ASPECTS OF SPEED

Effects of Flashing Lights on Driver Speed Behaviours within School Zones

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Biography

He holds the position of Road Safety Analyst with Main Roads Western Australia, working on a number of road safety, traffic and road engineering research projects, including the evaluation of the 50 km/h speed limit on residential streets in the state, monitoring driver speed behaviours on the state road network and other road safety trials. He has produced a number of reports in areas of traffic and road safety in Western Australia. He is a member of a number of road safety committees and task forces in the state representing Main Roads.

Abstract

A trial was conducted to assess the effects of flashing lights on driver speed behaviours within school zones on a sample of 60 km/h and 70 km/h roads. Two speed surveys were undertaken on each of the selected sites within the school zones over full 5 school days of the week, four months before and twelve months after the installation of the flashing lights.

The study found that the effects of flashing lights were more pronounced during the morning than during the afternoon school zone time period. In the morning school zone time period, the flashing lights were associated with an average reduction in mean speed of 1.83 km/h, while the afternoon period showed a significantly less reduction of only 0.81 km/h. When the means were adjusted for “seasonal differences in driver speed behaviours”, the reductions increased to 2.62 km/h and 1.65 km/h, respectively.

The morning school zone time period showed a reduction in the 85th percentile of 2.4 km/h while the afternoon period showed a reduction of 0.6 km/h. After adjustment for the “seasonal differences”, it was estimated that the reduction in the 85th percentiles could be as high as 2.8 km/h for the morning and 1.1 km/h for the afternoon period.

It was found that with the installation of the flashing lights driver compliance to the speed of 50 km/h, 10 km/h above the speed limit, increased such that there was a substantial reduction in the percentage of vehicles travelling above the speed when compared to the driver compliance prior to the installation of the lights; that is, 24.3% and 12.4% for the morning and afternoon school zone time periods, respectively.

Analysis of the effects of the flashing lights by 15-minute intervals suggests that the greatest reductions in the mean speed after the installation of traffic lights were associated with the greatest mean speeds prior to the installation.

Despite the differences in the effects between the school zone time periods and within the periods, the study results suggest that the flashing lights make positive influences on driver speed behaviours when travelling through the school zones.

1. INTRODUCTION

Western Australian drivers customarily experience difficulty in complying sufficiently with the 40 km/h speed limit imposed within defined school zones. Previous research (Radalj, 2002) found that the average speed of vehicles through the school zones under traffic free flowing conditions (headway >= 4 sec) was approximately 49 km/h on 50/60 km/h speed limit roads. The study indicated that the 85th percentile for the zones was approximately 60 km/h. The compliance rate to the speed of 10 km/h above the 40 km/h speed limit was approximately 50%. The study also found that 40 km/h speed limit markings within the defined School Zones on local roads have no significant effect on driver speed behaviours in addition to the effects inflicted on drivers by the standard regulatory signs. However, there may be an increase in driver awareness of the school zone.

Despite the relatively low number of recorded collisions in the vicinity of primary and secondary schools, there is a high level of public concern for road safety and the desire for safer roads, which can be achieved when drivers exercise caution by slowing down to the speed limit of 40 km/h. The South Australian state road authority (Transport SA) has imposed a speed limit of 25km/h within school zones, when children are present, in order to obtain the desired safety for school children. The Victorian, Tasmanian and New South Wales state road authorities all have 40km/hr speed limits in place for school zones during designated times. In Western Australia, for the purpose of consistency across the metropolitan and regional areas, the speed limit of 40 km/h applies only within the defined school zones on the school days in two time frames: the morning, between 7:30am and 9:00am, and the afternoon between 2:30pm and 4:00pm. The zones usually cover the surrounding roads of the primary and secondary schools.

If found effective, the pro-active approach of flashing lights to reduce vehicle speeds is one of the relatively low cost methods that can be utilised to improve road safety without sacrificing a reasonable vehicle flow in the designated school zones. The flashing lights have been sparingly used in NSW to increase driver awareness of the presence of school zones. The NSW Road Traffic Authority (RTA) has conducted a number of trials with various types of the flashing lights to assess their effectiveness within the school zones (Elliot, 2003). One of the products used by RTA, manufactured by Screentech (Aust) Pty.Ltd, was used in this trial. Main Roads Western Australia has undertaken an experimental trial program of installing flashing lights in a sample of school zones on 60 km/h or higher speed limit roads within the metropolitan area. It was anticipated that the installation of the flashing lights at the school zones would significantly change driver speed behaviours, during the operational periods, by increasing the compliance to the speed limit and reducing the number of drivers speeding excessively through the zones.

The objective of the study was to assess changes in driver speed behaviours within school zones accounted for by the flashing lights in addition to the effects associated with the standard regulatory (or warning) signs installed at the school zone entries. It was anticipated that the findings of this study would be used to assist the justification for the installation of flashing lights at school zones as a countermeasure to improve the road safety, particularly on roads assessed as high safety risks or on high speed limit roads above 50 km/h. In this study, the potential safety benefits of the flashing lights were measured in terms of reductions in several speed indices after installation of the flashing lights.

2. METHODOLOGY

The flashing lights trial was implemented by installing a pair of flashing lights at seven selected school zones. The pair of flashing lights was installed at each approach of the school zone on the top of the standard regulatory sign posts. The flashing lights assembly consists of two diagonally placed LEDs run by batteries charged by solar panels.

