be considerably less than the desired or maximum speed, and the travel time on the link may be considerably greater than that suggested by the free speeds of traffic on the road.

To provide a better understanding of this in urban conditions, the (then) Federal Office of Road Safety commissioned research on the relationship between changes in cruise speed and changes in average (all) speeds in different road environments, including residential 60 kmh zoned streets (SMEC 1998). The cruise speed represents the maximum speed at which the average driver traverses each segment of a travel route. It is typically the free speed (speed of a vehicle observed with greater than a minimum headway) observed in traditional speed surveys; mean speeds from these surveys are really average free speeds.

SMEC simulated the situations where the speed limit on a road link was reduced by 5 and 10 kmh, respectively, and increased by 5 kmh. The analyses were based on the premise that the expected change in speed of vehicles travelling above or within 10 kmh of a new limit will be in proportion to the change in the speed limit. Where the speed profile was generally reduced (increased), the total travel time was increased (reduced) in the simulation so that the total length of the trip remained constant. The average of all speeds was then calculated for each change in the speed limit. In the real data they collected from urban 60 kmh zoned roads in Melbourne, the mean cruise speed was 57 kmh. It was assumed that the change in mean cruise speed would have been the same magnitude as the change in the speed limit.

Figures 1 and 2 show the average (all) speeds estimated by SMEC during off-peak and peak periods, respectively, for cruise speeds of 47, 52, 57 and 62 kmh. Also shown is the linear extrapolation of the end points, down to 35 kmh and up to 85 kmh. These extrapolations should be considered as indicative only, with the most reliable estimates being between 47 and 62 kmh. Over this 15 kmh range of cruise speeds, the average (all) speeds was estimated to vary by only 5.3 kmh during off-peak periods and by 2.8 kmh during peak periods.

For the purpose of estimating the average of all speeds on residential streets for cruise speeds in the range 35 to 85 kmh, the simple averages of the average speeds shown in Figures 1 and 2 were calculated, assuming that off-peak and peak traffic is equally represented on residential streets. The estimated average of all speeds was then used to calculate the travel time on the links for each cruise speed.

Figure 1: Average of all speeds during off-peak periods v. cruise speeds on residential streets in Melbourne

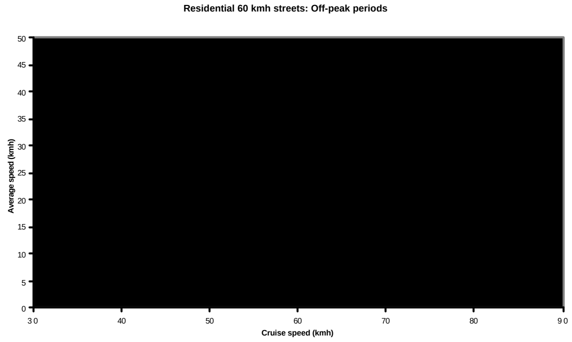
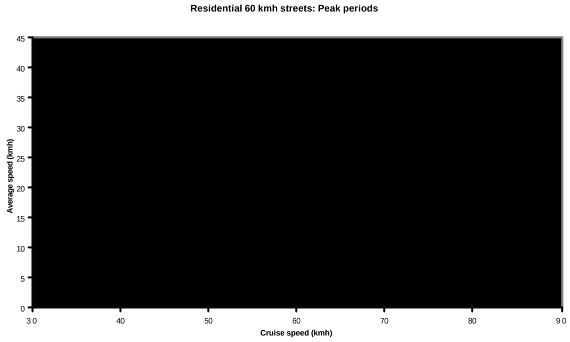


Figure 2: Average of all speeds during peak periods v. cruise speeds on residential streets in Melbourne



SMEC (1999) extended the analysis in SMEC (1998) to consider higher-order effects of the changes in cruise speed across the whole Melbourne road network, using a transport network model. The model simulated a change in the routes selected, change in the transport mode selected, and change in the total number of trips. The simulations were based on situations where the speed limit was reduced by 5 and 10 kmh, respectively, and increased by 5 kmh, as before in the link-level analysis. Unfortunately, the speed limits were reduced or increased simultaneously on all roads in the network, not just the residential 60 kmh zoned streets which are the focus of this study. Hence it is not possible to estimate the network-level effects of the change in cruise speeds on residential streets alone.

