Optimum speeds on rural roads based on 'willingness to pay' values of road trauma

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Abstract

The optimum speed is one which minimises the total social costs of the impacts of speed, including the costs of road trauma, travel time, air pollution emissions, noise and vehicle operating costs. Previous research has estimated the optimum speeds for cars and trucks on various classes of rural roads in Australia, based on 'human capital' costs of road trauma. This paper presents estimates of the optimum speeds if the changes in road trauma are valued using recent 'willingness to pay' estimates. If speed limits were set so that all cars and trucks travelled at their optimum speed on each class of road, there would be a 34% reduction in crash costs and an overall 3.4% reduction in total social costs on rural highways in Victoria.

Keywords

Economic analysis, Optimum speed, Social costs, Speed, Speed limits

Introduction

The goal of the Safe System approach to eliminate death and serious injury puts a focus on the speeds (and masses) of vehicles involved in crashes. An optimum speed limit is one that provides maximum benefit from reduced travel times while minimising the costs of road trauma, air pollution emissions and vehicle operating costs. This paper summarises the calculation of the optimum speeds for the range of Australian rural road types: rural freeways, multi-lane divided roads, and single-lane undivided roads, with and without shoulder-sealing. Optimum speeds had been initially estimated using 'human capital' costs of road trauma [1, 2]. The system-wide impacts if cars and trucks were to travel at their optimum speeds, as a basis for setting speed limits in each road environment, had then been calculated. While the optimum speed of cars on rural freeways and divided roads was higher than existing speed limits, it was found that crash costs across the full rural road system would decrease by at least 10% and total travel time would increase by only 1% [3]. This paper re-examines the optimum speeds on rural roads if road trauma is valued using the 'willingness to pay' approach.

Previous research on optimum speeds

Research in Europe has examined the collective impacts of vehicle speeds on road trauma, travel times, operating costs, and air and noise pollution [4-11]. The optimum speed for a class of road was defined as one which minimises the total social costs of the impacts of speed. The optimum speed has been estimated for urban roads, where speed limits are generally 50 km/h in Europe, and for rural freeways and divided and undivided roads. The European research has generally found that optimum speeds on rural roads were 15-25 km/h lower than current European speed limits and travel speeds. For example, in Great Britain during the 1990s, it was found that optimum speeds were up to 15 mph lower than existing limits on rural motorways and 'A' roads. Similarly, in Sweden it was found that travel speeds were 15-25 km/h higher than the optimum speed for each class of rural road [8].

A framework for assessing the impacts of speed was developed as part of the European project MASTER (Managing Speeds of Traffic on European Roads) [12]. The MASTER project developed a computer spreadsheet to allow all the impacts of a change in speed management policy to be recorded, and analysed where appropriate. The author used the MASTER framework to estimate the optimum speed on urban residential streets in Australia [13, 14]. The optimum speed depended on the method used to value road trauma. When 'human capital' valuations of road trauma costs [15] were used, the analysis suggested that the optimum speed on residential streets is 55 km/h. When the analysis was repeated making use of road trauma costs valued by a 'willingness to pay' approach [16], the analysis suggested that the optimum speed on residential streets is 50 km/h.

The author also used a modified MASTER framework to aggregate the economic costs and benefits of changes to speed limits on rural roads in Australia [1, 2]. The key modification was that the effects of speed on road trauma levels were calculated using relationships linking changes in average free speed with changes in crashes at each severity level on rural roads, developed in Sweden by Nilsson [17, 18]. Road trauma was valued by 'human capital' unit costs related to the injury severity of crash outcomes [15], and some estimates used early 'willingness to pay' values of crashes [16]. The unit cost of a fatal crash was valued at $1.74 million and $4.55 million, respectively, in year 2000 dollars. Net costs and benefits were estimated over a range of mean travel speeds (80 to 130 km/h) for the following road classes:

- freeway standard rural roads
- other divided rural roads (not of freeway standard)
- two-lane undivided rural roads (with and without shoulder sealing).