2.1 Sample

Of the seven pairs of flashing lights installed in the trial, 4 sets were installed in school zones where speed data was collected before and after their installations. The data was collected using vehicle classifiers at 8 sites within the sample of 4 school zones, two sites per zone, one in each direction of traffic flow. Where possible, the classifiers were placed in the middle of the school zones, in order to capture most likely representation of free flowing vehicle speeds. The remaining 3 zones as a part of the experimental trial were not included in the evaluation study due to unavailability of the “before” installation data. The data was collected over a complete cycle of a working week covering school zone time periods from Monday to Friday.

The speed limits on both sides of the school zones were 60 km/h for 3 sites and 70km/h for the fourth site. All four sites were located on relatively busy roads. The visibility of the flashing lights was satisfactory in all cases except from one direction at one of the sample sites.

Data from the vehicle classifiers was collected prior to the installation of the flashing lights in June and July 2002, and repeated at the same locations, in October 2003, 12 months after installation of the flashing lights.

In order to achieve a high level of consistency and reliability of the data, the vehicle classifiers for the “after” data were placed at exactly the same site location as where the “before” data was collected. Both installations were conducted by the same personnel.

2.2 Analysis

Evaluation of the effectiveness of the flashing lights within the school zones is based on the “before/after” study design by which sets of vehicle speed data collected before and after the installation of the flashing lights is compared on a number of indices such as: mean speeds, 85^{th} percentiles and proportion of vehicles travelling with various speeds, below and above the designated speed limit of 40 km/h over the school zones time periods, morning and afternoon.

In order to estimate the magnitude of effects of the flashing lights, the study considered the differences in the time of the year the surveys were conducted and subsequently adjustments were made based on the “seasonal” differences in driver behaviours between the two surveys. The “before” data was collected over the months of June/July (i.e. winter months), whereas the "after" data was collected in October/November (i.e. spring and beginning of the summer months). Generally, it was expected that vehicles travel with lower speeds in winter periods than in the summer months. Therefore, the indices derived from the "before" data were expected to be lower than the indices derived from the "after" data if the data was collected on the same sites without the flashing lights. It can be said that any observed differences in driver speed behaviours between before and after measurements would be biased towards the lower rather than higher effects of flashing lights. For these possible differences in speeds due to the times of the surveys, the study attempted to make adjustment for such possible differences in driver speed behaviours using the speed data of the non-school zones time periods, denoted as "other times", 9:00am to 2:30pm and 4:00pm to 7:30am. The data defined as "other times" was collected over the same periods in both surveys. In order to control for possible variation in driver speed behaviours between the times of the day, any data from non-overlapping data collection periods was removed from the data analysis.

If the weather condition or the time of the year within which the "before" data was collected had been associated with lower vehicle speeds then the differences in the speed indices between the surveys in this study would represent the most conservative estimates of the flashing lights effects on driver speed behaviours.

2.3 Assumptions and Data Filtering and Study Limitations

Due to the relatively short time period between the two surveys, it was assumed that all other extraneous factors such as traffic exposure, enforcement, or traffic safety publicity were similar within the observation periods. Additionally, it can be assumed that there were no significant changes in driver behaviour at the time of the "after" survey due to the factors that could have influenced driver speed behaviours over the period between the two surveys.

The study was limited to the assessment of the effects of flashing lights on driver speed behaviours rather than on the assessment of the effects on other driver behavioural attributes such as driver alertness to possible presence of children or other road users within the school zones. It is hypothesised that any reduction, no matter how minor, in vehicle speeds passing through the school zones installed with the flashing lights would increase driver attentiveness and alertness to unexpected hazards. As a result, this would reduce reaction time in case of the need to reduce the travel speed or need to stop, therefore creating a safer environment for school children and other road users.

3. ANALYSIS AND DISCUSSIONS

An assessment of the effectiveness of the flashing lights was measured in terms of changes in speed when the lights were flashing during the school zone time periods, morning and afternoon, as opposed to when the lights didn't exist at the school zones (prior to the trial).

The two speed surveys resulted in 655501 vehicle details of which 153315 were recorded during the designated school time periods, 7:30am to 9:00am and 2:30pm to 4:00pm. The remainder of the number of vehicles in the sample, 502186, were recorded over the same days and times other than school zone time periods.

3.1 Flashing Light vs. No Flashing Lights – Combined Morning and Afternoon Data

Mean Speed and the 85th Percentiles

Comparison of the mean speeds for the two surveys before and after the installation of the flashing lights indicated that on average vehicle travel speeds were lower during the school zone times when the flashing lights were in operation (after) than when they were not (before). For the combined school zone periods - morning and afternoon - the mean speed of the vehicles travelling during the flashing lights operational periods was 1.32 km/h (95% C.I.: 1.42 to 1.22 km/h) lower than during the same periods before the installation of the lights, 47.13 km/h and 48.45 km/h, respectively.

Similar to the differences between the mean speeds for the school zones periods the 85th percentile during the "after" period was 0.9 km/h lower than during the "before" period, 59.0 km/h vs. 60.1 km/h.

3.2 Comparison between School Zone Time Periods – Morning vs. Afternoon

Analysis of the variance showed that there was a significant interaction between the two factors, Period and Survey ($p < 0.0001$), indicating that the effects of the flashing lights had a significantly different effect on driver speed behaviours during the school zone time periods, such that the flashing lights had significantly higher effects on driver speed behaviours during the morning school zone time period than during the afternoon period (refer Figure 1).