For this reason, the analysis in this study was confined to a link-level examination of changes in cruise speed. It is assumed that there was no change in traffic volumes on residential streets as a result, and hence that there was no change in consumer surplus (Kallberg and Toivanen 1998) associated with the changes in cruise speed. Given that residential streets are principally used by drivers at only the beginning and end of their trips in most circumstances, and that there are few options associated with this practice, it is believed that the assumption is reasonable. The exception may be in circumstances where the cruise speeds are at their lowest levels (eg. 35-40 kmh), when drivers may be attracted to higher speed collector streets and arterial roads.

3.4 AIR POLLUTION EMISSIONS

Speed of a vehicle has considerable effect on the air pollutants it emits. There are pollutants directly related to fuel consumption (eg. carbon dioxide, lead, and oxides of nitrogen) as well as those resulting from incomplete combustion (eg. carbon monoxide, hydrocarbons, and particulates). The amount of pollutant emitted at a given speed depends on whether the vehicle is accelerating or travelling at a steady speed (SMEC 1998, Ward et al 1998). Hence the total pollution emitted from a vehicle is related to whether it is driven smoothly or aggressively.

Ward et al (1998) have presented estimates of the levels of emissions from a typical stream of vehicles travelling at steady speeds between 30 and 90 kmh on flat roads. These estimates have been interpolated to estimate the air pollution emission impacts (in grams per 1000 km) for carbon monoxide, hydrocarbons, oxides of nitrogen, and particulates at each cruise speed. Ward et al did not present information to estimate the impacts of carbon dioxide related to travel speed. Since their estimates relate to travel at steady speeds, they probably represent the lower bounds of the impacts observed in practice.

3.5 NOISE POLLUTION

The impact of noise pollution from vehicles travelling in urban areas increases with speed and is also related to the population density within noise zones at each decibel level. Because of the complexity of this relationship, it was not possible to obtain an adequate impact function to represent noise pollution in residential streets. For this reason, the impacts of noise pollution at each speed could not be quantified in this study. However, as Elvik (1998) noted, the impacts of noise pollution in urban areas are likely to have a substantial cost.

4 VALUATION OF COSTS AND BENEFITS

4.1 ROAD TRAUMA

There are two basic approaches to valuing road trauma (Steadman and Bryan 1988):

- the "ex-post" approach, which examines the costs of road trauma which has already occurred (also known as the "human capital" approach)

- the "ex-ante" approach, which seeks to determine the amount the community would pay to prevent road trauma in the future (also known as "willingness to pay")

BTE (2000) has recently provided new estimates of the human capital costs of road trauma in Australia during 1996. These estimates were updated to year 2000 values using the Consumer Price Index for Melbourne. The updated estimates of the human capital cost of road crashes, by the injury level of the most severe injury, in year 2000 A$ are:

fatal crashes	$ 1,740,359
serious injury crashes	$ 429,553
other injury crashes	$ 14,504

These estimates were combined in the proportion of the different crash types which occurred on local streets in Melbourne during 1995 to provide an estimate of the human capital cost of casualty crashes on average, namely:

all casualty crashes (average)	$ 152,273

Earlier, BTCE (1997) had derived willingness-to-pay values of road trauma in Victoria during 1992, based on willingness-to-pay approaches in the USA and human capital costs for Australia at that time. They provided high and low estimates of the willingness-to-pay values of road trauma per person, at each level of injury severity, which differed only in the cases of serious and medically treated injury. The high estimates were chosen for this study because the human capital estimates of the cost of road injury in Australia have increased substantially since 1997.

The willingness-to-pay estimates per person were combined according to the average number of persons injured to each level of severity in fatal, serious injury and other injury crashes, respectively, in urban Melbourne (Corben et al 1994). These estimates were then updated to year 2000 A$ using the Consumer Price Index, and averaged by the proportion of each crash type on local streets in Melbourne, to provide the following estimates of the willingness-to-pay values of road crashes:

fatal crashes	$ 4,550,944
serious injury crashes	$ 368,964
other injury crashes	$ 82,030
all casualty crashes (average)	$ 216,655

It was noted that the willingness-to-pay estimate of the value of a serious injury crash was below the human capital cost based on BTE (2000). This was considered likely to be due to methodological differences compared with BTCE (1997), but it was beyond the scope of this study to rationalise these differences.