Method of this study

The effects of speed on road trauma levels were calculated using relationships linking changes in average free speed with changes in numbers of fatal, serious injury and minor injury crashes, as follows:

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

where n_A = number of crashes after the speed change
n_B = number of crashes before the speed change
v_A = mean or median free speed after
v_B = mean or median free speed before
p = estimated exponent depending on the injury severity of the crashes.

Relationships of this form were originally developed by Nilsson based on research linking changes in median free speeds with changes in crash frequencies at various injury severities, as a result of many changes in rural speed limits in Sweden during 1967-1972 [17]. Meta-analysis of a large number of subsequent studies of road trauma changes associated with speed limit changes has since been conducted [19-21]. The analysis confirmed Nilsson's relationships on rural roads and freeways, but found that the relationships were weaker or non-existent on urban roads. The final exponent estimates (p) for fatal crashes (4.1), serious injury crashes (2.6) and slight injury crashes (1.1) on rural roads and freeways [21] were used for this paper.

On rural roads it was generally assumed that travel time = link length/free speed of traffic flow (cruise speed). This was considered to be a reasonable assumption on rural roads where traffic congestion, and hence constrained speeds, are a rarity. Travel time was valued by Austroads estimates of time costs reflecting the vehicle type and trip purposes [22].

Vehicle operating costs for cars, light commercial vehicles and rigid and articulated trucks were based on Austroads published models linking these costs with speed [22]. Emission rates of air pollutants of each type were derived from research conducted as part of the MASTER project [23, 12]. Increased fuel consumption and emission rates associated with deceleration from cruise speeds for sharp curves (and occasional stops) on undivided rural roads, and then acceleration again, were estimated from mathematical models calibrated for this purpose in the United States [24].

The analysis also provided estimates of average speeds over 100 kilometre sections of curvy undivided roads and these average speeds were used to adjust the travel times on these roads. Air pollution cost estimates were provided by Austroads [22]. Noise pollution related to speed could not be estimated nor valued. This social cost was considered to be small along rural highways in Australia, but could be substantial in urban areas. Further details of the analysis method are given in two comprehensive reports [1, 25].

In contrast with a previous paper using 'human capital' costs of crashes [3], this paper has valued the changes in crashes in each road environment by 2011 'willingness to pay' (WTP) values. The value of each crash saved, by maximum injury severity in the crash, has been calculated from WTP estimates of the values assigned to preventing person casualties in a study commissioned by the NSW Roads and Traffic Authority [26]. The value assigned to each crash, in 2011 dollars, was:

- fatal crash $8.03 million
- serious injury crash $472,000
- minor injury crash $103,000.

An Austroads project found that there is general agreement that WTP is the most appropriate for determining crash costs and that it is consistent with the Safe System approach. Australia has fallen behind other countries by valuing lives and safety benefits at low levels using the human capital approach and WTP should be adopted [27]. The Safe System approach puts even higher, perhaps infinite, value on preventing road deaths and serious injuries. A later Austroads report noted the study commissioned by the NSW Roads and Traffic Authority to provide WTP estimates and recommended the use of WTP unit costs alongside human capital costs [28].

To match the crash costs valued in 2011 dollars, the unit costs of travel time, air pollution emissions and vehicle operating were updated from 2007 values [22] to 2011 dollars using the ABS Consumer Price Index for the average of the capital cities.

Assumptions for the analysis

1. It was assumed that vehicles of each type cruise at their speed limit, so that their average speed is the same as the limit, unless their speed is reduced by slowing for curves or stopping in some parts of the road section (e.g. at crossroads or in towns).
2. Apart from where indicated, the rural roads are relatively straight without intersections and towns, allowing vehicles to travel at cruise speed throughout the whole road section. This was assumed to be 100 km/h for each type of vehicle, except for light vehicles on rural freeways and divided roads where it was assumed that they cruise at 110 km/h.