3.2.1 Differences between Means – Morning vs. Afternoon

Comparison between the one and a half hour time periods, morning and afternoon, indicates that the mean speed difference between the "before" and "after" surveys was significantly higher than the mean difference for the afternoon period, 1.83 km/h and 0.81 km/h, respectively (refer Table 1, Figure 1). Based on these estimates it can be inferred that the flashing lights had a better effect on driver speed behaviours during the morning period than during the afternoon period. This anomaly in the effect of the lights could possibly be explained by a significantly larger spread of activities within the school zones in the morning than in the afternoon. Under normal circumstances students' arrivals to school in the morning is fairly irregular, scattered over the entire period with a sizeable concentration of arrivals at the times close to beginning of the school sessions. On the hand, departures from the school in the afternoon period is fairly visible only within a relatively short time interval within the school zone period, such that a large proportion of the school time period may not be represented by any activity within the zone. This lack of activity may encourage drivers to travel slightly faster than if some form of activity exists. Other reasons for the difference could be associated with greater enforcement and more publicity and media campaign on safety around schools in mornings than in afternoons.

School Zone Time Period	Survey	N	85th Percentile			Mean Speeds		
			Value %	Diff. Aft.-Bef.	Adj. Diff.	Value	Diff. Aft.-Bef.	Adj. Diff.
Afternoon	After	42711	60.8	-0.6	-1.06	48.92	-0.81	-1.65
	Before	38987	61.4			49.72		
Morning	After	38264	55.6	-2.4	-2.83	45.14	-1.83	-2.62
	Before	33353	58.0			46.96		
Other	After	270059	67.3	0.5	0.00	60.16	1.00	0.00
	Before	232127	66.8			59.15		

Table 1. Mean speeds and 85th percentiles before and after installation of flashing lights

3.2.2 Differences between 85th Percentiles Morning vs. Afternoon

The observed effects of the flashing lights measured in terms of the mean speeds are also visible through the reduction in the 85th percentiles during their operation when compared to the school zone time periods when the lights were non-operational (refer Figure 2).

The morning school zone period experienced a significantly larger reduction in the 85th percentile than the afternoon period, 2.4 km/h and 0.6 km/h, respectively. After the installation of the flashing lights during the morning period, 85% of the vehicles were travelling at or below 55.6 km/h compared to the speed of 58.0 km/h before the installation.

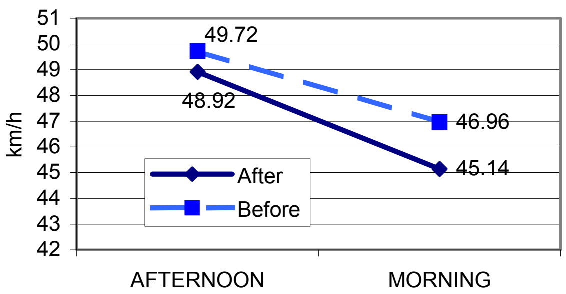

Figure 1. Differences in mean speeds

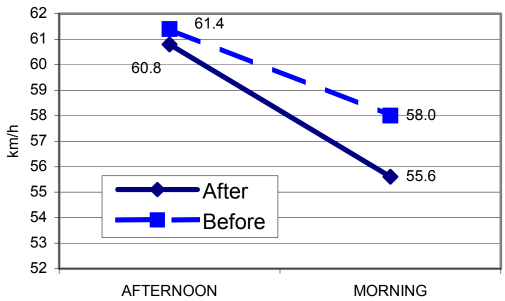

Figure 2. Differences in the 85th percentiles

The 85th percentiles for the afternoon period were significantly higher than for the morning periods on both occasions, ranging between 3 and 5 km/h for the before and after surveys, respectively. The 85th percentiles for the afternoon period were 61.4 km/h before and 60.8 km/h after the installation of the lights.

The data suggests that on average during the afternoon school zone period, drivers travel with approximately 3 km/h higher speeds than during the morning period. Similarly, the 85th percentile is also 3 km/h higher in the afternoon period than in the morning period.

3.3 Proportion of Vehicles Travelling at Various Speed Ranges

Analysis of proportions of vehicles travelling at various speeds before and after the installation of flashing lights suggests that there was a substantial reduction in percentage of vehicles travelling above 50 km/h, after the installation when compared to before the installation of the lights. The average percentage reduction for the two school zone time periods was 6.7% (see Table 2).The proportion of drivers travelling below 50 km/h was increased from 61.0% to 67.7%. This increase in the proportion of drivers travelling at slower speeds, below 50 km/h, after installation of the flashing lights is more pronounced in the morning than in the afternoon period. The morning increase was estimated at 7.6% compared to the afternoon period of 5.6%. The morning compliance rate increased from 68.5% to 76.1% compared to the afternoon increase from 54.5% to 60.1%. When the compliance to 10 km/h above the speed limit of 40 km/h, i.e. speed of 50 km/h, is compared between the two periods, the data suggests that driver compliance to the speed limit in the morning is significantly greater than in the afternoon period, with or without flashing lights.

School Zone Time	Survey	Speed							
		<= 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 90	>= 90	Total
Afternoon	After	7934	17758	9829	6033	1041	92	24	42711
		18.58*	41.58	23.01	14.13	2.44	0.22	0.06	
	Before	6952	14301	10517	6113	991	100	13	38987
		17.83	36.68	26.98	15.68	2.54	0.26	0.03	
	% Change	0.75	4.90	-3.97	-1.55	-0.10	-0.04	0.03	
Morning	After	11963	17172	5513	3078	484	43	11	38264
		31.26	44.88	14.41	8.04	1.26	0.11	0.03	
	Before	8218	14625	6549	3318	571	63	9	33353
		24.64	43.85	19.64	9.95	1.71	0.19	0.03	
	% Change	6.62	1.03	-5.23	-1.91	-0.45	-0.08	0.00	
Total	After	19897	34930	15342	9111	1525	135	35	80975
		24.57	43.14	18.95	11.25	1.88	0.17	0.04	
	Before	15170	28926	17066	9431	1562	163	22	72340
		20.97	39.99	23.59	13.04	2.16	0.23	0.03	
	% Change	3.60	3.15	-4.64	-1.79	-0.28	-0.06	0.01	

* Row percent

Table 2. Distribution of speeds before and after installation of flashing lights

3.4 Variation in Effects of Flashing Lights between 15-minute Intervals

Analysis of speed data for the speed zone time periods, morning and afternoon, shows a significant variation in the effects of flashing lights within the zones. The greatest effects are shown at the beginning of the school zone operational time, morning and afternoon, and the least during the last quarters of the periods.