4.2 TRAVEL TIME

Thoresen (2000) gives estimates of the value of travel time (per hour of travel) related to vehicle type and urban/rural location of trip. Information was not available on the composition and trip purpose of traffic in residential streets to calculate an average of the cost of travel time. However, Elvik (1999) suggested that the proportion of heavy vehicles (trucks and buses) in residential areas could be expected to be relatively small. In addition, the proportion of trips that are business trips is likely to be smaller in residential areas than in other areas.

For these reasons, it was assumed that all of the travel in residential streets was private car travel, for the purpose of valuing travel time in this study. Thoresen (2000) has provided an estimate of $7.61 per hour for the value per occupant of travel time in urban areas, and an estimate of 1.6 occupants per car. Together these figures provided the estimate of $12.18 per hour for the cost of travel time in residential streets which was used in this study.

4.3 AIR POLLUTION EMISSIONS

Air pollution cost estimates were provided by Cosgrove (1994). The Consumer Price Index was used to provide estimates in year 2000 A$, namely:

?? Carbon monoxide	$ 0.002 per kilogram
?? Hydrocarbons	$ 0.44 per kilogram
?? Oxides of nitrogen	$ 1.74 per kilogram
?? Particulates (PM10)	$ 13.77 per kilogram
?? Carbon dioxide	$ 0.022 per kilogram

5 ESTIMATION OF OPTIMUM SPEED ON RESIDENTIAL STREETS

5.1 BACKGROUND

The Regulatory Impact Statement (RIS) released by the Victorian Government regarding the proposed regulations to reduce the default speed limit on lengths of road in built-up areas from 60 kmh to 50 kmh (VicRoads 2000) has provided useful basic data for this study. This information has been incorporated in the modification to the spreadsheet developed by the MASTER project which was used in this study to examine the impacts of a range of cruise speeds, under various assumptions.

The RIS estimated that 5.275 billion vehicle kilometres per annum are travelled on urban residential streets in Victoria, most of which are in Melbourne. It was also estimated that there are 69,600 residential streets in Victoria. For the purpose of the spreadsheet, it was assumed that the average length of each residential street is one kilometre. This resulted in an estimate of the Annual Average Daily Traffic (AADT) of 207.65 vehicles per day. In practice, these somewhat arbitrary assumptions were not critical because the key data used was the total vehicle kilometres. As discussed in section 4.2, it was assumed that all of the travel in residential streets was private car travel on personal business and commuting trips.

The information and assumptions to provide impact functions for vehicle operating costs, travel time and air pollution emissions related to cruise speed were described in section 3. These impact functions and the unit prices of each impact were unchanged for each of the scenarios considered. The specific impact functions and cost estimates used for the effects of cruise speed on accidents will be described for each scenario below. In each case it was assumed that there were 2000 casualty crashes per annum on residential streets in Victoria, as estimated in the RIS, and that the corresponding mean travel speed on these streets was 57 kmh, based on SMEC's (1998) observations of real traffic in Melbourne.

The total monetary impacts of vehicle operating costs, travel time costs, crash costs, and air pollution costs were calculated for each cruise speed considered. The cruise speed at which the total costs were at a minimum was considered to be the optimum speed, under the assumptions and for the scenario considered. It should be noted that the optimum speed has been estimated in this study only to the nearest 5 kmh in the range of cruise speeds between 35 and 85 kmh. As also noted in section 3.3, the most reliable estimates are likely to be those falling between 47 and 62 kmh.

5.2 HUMAN CAPITAL VALUATION OF CRASH COSTS

The initial scenarios considered were those where the costs of crashes were based on the "human capital" estimates provided by BTE (2000), updated to year 2000 prices. The total monetary impact of each cruise speed considered depended on the specific relationship between speed and road trauma. Each relationship will be addressed in turn in the following sections.

5.2.1 Kloeden et al's relationship between speed and casualty crashes

The comparison based on Kloeden et al's (1997) estimates of the relative risk of a casualty crash at each speed is shown in Figure 3. The minimum total cost occurred at a cruise speed of 60 kmh (estimated $3.361 billion p.a.), however it can been seen that the total cost is relatively constant in the range 50 to 60 kmh. The risk of a casualty crash was estimated by Kloeden et al to vary relatively little at speeds below 60 kmh.