3. The mix of traffic by vehicle type is the same on each class of rural road, namely 67% passenger cars, 20% light commercial vehicles (LCVs), 5% rigid trucks and 8% articulated trucks. These estimates were derived from the NRTC Mass Limits Review and ABS Surveys of Motor Vehicle Usage during the late 1990s [1].
4. Crashes involving material damage only, and no personal injury, were not included in the analysis of crash changes with speed, and the likely change in these crashes with changes in mean speeds (albeit to a lesser extent than fatal and injury crashes) was not valued. Material damage crashes represented about 16.3% of total crash costs in Australia during 1996 [15].
5. The travel time savings (costs) associated with increased (decreased) speeds on the rural road sections are of sufficient magnitude to be aggregated and valued.
6. The economic valuations of travel time, road trauma, and air pollution emissions provided an appropriate basis for an analysis which summates their values, together with vehicle operating costs, in a way which represents the total social costs of each speed. In other words, the valuations are an appropriate basis for aggregating these tangible and intangible values of each impact so that the total cost to society of each speed can be seen.
7. Illustrative rural traffic volumes used in the analysis were 20,000 vehicles per day for freeways, 15,000 for divided highways and 1000 for undivided roads. The analysis does not depend on these assumptions being correct.

Optimum speeds in each road environment

The analysis estimated the potential economic costs and benefits of changes in travel speeds on rural roads in Australia. Net costs and benefits were estimated over a range of mean travel speeds (70 to 130 km/h) for the following road classes:

- freeway standard rural roads (dual carriageway roads with grade-separated intersections and a design speed of 130 km/h, usually designed as such when originally constructed)
- other divided rural roads (not of freeway standard)
- two-lane undivided rural roads (standard-width and shoulder-sealed roads, with different crash rates, were considered separately).

The analysis considered changes in mean travel speeds in 5 km/h steps up and down from the current speed limits. The optimum speed was defined as the one that minimises the total social cost contribution at that speed (to the nearest 5 km/h).

Rural freeways

The economic impacts of speed on rural freeways are different for cars and LCVs (Figure 1) compared with the impacts for trucks (Figure 2). The optimum speed for cars is 110 km/h (shown with arrow) and 95 km/h for trucks when road trauma is valued by the ‘willingness to pay’ values of road trauma.

If trucks were to reduce their speed on rural freeways to 95 km/h, it is estimated that there would be a 1.2% reduction in casualty crashes on these roads, but a 4% reduction in crash costs. The greater proportionate reduction in crash costs is because crashes involving trucks are much more likely to result in death or serious injury than crashes involving light vehicles.

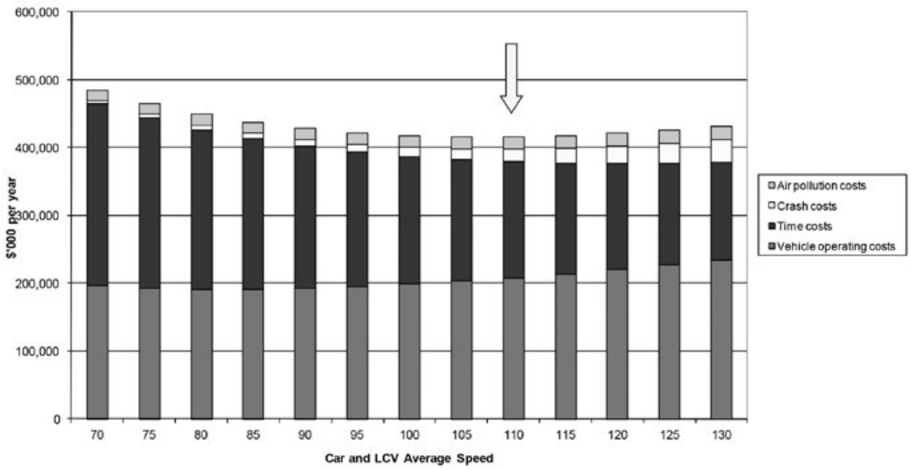

Figure 1. Impacts of car and LCV speeds on rural freeways (100 km section)