3.4.1 Distribution of Mean Speeds and 85th Percentiles

The greatest reductions in the mean speed after the installation of traffic lights is associated with the highest mean speeds before the installation (refer Figure 3). The mean speed and the 85th percentile differences ranged between 0 km/h to 5 km/h. The lowest mean and lowest 85th percentile were recorded between 8:15am and 8:30am in both surveys.

Both distributions followed “U –shaped” distributions, more concaved for the morning than the afternoon period, when drivers tend to travel with higher speeds over the entire school zone period. This behaviour may be associated with a relatively short lasting activity within the zones during the afternoon school zone time period. The observed effects of the flashing lights for even relatively small periods of time within the school zones could be of a substantial significance because a reduction in the speed of up to 5 km/h is associated with the reduction in the risk of a casualty crash of up to 50% (Kloeden et al., 1997).

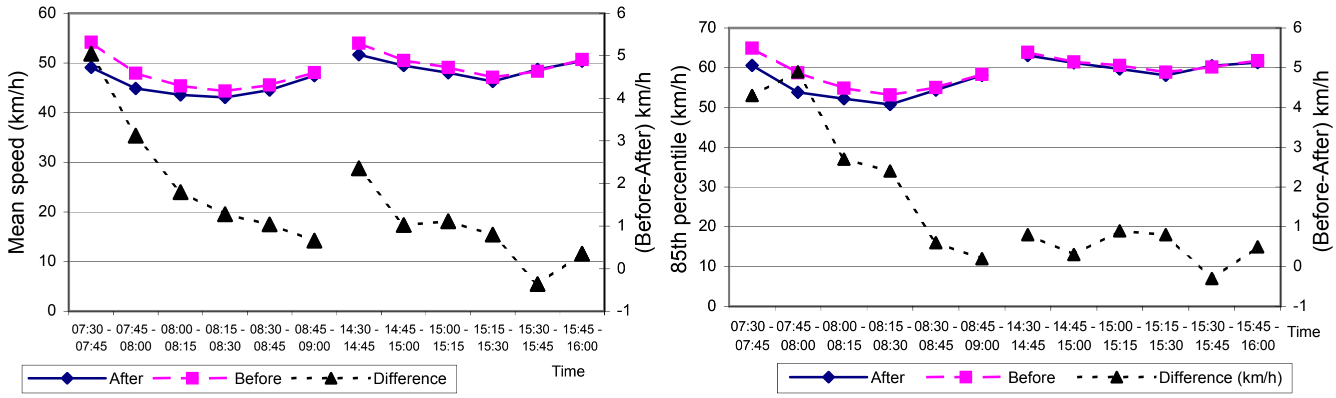

Figure 3. Distribution of mean speeds and the 85th percentiles by 15-minute intervals

Analysis of the mean speeds and 85th percentiles by 15-minute intervals suggests that the magnitude of the effects of the flashing lights is not entirely related to the magnitude of the activities within the school zones, however it related to the periods when lesser activity or no activity is observed. This anomaly may be accounted for by established driver speed behaviours when a substantial activity is present; in general, resulting in the lowest mean speeds irrespective of the presence of the flashing lights. The lowest mean speeds coincide with the highest activities within the zones accompanied by a relatively small reduction in the mean speed. This may be due to possible speed saturation level beyond which drivers would not under normal circumstances undertake unless enforcement is increased.

3.4.2 Analysis of Proportions of drivers travelling above 50 km/h

Analysis of the vehicle speeds above 50 km/h before and after the installation of the flashing lights suggests that a large proportion of drivers that used to travel with speeds greater than 50 km/h prior to the treatment have changed their driving behaviours towards the lower speeds below 50 km/h. The data indicates that after the introduction of the flashing lights there was a reduction in the proportion of drivers that used travel above 50 km/h in the order of 3% to 38%, depending on time within the school zone operational time period (see Figure 4).

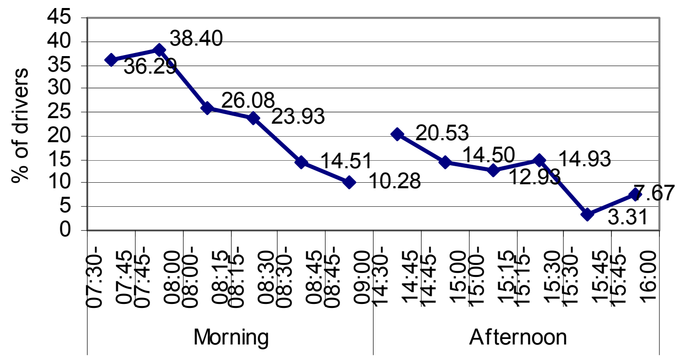

Figure 4. Percentage reduction in proportions of vehicles travelling above 50 km/h "after" compared to "before" installation of flashing lights by 15-minute intervals

The largest reduction in the proportion of drivers travelling above 50 km/h was recorded between 7:45am and 8:00am, 38%, represented by the reduction from 34%

to 21% of all vehicles recorded during the 15-minute interval. Average reductions in the proportions were 12.4% and 24.3%, for afternoon and morning periods, respectively. For both school zone time periods the average was 17.3%.

