

## **Rationalisation of speed limits within the Safe System approach**

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### **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. The principal role of vehicle speed is the build up of kinetic energy which needs to be dissipated in each crash, no matter how caused, often resulting in injury to the humans involved. However the dissipation of kinetic energy only becomes relevant if a crash occurs. There are high quality road environments that minimise vehicle interactions by grade-separation, median barriers and lane discipline, and prevent fixed-object collisions by adequate roadside clearance or barriers. Such freeway-type road environments already exist and high speed limits are allowed on them because crash risks are minimal. A Safe System should aim for as much of its road system as possible to be at this high quality standard, particularly in rural areas. An optimum speed limit could be set that provides maximum benefit from reduced travel times and minimises 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. 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, are then calculated. A rationalisation of speed limits to reflect the innate expectations of drivers, but also based on rational analysis of all the costs and benefits, may result in greater compliance with speed limits and make intensive speed enforcement more palatable and even unnecessary long-term.

### **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 (Nilsson 1984; Andersson et al 1991; Peters et al 1996; Rietveld et al 1996; Carlsson 1997; Toivanen and Kallberg 1998; Elvik 1999). The optimum speed for a class of road has been 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 are 15-25 km/h lower than current European speed limits and travel speeds.

### **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 (Nilsson 1984), as follows:

$$n_A = (v_A/v_B)^p * n_B$$

- where
- $n_A$  = number of crashes after the speed change
  - $n_B$  = number of crashes before the speed change
  - $v_A$  = mean or median speed after
  - $v_B$  = mean or median speed before
  - $p$  = exponent depending on the injury severity of the crashes:
    - $p = 4$  for fatal crashes
    - $p = 3$  for serious injury crashes
    - $p = 2$  for minor injury crashes.

These relationships were based on research linking changes in median 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. Elvik, Christensen and Amundsen (2004), Elvik (2009), and Cameron and Elvik (2010) have since conducted meta-analysis of a large number of subsequent studies of road trauma changes associated with speed limit changes. They confirmed Nilsson's relationships on rural roads, with values of  $p$  generally as indicated above, but found that the relationships were weaker or non-existent on urban roads.

Vehicle operating costs for cars, light commercial vehicles and rigid and articulated trucks were based on Austroads published models linking these costs with speed (Thoresen 2000; Thoresen, Roper and Michel 2003). Emission rates of air pollutants of each type were derived from research conducted as part of the Managing Speeds of Traffic on European Roads (MASTER) project for the European Commission (Robertson, Ward and Marsden 1998, Kallberg and Toivanen 1998). 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 USA (Ding 2000). The analysis also provided estimates of average speeds over 100 km sections of curvy undivided roads. Air pollution cost estimates were provided by Cosgrove (1994). 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.

On rural roads it was assumed that travel time = link length / 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. Kallberg and Toivanen (1998) noted that, in urban conditions, a considerable part of the travel time may be spent not moving at all or moving at very low speeds. Travel time was valued by Austroads estimates of time costs reflecting the vehicle type and trip purposes (Thoresen, Roper and Michel 2003). Road trauma was valued by standard 'human capital' unit costs related to the injury severity of crash outcomes (BTE 2000), and also by 'willingness to pay' values (BTCE 1997) to test the sensitivity of the key results to this assumption. Further details of the study method are given in Cameron (2003, 2004).

## **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.
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.
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 (BTE 2000).
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 current valuations are an appropriate basis for 'trading off' these tangible and intangible values of each impact.
7. Illustrative rural traffic volumes used in the analysis were 20,000 vehicles per day for freeways, 15,000 for divided highways and 1,000 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 (80 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 125 km/h (shown with arrow) and 100 km/h for trucks when road trauma is valued by the ‘human capital’ approach. It would be 5 km/h lower in each case if ‘willingness to pay’ values of road trauma were used.