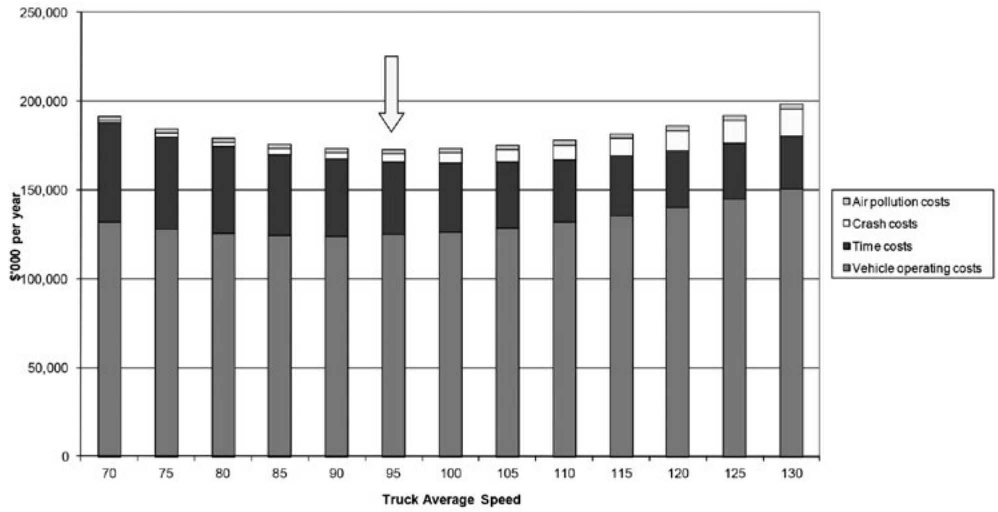

Figure 2. Impacts of truck speeds on rural freeways (100 km section)

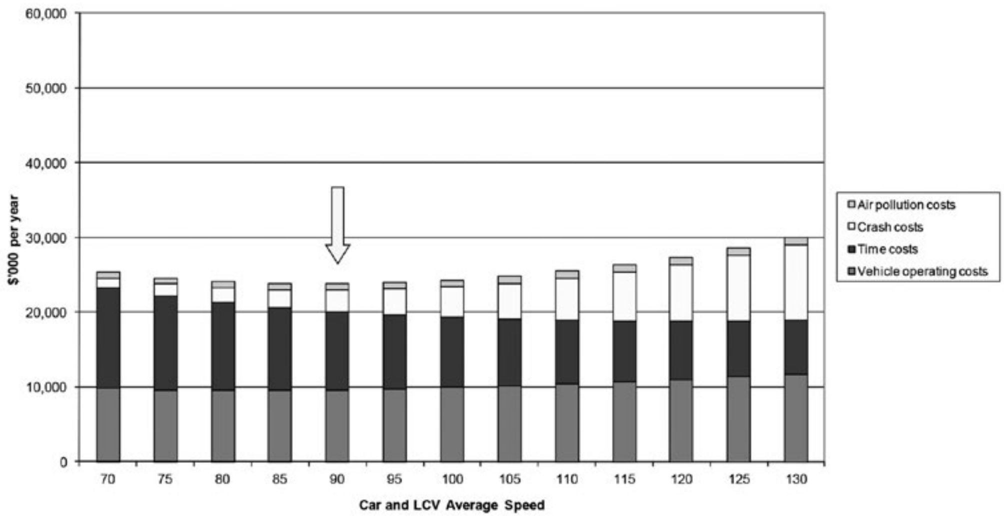

Figure 3. Impacts of car and LCV speeds on straight undivided rural roads (100 km section)

Divided roads

The economic impacts of speed on rural divided roads were similar to the impacts on freeways, except that the risk of a crash is higher. The optimum speed for cars is 95 km/h and 90 km/h for trucks when road trauma is valued by the 'willingness to pay' approach.