3.5 Other Non-school Zones Time Period

Investigation of the mean and the 85th percentile estimates for the period other then the school zone time periods within which 40 km/h speed limit applies found that the mean speed in June/July 2002 was approximately 1 km/h less then in October/ November 2003, 59.15 km/h and 60.16 km/h, respectively. Similarly, the 85th percentile in 2002 was found to be 0.5 km/h less than in 2003 (refer Table 1). It can be assumed that if the “before” data was collected over the same period as the “after” data, in October/November, then the mean vehicle speed would be expected to be up to 1 km/h higher than the one observed in the June/July survey. If this is correct, then it is valid to adjust the school zone “before” data for the differences observed on the “other” period data.

3.6 Adjustment for Vehicle Speeds Due to Seasonal Variation

If the mean adjustment factor derived from the “other” period of 1/59.15 was applied to the prior installation school zone periods, morning and afternoon, then the estimated “real” mean differences would be significantly larger than those observed. For the 15-minute intervals, the effects of flashing lights measured in terms of mean speeds would be increased in the range of 0.8 to 0.9 km/h (refer Figure 5). It is expected that the risk of casualty crashes on these types of roads with the speed limit of 60 km/h for some of the 15-minute intervals would be decreased by more than 50%. For the morning and afternoon school zone periods, the adjusted mean speed reductions were 2.62 km/h and 1.65 km/h, compared to the observed means of 1.83 km/h and 0.81 km/h, respectively.

Similar to the increase in the mean speed for the “other” period in the October/ November survey compared to the survey conducted in June/July, the October/ November survey recorded an increase in the 85th percentile of 0.5 km/h. If similar adjustment was applied to the 85th percentile for the increase of the “other” period in the October/November survey, then the expected effect of the flashing lights would be a reduction in the 85th percentile of 2.83 km/h and 2.83 km/h for the morning and afternoon periods, respectively. The adjusted 85th percentile reductions for the 15-minute intervals ranged between 0.2 and 5.3 km/h (see Figure 5).

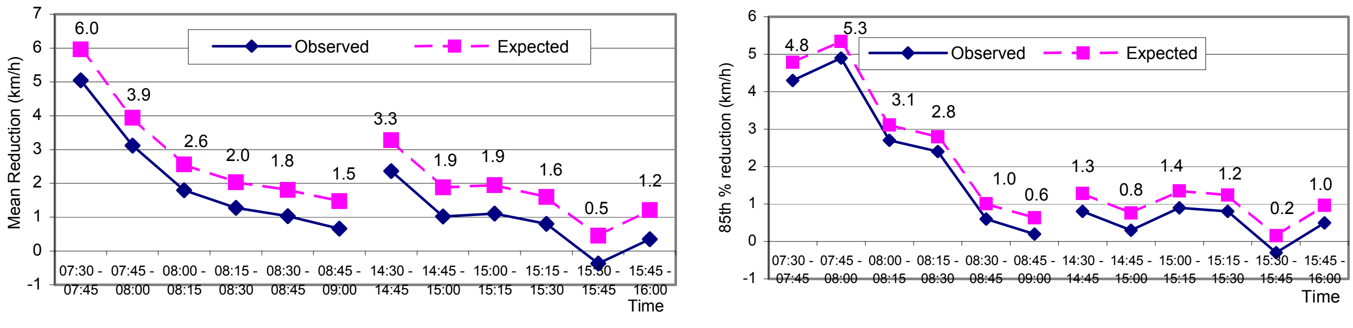

Figure 5. Adjusted reductions in mean speeds and 85th percentiles by 15-minute intervals

4. CONCLUSIONS

The findings of the study related to the effects of the flashing lights within the school zone on driver speed behaviours may be summarised as follows:

- Effects of flashing lights seem to be more pronounced during the morning than during the afternoon school zone time period. In the morning school zone time period, the flashing lights were associated with an average reduction in the mean speed of 1.83 km/h, while the afternoon period showed a significantly less reduction of only 0.81 km/h. The mean reduction for both periods was estimated at 1.3 km/h. When the means were adjusted for "seasonal differences in driver speed behaviours", the reductions were greater than the observed, 2.62 km/h and 1.65 km/h, respectively.

- The morning period showed a reduction in the 85th percentile of 2.4 km/h compared to the afternoon period reduction of 0.6 km/h. After adjustment for the "seasonal" differences, it is estimated that the reduction in the 85th percentiles could be as high as 2.8 km/h for the morning and 1.1 km/h for the afternoon period.

- Proportion of drivers travelling up to 10 km/h above the speed limit of 40 km/h was significantly greater in the morning than in the afternoon period, with or without flashing lights. The flashing lights resulted in the average percentage reduction of 6.7% for the two school zone time periods. Proportion of drivers travelling below 50 km/h was increased from 61% to 67.7%, more pronounced in the morning than in the afternoon. The morning compliance rate to 10 km/h above the speed limit was increased from 68.5% to 76.1% compared to the afternoon increase from 54.5% to 60.1%.

- It was estimated that the installation of flashing lights was associated with the average reductions in the proportions of drivers travelling above 50 km/h of 12.4% and 24.3%, for afternoon and morning periods, respectively. For both school zone time periods the average reduction was 17.3%.

- Analysis of effects of flashing lights by the15-minute intervals suggests that:

  - The greatest reductions in the mean speed after the installation of traffic lights was associated with the highest mean speeds before the installation.

  - The mean speed difference and the 85th percentile difference ranged between 0 km/h and 5 km/h The distributions of the mean speeds for the intervals for the two periods followed U–shaped distributions, more concaved for the morning than the afternoon period.