The 95% confidence limits on Kloeden et al’s estimates were also relatively wide and for this reason it was decided to consider the influence on the comparison if the lower 95% confidence limits were used instead of the central estimates of relative risk (Figure 4). The minimum total cost then occurred at a cruise speed of 50 kmh (estimated $3.295 billion p.a.).

Figure 3: Impacts of speed based on Kloeden et al’s relationship

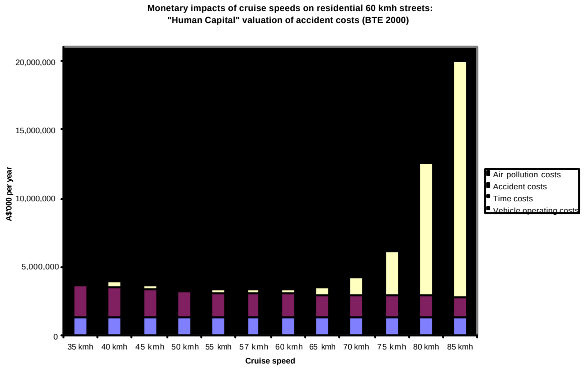
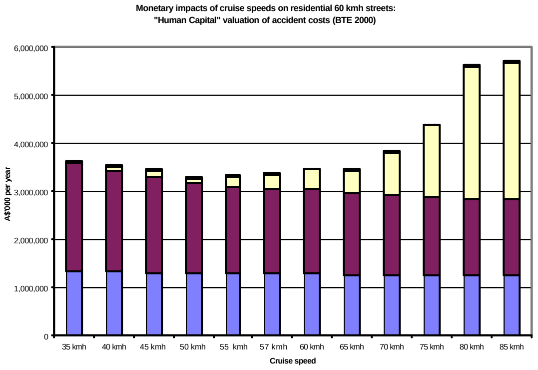


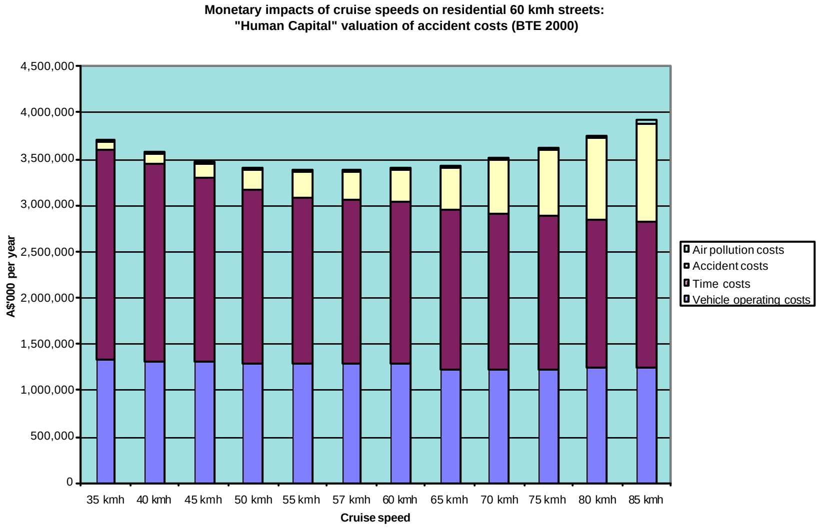
Figure 4: Impacts of speed based on Kloeden et al’s relationship (lower limits of risk)



5.2.2 Nilsson’s relationships between speed and crashes of different injury severity

The comparison based on Nilsson’s (1984) relationships linking mean travel speed with fatal, serious injury, and other injury crashes is shown in Figure 5. For this analysis, the total of 2000 casualty crashes per annum assumed to occur on residential streets was sub-divided in the proportion of fatal, serious injury, and other injury crashes which occurred on local streets in Melbourne during 1995. Thus it was assumed that there are 24 fatal crashes, 564 serious injury crashes, and 1412 other injury crashes per annum on residential streets, on which mean travel speeds are currently 57 kmh, for the purpose of applying Nilsson’s relationships.

Figure 5: Impacts of speed based on Nilsson’s relationships



The minimum total cost occurred at a cruise speed of 55 kmh (estimated $3.382 billion p.a.). As in section 5.2.1 (Kloeden et al’s relationship), it can be seen that the total cost is relatively constant in the range 50 to 60 kmh. As the number, severity and cost of crashes rises in that range, the cost of travel time falls, leading to the total cost being very stable.