Undivided roads

The economic impacts of speed on straight sections of standard (up to 7 metres sealed width) undivided rural roads for cars and LCVs (Figure 3) and trucks (Figure 4) shows that the optimum speeds are lower than on rural freeways and divided roads. Analysis was also carried out for undivided roads through curvy terrain and occasional crossroads and towns, each feature requiring slowing from cruise speeds at the speed limit (Figures 5 and 6). This analysis took into account the substantial increases in operating costs associated with deceleration and acceleration, especially for trucks, and the associated increases in air pollution and fuel consumption per vehicle-kilometre.

The optimum cruise speed for cars and light commercial vehicles (LCVs) travelling on these roads is estimated to be 90 km/h if the road is straight without crossroads and towns (Figure 3), but only 85 km/h if the road has many sharp bends and includes intersections and towns requiring stopping (Figure 5). The optimum cruise speed for trucks is estimated to be 85 km/h on both straight roads and on curvy undivided roads of the same standard (Figures 4 and 6).

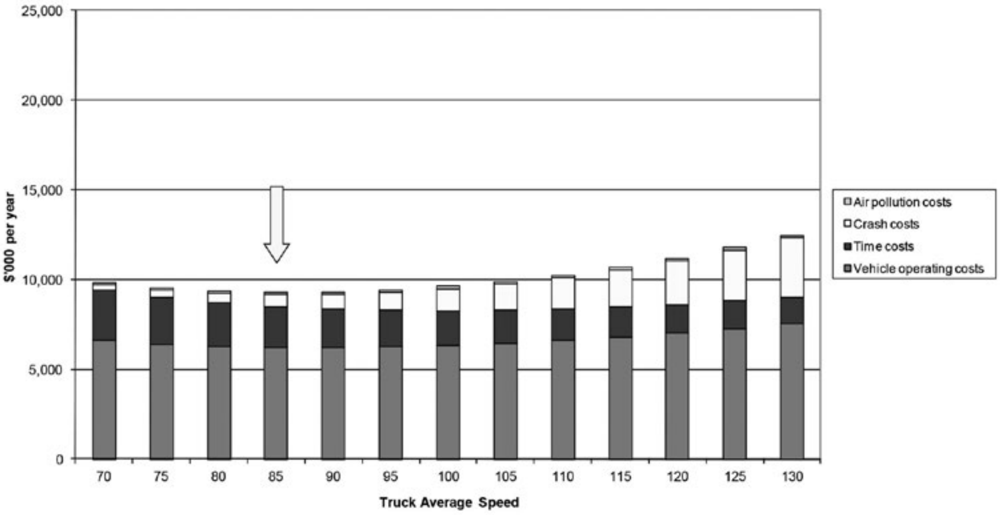

Figure 4. Impacts of truck speeds on straight undivided rural roads (100 km section)