  - Magnitude of the effects of the flashing lights appears to be inversely related to the magnitude of the activities within the school zones, i.e. the greater presence of activity is observed the less effect the flashing lights have on driver speed behaviours. This anomaly may be accounted for by established driver speed behaviours when a substantial activity is present, resulting in the lowest mean speeds irrespective of the presence of flashing lights.

- The lowest mean speed reductions coincide with the highest activities within the school zones accompanied by a minor reduction in the mean speed. This may be due to possible speed saturation level beyond which drivers would not under normal circumstances undertake unless enforcement is increased.

- Flashing lights were associated with a reduction in the proportion of drivers that used travel above 50 km/h in order of 3% to 38%, depending on time within the school zone operational time period.

In summary, the effects of flashing lights vary between the school zone times, morning and afternoon, and times within these periods. The mean speed reduction could be as high as 5 km/h. However, the effects are largely dependent on activity within school zones and the magnitude of drivers' "acceptable" speeds within the zones when the flashing lights are not present, guided by standard regulatory signs and perceived "safe" speeds for the environment.

The study demonstrated that the application of engineering practices, such as installation of flashing lights, results in greater speed limit compliance on relatively high-speed roads than it would normally be achieved with the standard regulatory signs, and therefore improves traffic safety on sections of roads exposed to high concentration of young pedestrians.

5. RECOMMENDATIONS

It is recommended that the flashing lights be installed on similar speed limit roads to those in the trial, greater or equal to 60 km/h. Although their effects may not be constant over the entire school zone operational periods due to the speed limit constraint of 40 km/h and driver compliance to the speed limit, there are time intervals within the time periods when the flashing lights demonstrate substantial effects resulting in the average speed reductions in excess of 5 km/h. These reductions in the average speed, in a case of a crash, would reduce crash casualty risk by up to 50%, and significantly greater if a crash involves a pedestrian.

If the flashing lights were installed on selected roads, then they need to be exceptionally reliable in their operations for the reason that drivers who regularly traverse the route may fully rely upon the lights rather than on regulatory signs guiding the school zone operational times. As a result, the flashing lights installation may result in negative consequences.

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POTENTIAL BENEFITS AND COSTS OF SPEED CHANGES ON RURAL ROADS

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ABSTRACT

This study explored the potential economic costs and benefits of changes to speed limits 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).

Specific objectives were to explore a number of scenarios, such as:

- increasing limits on high standard roads with a low crash rate (per vehicle-kilometre) from 110 to 130 km/h (or intermediate speeds)
- increasing limits on high standard roads with a low crash rate from 110 to 130 km/h subject to a variable speed limit system that would reduce speeds under adverse conditions such as poor light, bad weather or dense traffic ('VSL option')
- decreasing limits on lower standard rural roads with higher crash rates.

PREVIOUS RESEARCH

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.

Cameron (2000) used similar methods to estimate the optimum speed on urban residential streets in Australia. He found that it depended on the method used to value road trauma. When the 'human capital' valuations of road trauma costs (BTE 2000) 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 the 'willingness to pay' approach (BTCE 1997), the analysis suggested that the optimum speed on residential streets is 50 km/h. Noise costs in urban areas could not be valued in the analysis, but the travel time on residential streets was.

METHOD OF THIS STUDY

The effects of speed on road trauma levels were calculated using well-established relationships linking changes in average free speed with changes in numbers of fatal, serious injury and minor injury crashes on rural roads (Nilsson 1984), as follows:

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

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

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 a large number of changes in speed limits on Swedish rural 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, 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).

It was assumed that travel time = link length / speed of traffic flow. 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 method of this study are given in Cameron (2003). The study also involved a number of assumptions given in the following section.

ASSUMPTIONS

1. The current speed limits on freeway standard and other divided rural roads are 110 km/h for cars and light commercial vehicles (LCVs) and 100 km/h for all rigid and articulated trucks, and the speed limit on undivided rural roads is 100 km/h for all types of vehicle.

2. 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.

3. 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.

4. The mix of traffic by vehicle type is the same on each class of rural road, namely 67% passenger cars, 20% light commercial vehicles, 5% rigid trucks and 8% articulated trucks. This mix was assumed not to vary by time of day, which may be questionable on rural freeways and other divided roads.

5. Crashes involving material damage only, and no personal injury, were not included in the analysis of crash changes with speed, and the likely increase in these crashes with increased 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).

6. Scenarios in which truck speed limits are lower than light vehicle limits have been analysed on the assumption that the (increased) speed differential between these vehicle types does not in itself increase crash risk or the severity of the crash outcome. This assumption was considered reasonable for low differentials in speed but may be questionable for differentials more than, say, 15 km/h.

7. The changes in speed limits are assumed not to increase or reduce travel demand and traffic flows of each vehicle type on the road sections.

8. The travel time savings on the rural road sections are of sufficient magnitude to be aggregated and valued.

9. The current economic valuations of travel time, road trauma, and air pollution emissions provide an appropriate basis for 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. (Results using alternative valuations of road trauma increases and decreases are also presented).

10. Assessment scenarios involving variable speed limit systems do not include any estimates of capital and maintenance costs for the systems.

11. Illustrative 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.

RESULTS

The estimated effects of the different speed limit changes on 100 km sections of the three classes of rural roads are given in Tables 1 and 2. Table 2 also includes an estimate (to the nearest 5 km/h) of the optimum speed, for all vehicles combined, and also for the light vehicles and trucks separately.

Table 1: Travel time savings and road trauma increases per 100 km of road.