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

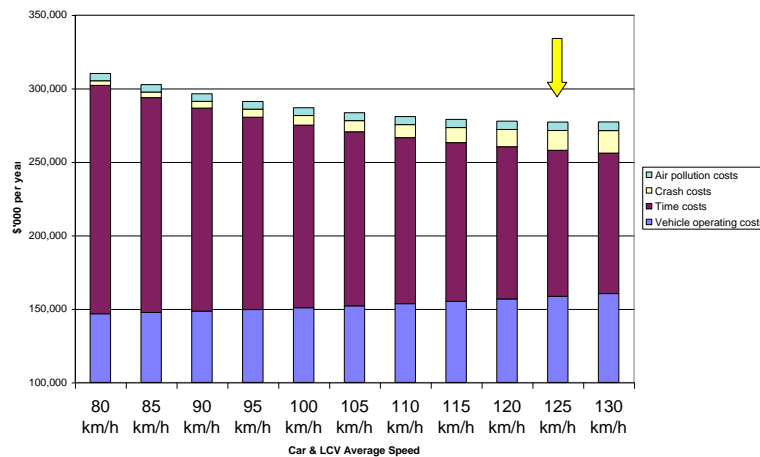
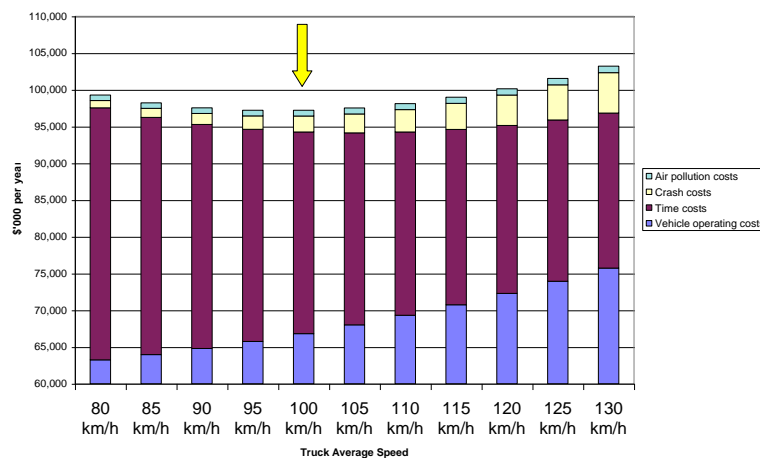


Figure 2: Impacts of truck speeds on rural freeways (100 km section)



### Divided roads

The economic impacts of speed on rural divided roads were very similar to the impacts on freeways. The optimum speed for cars is 120 km/h and 95 km/h for trucks when road trauma is valued by the ‘human capital’ approach. It would be 10 km/h lower for cars and 5 km/h lower for trucks if ‘willingness to pay’ values were used.

### Undivided roads

The economic impacts of speed on straight sections of standard (7.0 m sealed) undivided rural roads for cars and LCVs (Figure 3) and trucks (Figure 4) shows that

the optimum speeds are much lower than on rural freeways and divided roads. Analysis was also carried out for standard 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.

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

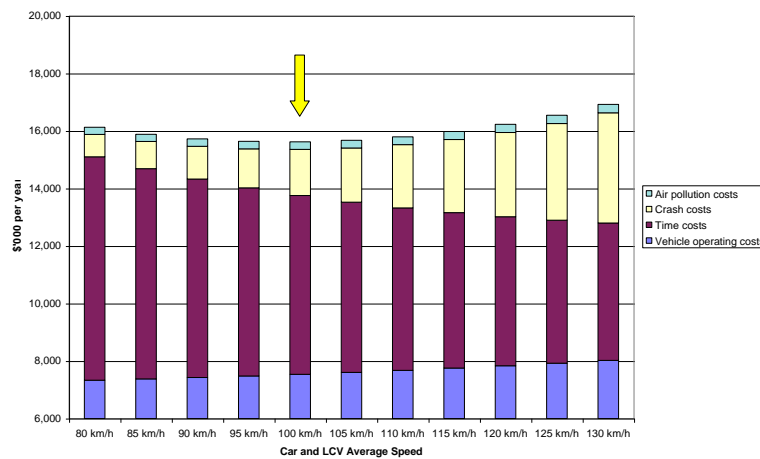
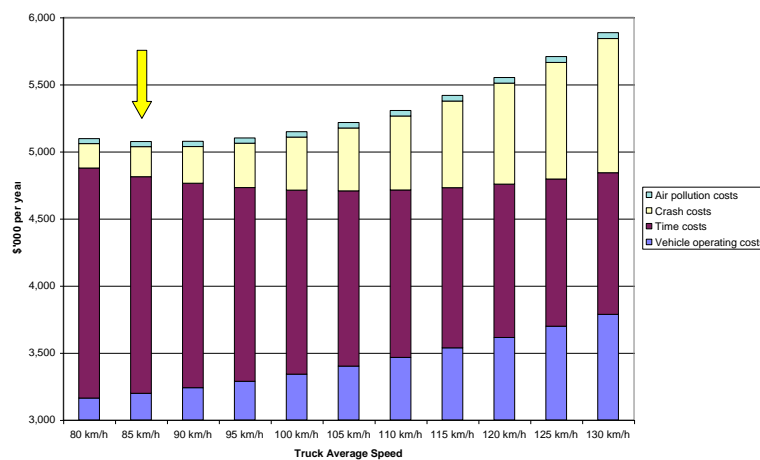


Figure 4: Impacts of truck speeds on undivided rural roads (100 km section)



The optimum cruise speed for cars travelling on these roads is estimated to be 100 km/h if the road is straight without crossroads and towns, 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, and no more than 80 km/h on curvy undivided roads of the same standard (Figure 6). Optimum cruise speeds would be somewhat lower if 'willingness to pay' values were used for crash costs.