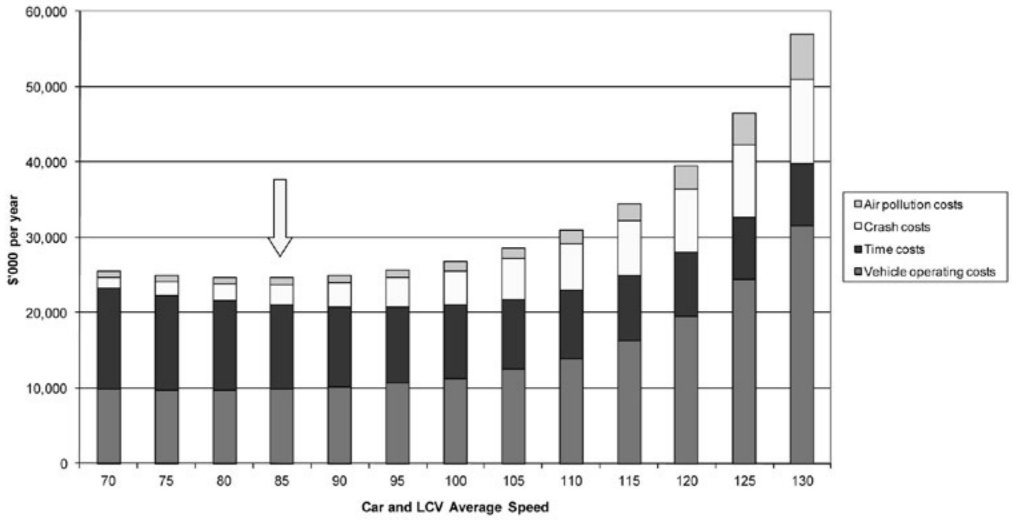

Figure 5. Impacts of car and LCV speeds on undivided rural roads with curvy alignment, crossroads and towns (100 km section)

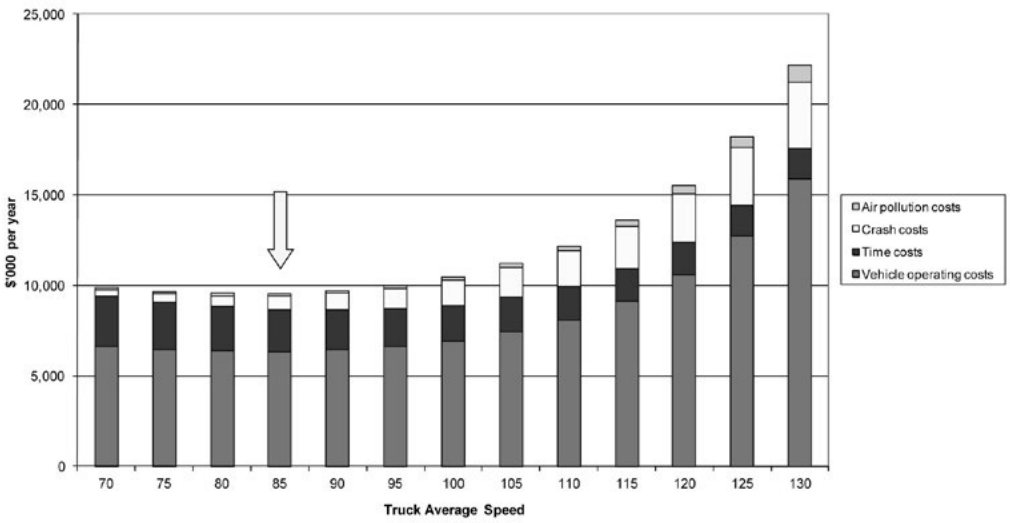

Figure 6. Impacts of truck speeds on undivided rural roads with curvy alignment, crossroads and towns (100 km section)

The corresponding pair of charts for cars and LCVs (Figures 3 and 5) and for trucks (Figures 4 and 6) are shown on the same scale so that the influence of curvy terrain, crossroads and towns on total economic costs at the higher cruise speeds, compared with the total costs on straight, unimpeded roads, can be seen.

Undivided roads with shoulder sealing

The optimum cruise speed on the higher standard undivided roads with shoulder sealing is estimated to be 90 km/h for both cars and trucks if the road is straight without crossroads and towns, but only 85 km/h for both vehicle types if the road has many sharp bends and includes intersections and towns requiring stopping.

Summary of optimum speeds in each road environment

Table 1 summarises the estimate (to the nearest 5 km/h) of the optimum speed in each road environment for light vehicles and trucks separately. The optimum speeds using the 'human capital' costs of road trauma [3] are also shown for comparison with those estimated using the 'willingness to pay' values. The Safe System approach puts greater value on preventing road deaths and serious injuries than in the past. While 'willingness to pay' may not fully reflect that value, it is a better basis for defining optimum speeds.