	Travel time saving per vehicle per 100km (min.)		**Road trauma increases per 100km of road per year**		
Scenario	Cars & LCVs	Trucks	Fatal crashes	Serious injury crashes	Other injury crashes
RURAL FREEWAYS (20,000 vehicles per day)					
Speed limit raised to 130 km/h (base scenario)[1]	8.4	13.8	2.8	11.1	14.1
Trucks limited to 100 km/h	8.4	0.0	1.6	8.4	11.6
Variable speed limit (VSL)[2]	5.6*	0.0	0.7	3.7	4.9
VSL (day limit 120 km/h)[2]	2.5*	0.0	0.2	1.0	1.3
RURAL DIVIDED ROADS (15,000 vehicles per day)					
Speed limit raised to 130 km/h (base scenario)[3]	8.4	13.8	3.4	13.6	17.2
Trucks limited to 100 km/h	8.4	0.0	1.9	10.3	14.2
Variable speed limit (VSL)[4]	5.6*	0.0	0.9	4.6	6.0
VSL (day limit 120 km/h)[4]	2.5*	0.0	0.3	1.3	1.6
STANDARD 7.0 M SEALED TWO-WAY UNDIVIDED ROADS (1,000 vehicles per day)[5]					
Speed limit raised to 130 km/h (base scenario)	13.8	13.8	0.8	3.3	4.1
Raised on curvy roads with crossroads and towns	9.8	9.8	0.9	3.7	4.6
SHOULDER-SEALED 8.5 M TWO-WAY UNDIVIDED ROADS (1,000 vehicles per day)[5]					
Speed limit raised to 130 km/h (base scenario)	13.8	13.8	0.5	2.1	2.6
Raised on curvy roads with crossroads and towns	9.8	9.8	0.6	2.3	2.9

[1,3] Speed limit raised from 110 km/h (cars and LCVs) and 100 km/h (trucks) to 130 km/h (all vehicles).

[2,4] Day speed limit for cars and LCVs raised to 130 km/h (or 120 km/h where indicated); night speed limit reduced to 100 km/h; truck speed limit fixed at 100 km/h during all times.

[5] Speed limit raised from 100 km/h to 130 km/h for all types of vehicle.

* Travel time savings averaged across all times of day (assuming 20% of total traffic at night).

Table 2: Economic impacts of scenarios, & estimated optimum speeds.

Scenario	Effect on total economic cost: Change ($ million) p.a./100 km	Effect on total economic cost: Percentage change	Optimum Speed (km/h) (speed which minimises total economic cost): All vehicles combined	Optimum Speed (km/h): Cars & LCVs	Optimum Speed (km/h): Trucks
RURAL FREEWAYS (20,000 vehicles per day)					
Base scenario[1]	2.350	0.6%	120	125	100
- 'Willingness to pay' (WTP) values of road trauma	10.497	2.7%	110	120	95
Trucks limited to 100 km/h	-3.641	-1.0%	n.a.	125	100
Variable speed limit (VSL)[2]	-3.483	-0.9%			
- WTP values of road trauma	-1.308	-0.3%			
VSL (day limit 120 km/h)[2]	-2.334	-0.6%			
- WTP values of road trauma	-1.735	-0.4%			
RURAL DIVIDED ROADS (15,000 vehicles per day)					
Base scenario[3]	6.454	2.2%	110	120	95
- 'Willingness to pay' (WTP) values of road trauma	16.453	5.5%	105	110	90
Trucks limited to 100 km/h	0.372	0.1%	n.a.	120	95
Variable speed limit (VSL)[4]	-1.201	-0.4%			
- WTP values of road trauma	1.468	0.5%			
VSL (day limit 120 km/h)[4]	-1.363	-0.5%			
- WTP values of road trauma	-0.627	-0.2%			
STANDARD 7.0 M SEALED TWO-WAY UNDIVIDED ROADS (1,000 vehicles per day)[5]					
Base scenario	2.040	9.8%	95	100	85
Curvy roads with crossroads and towns	14.781	66.3%	85	85	At most 80
SHOULDER-SEALED 8.5 M TWO-WAY UNDIVIDED ROADS (1,000 vehicles per day)[5]					
Base scenario	1.021	5.1%	105	105	90
Curvy roads with crossroads and towns	13.645	63.5%	85	90	85

[1,3] Speed limit raised from 110 km/h (cars and light commercial vehicles) and 100 km/h (trucks) to 130 km/h (all vehicles). Road trauma valued by 'Human Capital' approach (unless otherwise indicated).

[2,4] Day speed limit for cars and light commercial vehicles raised to 130 km/h (or 120 km/h where indicated); night speed limit reduced to 100 km/h; truck speed limit fixed at 100 km/h during all times of day.

[5] Speed limit raised from 100 km/h to 130 km/h for all types of vehicle. Road trauma valued by 'Human Capital' approach.

Rural freeways

An increase in the speed limit to 130 km/h on rural freeways would save each car 8.4 minutes and each truck 13.8 minutes per 100 km, but would increase the number of fatal crashes by 2.8 per year per 100 km of freeway. Casualty crash costs would increase by 89%, vehicle operating costs would increase by 7% and time costs would decrease by 17%. There would be a net cost increase of $2.35 million per year per 100 km of road, provided it is appropriate to value the road trauma increases by the 'human capital' approach. If road trauma is valued by society's 'willingness to pay' to prevent it, the net cost would be $10.5 million per year per 100 km. Since these alternative valuations of road trauma are central to the estimated economic output of the increased speed limit on rural freeways, the implications of their choice in making policy decisions needs to be considered carefully.