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

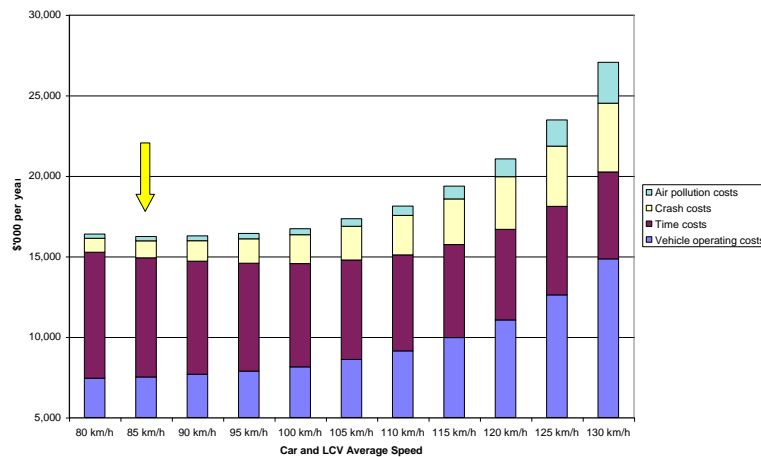
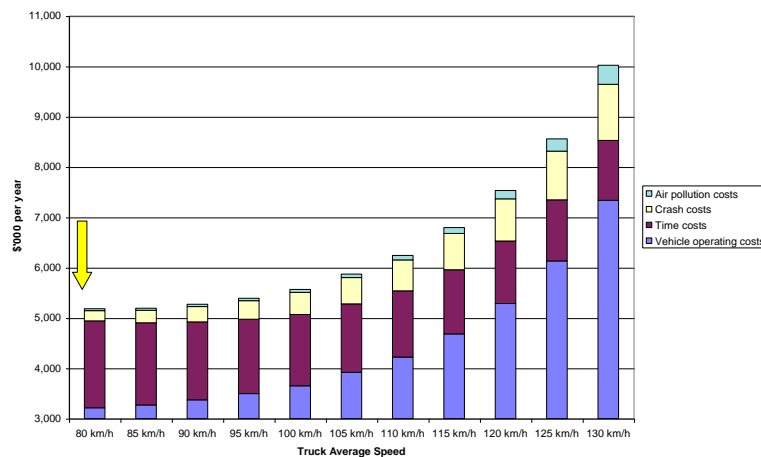


Figure 6: Impacts of truck speeds on undivided rural roads with curvy alignment, crossroads and towns (100 km section)



### Undivided roads with shoulder sealing

The optimum cruise speed for cars travelling on the higher standard undivided roads is estimated to be 105 km/h if the road is straight without crossroads and towns, but only 90 km/h if the road has many sharp bends and includes intersections and towns requiring stopping. The optimum cruise speed for trucks is estimated to be 90 km/h, but only 85 km/h on curvy undivided roads of the same standard.

### 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 all vehicles combined, and also for the light vehicles and trucks separately. On rural freeways and divided roads, the optimum speeds have been estimated using the traditional 'human capital' costs of road trauma and also 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 ‘human capital’ unit costs of road trauma (BTE 2000), except where indicated as using ‘willingness to pay’ (WTP) values of road trauma (BTCE 1997)**

Road environment	Optimum Speed (km/h)		
	All vehicles combined	Cars & LCVs	Trucks
<b>Rural freeways</b>	120	125	100
- <i>WTP values of road trauma</i>	110	120	95
<b>Rural divided roads</b>	110	120	95
- <i>WTP values of road trauma</i>	105	110	90
<b>Standard 7.0m sealed two-way undivided roads</b>	95	100	85
- curvy roads with crossroads and towns	85	85	At most 80
<b>Shoulder-sealed 8.5m two-way undivided roads</b>	105	105	90
- curvy roads with crossroads and towns	85	90	85

Using ‘willingness to pay’ values, the optimum speed on the rural freeways is 120 km/h for cars and light commercial vehicles and 95 km/h for trucks. If these speeds were to become the speed limits for each type of vehicle, respectively, there would be a net saving of \$1.36 million per annum per 100 km of rural freeway. There would be a travel time saving of 4.5 minutes per car, but an increase of 3.2 minutes per truck, and there would be an additional 0.6 fatal crashes per year per 100 km of freeway.