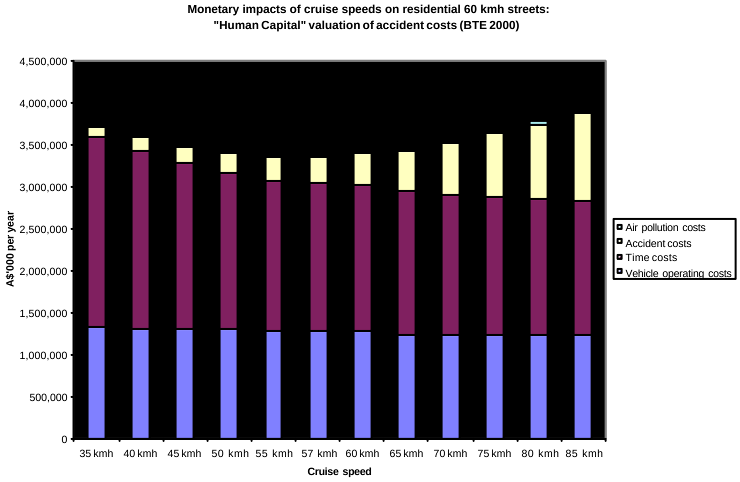
Nilsson’s relationships appear to produce more stable estimates of the total monetary impacts of different cruise speeds on residential streets. Kloeden et al’s estimates of the relative risk of casualty crashes at each speed are subject to uncertainty as indicated by the confidence limits on each estimate. When the lower limits of Kloeden et al’s estimates were used, they suggested a much lower optimum speed (50 kmh) than that found when the estimates were used directly (60 kmh).

5.2.3 Kallberg and Toivanen’s relationship between speed and casualty crash costs

The comparison based on Kallberg and Toivanen’s (1998) relationship linking changes in mean travel speed with changes in crash costs is shown in Figure 6. The changes in speed were referenced to the current mean travel speed of 57 kmh assumed for cars on residential streets, where it was assumed that 2000 casualty crashes per annum occur.

When applying Kallberg and Toivanen’s relationship, it was found that it produced unrealistic estimates of crash costs when considering speeds of 50 kmh or less. In this range of speeds, the constant **k** in the relationship was set at one, instead of two. Thus, in these cases, the ratio of crash costs was assumed to be directly related to the square of the ratio of the speeds (considered speed divided by 57 kmh). For speeds of 55 kmh and above, Kallberg and Toivanen’s relationship was used in unmodified form.

Figure 6: Impacts of speed based on Kallberg and Toivanen’s relationship


Monetary impacts of cruise speeds on residential 60 kmh streets:
"Human Capital" valuation of accident costs (BTE 2000)

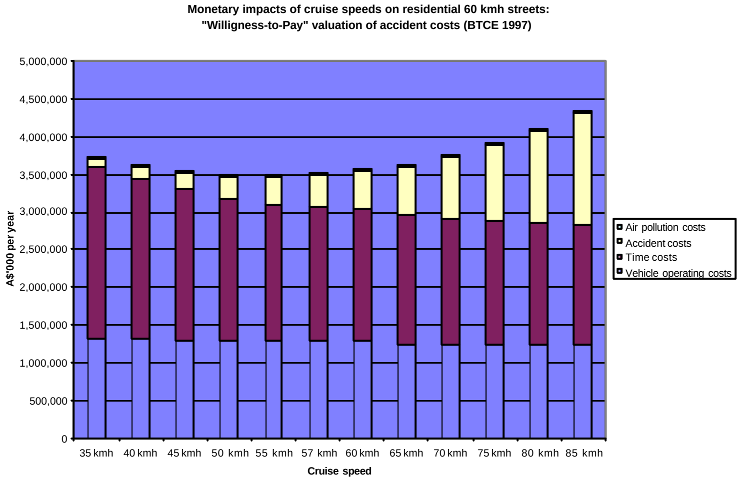
The minimum total cost occurred at a cruise speed of 55 kmh (estimated $3.371 billion p.a.). The results were very similar to those based on Nilsson’s relationships. However, there was concern that Kallberg and Toivanen’s relationship had been compromised at speeds below 55 kmh where it appeared to produce unrealistic results.