Table 1. Estimated optimum speeds using 'willingness to pay' (WTP) values of road trauma and using 'human capital' unit costs (BTE 2000)

	Current cruise speeds (speed limits)		Optimum speeds based on WTP values		Optimum speeds based on human capital costs	
Road environment	Cars and LCVs	Trucks	Cars and LCVs	Trucks	Cars and LCVs	Trucks
Rural freeways	110	100	110	95	125	100
Rural divided roads	110	100	95	90	120	95
Standard sealed two-way undivided rural roads	100	100	90	85	100	85
- curvy roads with crossroads and towns	100	100	85	85	85	80[a]
Shoulder-sealed two-way undivided rural roads	100	100	90	90	105	90
- curvy roads with crossroads and towns	100	100	85	85	90	85

[a] This estimate is less than 85 km/h because of the different vehicle operating cost model used in the previous analysis [3] compared with that used here [22], resulting in lower estimated cost at low speeds

Impact if all vehicles travelled at their optimum speed

If speed limits on each class of rural road (including rural undivided roads) were to be moved closer to the optimum speeds, there could be a substantial net gain in total economic costs across the road network. This is because a large proportion of rural road travel (and an even larger proportion of rural crashes) is on undivided roads.

Reliable data on rural traffic levels using each of the four classes of road analysed in this study was available for Victoria. This data allowed calculation of the total economic impacts across the Victorian rural road network if all vehicles travelled at the optimum speed for the road type and vehicle type. The analysis used the optimum speeds estimated in this study using 'willingness to pay' values of road trauma. The Victorian rural main road network was estimated to be 19,500 km long and carry about 15,200 million vehicle-kilometres per year.

Compared with the existing situation, assuming all vehicles travel at current speed limits, the change to travelling at the optimum speed in each road environment would result in a 13% increase in travel time, an 18% reduction in casualty crashes, and a 4-9% reduction in air pollution emissions of various types (Table 2).

Table 2. Physical impact if all vehicles changed to travelling at their optimum speed, compared to travelling at their current speed limits (rural Victoria roads)

Type of impact		Before	After	Change	
Total travel time on link, hours/day		328,762	370,592	41,831	12.7 %
Number of Crashes per year		3110	2560	-550	-17.7%
Emissions, t/year	Carbon monoxide CO	98,922	90,454	-8468	-8.6 %
	Hydrocarbons HC	31,480	30,209	-1271	-4.0 %
	Oxides of nitrogen NO_x	32,827	30,489	-2338	-7.1 %
	Particles PM	107,488	103,183	-4305	-4.0 %
	Carbon dioxide CO_2	2,945,926	2,701,964	-243,962	-8.3 %

The reduction in casualty crashes is estimated to represent a saving of 57 fatal crashes (approximately 34% of the rural road toll in Victoria), 248 serious injury crashes, and 247 minor injury crashes. When these savings in road trauma are valued using the 'willingness to pay' approach, there would be a 34% reduction in crash costs on Victoria's rural highways (Table 3).

The overall economic impact if all vehicles travelled at their optimum speeds was estimated to be a saving of $384 million per annum in total social costs. However, there would be a 13% increase in travel time costs to provide this total societal benefit in the rural areas of Victoria (Table 3).

Table 3. Economic impact if all vehicles changed to travelling at their optimum speed, compared to travelling at their current speed limits (rural Victoria roads)

$'000/yr	Before	After	Change	
Vehicle operating costs	5,469,519	5,233,412	-236,107	-4.3 %
Time costs	3,733,710	4,215,100	481,391	12.9 %
Crash costs	1,727,355	1,134,221	-593,134	-34.3%
Air pollution costs	352,503	316,001	-36,502	-10.4 %
Total	**11,283,086**	**10,898,734**		
Change			**-384,352**	**-3.4 %**

These economic impacts can be compared with those based on optimum speeds using human capital costs of road trauma [3], but are not directly comparable because the previous estimates used a different model of vehicle operating costs related to speed and all economic costs were in year 2000 dollars. Nevertheless, because the human capital approach produced higher optimum speeds, particularly for cars (Table 1), the overall savings in road trauma were not so great (10%) and the increase in total travel time was small (1%). Optimum speeds using human capital costs suggested speed limits of 120 to 125 km/h on freeways and other divided roads (though limits on undivided roads substantially less than 100 km/h for trucks, and for cars on the curvy roads with crossroads and towns).