On rural divided roads, the optimum speed is 110 km/h for cars and light commercial vehicles and 90 km/h for trucks, if ‘willingness to pay’ valuations of road trauma are used. If the truck optimum was to become their speed limit (but no change in limit for cars), the total impact would be a saving of \$864,000 per annum per 100 km of divided road. There would be no travel time saving for cars, but an increase of 6.7 minutes per truck, and there would be a reduction of 0.3 fatal crashes per year per 100 km of divided road.

Optimum speeds using ‘willingness to pay’ values of road trauma were not estimated for the various classes of undivided two-way rural roads because they were apparently lower than 80 km/h for some types of vehicle, especially on curvy roads with crossroads and towns, and 80 km/h was the minimum speed analysed.

## **OVERALL 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 (and perhaps even a net reduction in crash

costs). This is because a large proportion of rural road travel (and an even larger proportion of rural crashes) is on undivided roads. A reduction in crash costs may result because, although speed limits for cars would increase on freeways, their limits would decrease or remain the same on other roads, and truck speed limits would decrease on all roads, especially the undivided roads with higher crash rates.

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 ‘human capital’ 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 1.1% increase in travel time, 6.1% reduction in casualty crashes, and 3% to 7% 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**

\$'000/year	Before	After	Change	
<b>Total travel time on link, hours/day</b>	409,751	414,224	4,473	1.1 %
<b>Number of Crashes per year</b>	3,065	2,880	-185	-6.1%
<b>Emissions, t/year</b> Carbon monoxide CO	38,206	35,723	-2,483	-6.5 %
Hydrocarbons HC	6,632	6,289	-343	-5.2 %
Oxides of nitrogen NOx	25,358	23,583	-1,774	-7.0 %
Particles PM	524	507	-17	-3.3 %
Carbon dioxide CO2	3,713,286	3,590,728	-122,558	-3.3 %

The reduction in casualty crashes is estimated to represent a saving of 20 fatal crashes (approximately 10% of the rural road toll in Victoria), 69 serious injury crashes, and 96 minor injury crashes. When these savings in road trauma are valued using the ‘human capital’ approach, there would be 9.9% reduction in crash costs on Victoria’s rural highways (Table 3). If the savings in road trauma were valued by the ‘willingness to pay’ approach, there would be a greater percentage reduction in total crash costs because the ‘willingness to pay’ method puts greater value on fatal crashes and these crashes would be reduced to a proportionally greater extent.

The overall economic impact if all vehicles travelled at their optimum speeds was estimated to be a saving of \$86.99 million per annum in total social costs. There would be no more than 2% increase in travel time costs (and 1.1% increase in travel time) 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**

<b>\$'000/year</b>	<b>Before</b>	<b>After</b>	<b>Change</b>	
Vehicle operating costs	4,603,028	4,531,553	-71,476	-1.6 %
Time costs	3,112,171	3,169,007	56,837	1.8 %
Crash costs	671,628	605,453	-66,174	-9.9%
Air pollution costs	136,027	129,850	-6,177	-4.5 %
<b>Total</b>	<b>8,522,854</b>	<b>8,435,863</b>		
<b>Change</b>			<b>-86,991</b>	<b>-1.0 %</b>

An additional benefit could derive from Victorian drivers being provided with speed limits (both higher and lower than existing limits, as indicated to be appropriate by the analysis) which reflect the standard of the roads on which they would apply. This rationalisation of speed limits may also reflect the innate expectations of drivers on each road type. This may result in greater compliance with rural speed limits and make intensive speed enforcement more palatable to drivers and unnecessary in the longer term.

## CONCLUSIONS

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

1. Using 'willingness to pay' valuations of crash costs, the optimum speeds on rural freeways would be 120 km/h for cars and light commercial vehicles and 95 km/h for trucks. On divided rural roads, the optimum speeds would be 110 km/h and 90 km/h, respectively. If the speed limits on each of these rural roads were to be set at these optimum speeds for each vehicle type, there would be a reduction in total economic costs in each environment. However, there would be increases in road trauma on the rural freeways due to the increase in car speeds.
2. There is no economic justification for increased speed limits on two-lane undivided rural roads, even on the safer roads with sealed shoulders. 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. Using 'human capital' costs to value road trauma, the optimum speed for cars is about the current speed limit (100 km/h) on straight sections of these roads, but 10-15 km/h less on the curvy roads with intersections and towns. The optimum speed for trucks is substantially below the current speed limit, and even lower on the curvy roads. The optimum speeds would be even lower if 'willingness to pay' valuations of crash costs were used.

3. 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 the total economic costs on rural highways. There would be substantial reductions in crashes and crash costs across the rural road network, minor increases in travel time and costs, and the allowed speeds may then encourage greater compliance with the speed limits on each class of road.

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