Because of concern about the reliability of the estimates derived from either Kloeden et al’s relationship or Kallberg and Toivanen’s relationship, it was decided to consider only Nilsson’s relationships in the subsequent analysis in which road trauma was valued using the “willingness-to-pay” approach.

5.3 WILLINGNESS-TO-PAY VALUATION OF CRASH COSTS

A comparison based on the “willingness-to-pay” valuation of crash costs was also carried out, based on BTCE (1997) estimates updated to year 2000 prices (see section 4.1). Only Nilsson’s relationships linking travel speeds were used in this comparison, for reasons outlined in the previous section. The results are shown in Figure 7.

Figure 7: Impacts of speed based on Nilsson’s relationships and “Willingness-to-Pay” valuation of road crash costs


Monetary impacts of cruise speeds on residential 60 kmh streets:
"Willigness-to-Pay" valuation of accident costs (BTCE 1997)

The minimum total cost, when road trauma was valued by the willingness-to-pay method, occurred at a cruise speed of 50 kmh (estimated $3.493 billion p.a.). As with the results based on human capital costs, the total cost was relatively constant in the 50 to 60 kmh range.

6 DISCUSSION

This study aimed to estimate the optimum travel speed on urban residential streets in Australia which, for the most part, are currently zoned with a speed limit of 60 kmh (the exceptions mainly being municipalities in New South Wales and South East Queensland). The optimum speed was defined as the travel or cruise speed on residential streets which leads to the total cost of road trauma, travel time, vehicle operating costs, and air pollution emissions being at a minimum.

A limitation of this study was that noise pollution emissions could not be considered and their cost included in the total. No impact function to adequately represent the harm from vehicle noise in residential areas of Australia could be found. This was unfortunate because the cost of noise pollution in urban areas is likely to be substantial. Another limitation was the impacts of carbon dioxide emissions could not be considered. If impact functions for noise pollution and carbon dioxide emissions were to become available, they could readily be included in the spreadsheets. In the interim it should be noted that the magnitude of each of these pollutants is known to increase with travel speed. The optimum speed found if their costs were included would be no greater (possibly lower) than the optimum suggested by this study.

This study has been limited to a link-level analysis of residential streets and has assumed that no traffic would be diverted to collector streets or arterial roads if travel speeds on the residential streets decreased. The study has had to rely on an extrapolation of the relationships found by SMEC (1998) between cruise speeds and the average of all speeds, especially when considering travel speeds below 47 kmh. It is possible that at low travel speeds, traffic would be diverted from residential streets and the average (all) speeds would not reduce as much as expected. In this situation, travel times would not be as great and hence the total cost (as defined above) would also not be as great at the low speeds. While the reduction in traffic is perhaps a disbenefit from the road users' point of view, it may be perceived as a benefit from the point of view of residents and non-motorised travellers in the residential streets (Elvik 1999).

Against this background of information available and assumptions made, this study has been able to estimate the optimum speed in residential streets, given two scenarios for valuing road trauma and three methods for relating road trauma costs to travel speeds. Kloeden et al's (1997) estimates of relative crash risks related to travel speed were associated with uncertainty in the estimates which in turn appeared to lead to an unreliable estimate of the optimum speed. Their relationship of speed with casualty crashes did not take into account the distribution of injury severity related to speed; this may have led to unreliable results, especially at speeds below 60 kmh. Nilsson's (1984) relationships did not suffer from this deficiency and appeared to produce more stable estimates of the total monetary impacts for different travel speeds. Kallberg and Toivanen's (1998) relationship was derived from Nilsson's and, while it is simpler to use, did not produce substantially different results. In practice in this study, their relationship was compromised when considering speeds below 55 kmh, which may have led to unreliable results in this speed range.

When the "human capital" valuations of road trauma costs were used, the analysis based on Nilsson's relationships suggested that the optimum speed on residential streets is 55 kmh. It should be noted, however, that the estimate of the total monetary cost was relatively constant in the range 50 to 60 kmh. Only Nilsson's relationships were considered, for reasons given above, when the analysis was repeated making use of road trauma costs valued by the "willingness to pay" approach. In this case, the analysis suggested that the optimum speed on residential streets is 50 kmh. The optimum speed was lower because the higher valuation of road trauma at 50 kmh more than overcame the cost of additional travel time associated with a travel speed of 50 kmh, compared with 55 kmh.