Discussion

If rural speed limits are to be set taking into consideration the full range of costs of the impacts on road trauma, travel time, emissions and vehicle operating costs, then optimum speeds based on 'willingness to pay' valuations of road trauma are more consistent with the Safe System approach than those based on 'human capital' cost valuations. This method does not value savings in road trauma infinitely, but does provide a workable basis for rationalising all the costs of speed of each vehicle type on each class of rural road.

The optimum speeds of trucks on rural divided roads are lower than those calculated for light vehicles, especially on rural freeways where a 15 km/h difference has been estimated (Table 1). A lower speed limit for trucks than for light vehicles would appear appropriate on rural divided roads. The availability of at least two traffic lanes in each direction on these divided roads would facilitate the safe overtaking maneouvres that would be required to a greater extent if light vehicles and trucks had differential speed limits. Lower speed limits for trucks (than for light vehicles) are common in Europe, typically 90 km/h on multi-lane rural divided roads.

The optimum speeds on rural undivided two-lane roads for trucks and light vehicles, respectively, are essentially the same for each standard of road (Table 1). Hence, while lower speed limits appear appropriate for undivided rural roads, particularly through curvy road environments, there is no case for differential speed limits for trucks and light vehicles on any standard of undivided road. The need for increased opportunities for safe overtaking maneouvres on these roads, if general speed limits were reduced, would appear no greater than currently.

The findings of this paper depend on the functional relationships between speed and road trauma, travel time, air pollution emissions and vehicle operating costs, the assumptions made, and the input parameters. The sensitivity of the findings to variations in these factors has been tested only to a limited extent.

Conclusions

Within the limits of the assumptions made and the data available for this study, a number of conclusions about optimal rural speeds and speed limits were reached.

1. Using recent 'willingness to pay' valuations of crash costs, the optimum speeds on rural freeways would be 110 km/h for cars and light commercial vehicles and 95 km/h for trucks. On other divided rural roads, the optimum speeds would be 95 km/h and 90 km/h, respectively. These findings suggest that the current default rural speed limit of 100 km/h on divided roads, with a limit of 110 km/h on the higher quality freeways, is close to economically optimal for light vehicles but not for trucks. The analysis suggests that a limit of 90 km/h for trucks, with perhaps 95 km/h on freeways, would be appropriate.
2. There is economic justification for decreased speed limits on two-lane undivided rural roads, even on the safer roads with sealed shoulders. The optimum speed on straight sections of these roads is no more than 90 km/h for both light vehicles and trucks. The analysis suggests that the speed limit should be at most 90 km/h on undivided rural roads.
3. On undivided roads through terrain requiring slowing for sharp bends and occasional stops in towns, increased fuel consumption and air pollution emissions associated with deceleration from and acceleration to high cruise speeds would add very substantially to the total economic costs. The optimum speed for both light vehicles and trucks is about 5 km/h less on the curvy roads with crossroads and towns than the 90 km/h speed limit suggested above for undivided rural roads. The analysis suggests that a speed limit of 85 km/h would be appropriate for undivided rural roads through curvy road environments. However, if this figure is not acceptable (because it does not follow current speed limit practice based on multiples of 10 km/h) then a limit of 80 km/h should be considered.

4. Rationalisation of speed limits applicable to each class of rural road and for each type of vehicle, making the limits consistent with the optimum speed in each case, has the potential to reduce casualty crashes and crash costs substantially. Although travel times and costs would increase significantly, there would be a reduction in the total social costs on rural highways when all the benefits of reduced road trauma, air pollution emissions and vehicle operating costs from reduced speeds are considered.

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