The analysis described in this paper has presumed that it is legitimate to adopt an economic rationalist approach and to conduct a socio-economic cost-benefit analysis to choose the optimum speed in residential streets. Kallberg and Toivanen (1998) have suggested that the equity of the distribution of the costs and benefits also needs to be considered. There is also a broader perspective which argues that it is not legitimate to compromise road safety to meet other objectives because "life and health can never be exchanged for other benefits within the society" (Tingvall 1998).

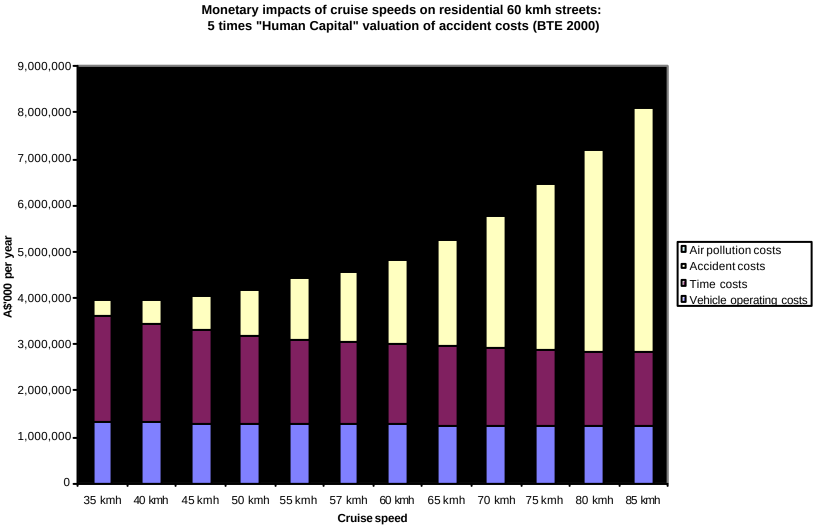
In residential streets, the road users at greatest risk of death or serious injury if involved in an impact with a vehicle are pedestrians and, in smaller numbers, bicyclists. It has been found that the risk of a pedestrian being killed when impacted by a vehicle travelling at 30 kmh falls to 10%, compared with a risk of 80% at 50 kmh

(Walz et al 1993). This finding has led to a demand for a maximum travel speed of 30 kmh on streets where there is mixed traffic (motorised and non-motorised) (Ministry of Transport and Communications 1997).

This travel speed is below the range of speeds considered in this study (35 to 85 kmh). However it was considered informative to examine the circumstances in which the analysis conducted here (using Nilsson's relationships) would lead to the conclusion that the optimum speed in residential streets should be no more than 35 kmh. This was done by multiplying the human capital estimates of road trauma costs by a constant multiplier. It was found that a multiplier of 5 resulted in the situation shown in Figure 8.

Thus if the values of road trauma costs were five times those estimated by BTE (2000), ie. approximately $8.7 million per fatal crash and $2.15 million per serious injury crash, a travel speed of 35 kmh (perhaps less) would be the maximum speed which could be economically justified. This is also close to the maximum speed which has been demanded by societies aiming to prevent all deaths and serious injuries on residential streets.

Figure 8: Impacts of speed if crash costs are valued 5 times higher



7 CONCLUSIONS

The optimum travel speed on urban residential streets in Australia depends on the value which society places on the deaths, serious injuries and other injuries which result from crashes associated with each speed. If the costs of road trauma are valued by the "human capital" approach, then the optimum speed appears to be 55 kmh. However, if road trauma is valued by the "willingness to pay" approach, then the optimum speed appears to be 50 kmh.

It should be noted that, in each case, the total cost of road trauma, travel time, vehicle operating costs, and air pollution emissions varies relatively little for speeds around the optimum speed. Thus the optimum speed should not be viewed as having been determined exactly in each case. The study was not able to consider the speed-related impacts of noise pollution and carbon dioxide emissions. Since the magnitude of these pollutants is known to increase with speed, it is likely that that the optimum speed would be no greater than that determined in this study, for each approach to valuing road trauma.

If road trauma was valued five times higher than the "human capital" approach, this study suggests that the optimum speed on residential streets would be at most 35 kmh. This is close to the maximum speed which has been demanded by societies aiming to prevent all deaths and serious injuries on residential streets.

8 ACKNOWLEDGMENTS

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