However, the analysis does indicate that the negative economic impacts of the increased speed limit on rural freeways could be overcome, and even made positive, if trucks were limited on such roads to 100 km/h. A further alternative would be a variable speed limit system, whereby the speed limit is reduced to 100 km/h for cars and light commercial vehicles under adverse road conditions (such as at night or other adverse condition approximately doubling the crash risk for about 20% of the traffic), and is fixed at 100 km/h for trucks at all times. (Issues associated with practical implementation, and cost, of a variable speed limit system were not part of the study.) If the increased speed limit under good conditions was no more than 120 km/h, the increase in road trauma would be minimal. This variable speed limit system would still result, however, in an increase in fatal crashes of 0.2 per year per 100 km of freeway, due to the increase in speed limit for 80% of the traffic, albeit during safer daytime conditions. This system would increase casualty crash costs by 7%, increase vehicle operating costs by 1% and reduce time costs by 4%.

Divided roads

The travel time savings if the speed limit were increased to 130 km/h on rural divided roads were estimated to be the same as on freeways, and the percentage change in crash costs would be similar. However the number of additional casualties would be higher because of the higher initial crash rate. Fatal crashes would increase by 3.4 per year per 100 km of divided road. Similar remarks regarding the economic analysis of rural divided roads apply as were made for freeways, except that a simple increase in the speed limit to 130 km/h would have a substantial economic cost ($6.45 million increase per year per 100 km of road). Even higher figures would be estimated with alternative valuations of leisure travel time and road trauma.

The economic loss on divided roads could be overcome to a large extent if trucks were limited to 100 km/h. However a variable speed limit system allowing speeds of 120 km/h under good conditions would not be as beneficial as on rural freeways. There would be an additional 0.3 fatal crashes per year per 100 km of road, but a saving of 2.5 minutes per car travelling over the 100 km section averaged over the whole day. A system allowing 130 km/h on divided rural roads during good conditions would result in greater road trauma levels.

Undivided roads

There is apparently no economic justification for increasing the speed limit to 130 km/h on the two-way undivided roads, especially the lower standard 7.0 m sealed roads without shoulder sealing.

On the straight undivided sections without intersections or towns, total costs on the 7.0 m roads would be increased by $2.04 million per annum per 100 km of road, or almost 10% of current costs. There would be travel time savings of 13.8 minutes per vehicle over 100 km, but an increase of 0.8 fatal crashes per year on the same road section. (The increase in casualty crash costs would be 142%, but the number of additional fatalities and casualties per 100 km road section would be lower than on divided roads because of the lower traffic volumes on typical undivided roads.)

On the lower standard undivided roads through curvy terrain requiring slowing and occasional towns requiring stopping, the average speed would be lower and the travel time savings would be only 9.8 minutes per vehicle over 100 km. The total cost associated with raising the speed limit, and hence the cruise speeds, to 130 km/h is estimated to be $14.78 million per annum per 100 km, due to increased fuel consumption predominantly and to increased air pollution emissions, each associated with the deceleration-acceleration required by slowing and stopping from 130 km/h cruise speed and returning to that speed.

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. 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. Optimum cruise speeds would be somewhat lower if 'willingness to pay' values were used for crash costs, or lower values were used for leisure time savings.

On the higher standard, 8.5 m shoulder-sealed undivided roads, an increase in the speed limit to 130 km/h would not result in as many additional crashes as on the lower standard roads, but the total cost would still increase by $1.02 million per annum per 100 km of straight road: about 5% of current total costs. The travel time savings would be the same as on the lower standard undivided roads, but on the straight sections without intersections or towns there would still be 0.5 additional fatal crashes per year per 100 km of road. These calculations assume equal traffic volumes on higher standard and lower standard undivided roads. In practice, traffic volumes are likely to be higher on the better roads, so the number of additional casualties and the net cost increase per section could be higher on these roads.

Again, as with the lower standard undivided roads, the higher standard roads through curvy terrain and passing through towns would experience substantial increases in total social costs associated with the increased speed limit, due to increased fuel consumption and emissions because of frequent deceleration and acceleration. The total cost associated with cruise speeds of 130 km/h on such roads would be $13.65 million per annum per 100 km of road. Travel time savings would be reduced compared with straight 8.5 m shoulder-sealed sections, and fatal crashes would be increased by 0.6 per year per 100 km of curvy road.

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.

DISCUSSION

Appropriateness of valuing travel time savings

There is a view that on some trips, the travel time saving per trip travelled at a higher speed is so small that the benefit cannot be perceived by vehicle occupants and hence has zero value. In rural areas, trip distances are typically longer than in urban areas and travel time savings per trip are potentially substantial if travelling at a higher speed. It has been estimated that 41 minutes per trip could be saved on a 700 km rural section of the Hume Highway if travelling at 130 km/h on the better one-third of road and 120 km/h on the remainder, compared with travelling at 110 km/h over its whole length (Crawford 2002). It is likely that vehicle occupants would perceive travel time savings of this magnitude over long rural trips and would place value on the time savings.

Another issue arising in the valuation of travel time savings on rural roads is the desirability of consistency in the valuation of leisure time in the travel time costs and in the road trauma costs. The 'human capital' crash cost estimates do not include any value for leisure time forgone by crash victims. For consistency reasons, it could be argued that when the human capital cost estimates are used, the leisure trip travel time savings should be valued at zero. This variation on the base scenario analyses for rural freeways and rural divided roads was considered in the study (Cameron 2003) but the results are not presented here.

'Willingness to pay' valuations of road trauma

There has been considerable attention given in the USA to valuing road trauma costs as comprehensively as possible, especially including values for lost quality of life in the case of killed and incapacitated crash victims. A leading US transport safety economist, Ted Miller, has argued that comprehensive crash costs, otherwise known as 'willingness to pay' values, should be used in benefit-cost analysis. This is because 'willingness to pay' values reflect society's consumer preferences when it comes to decisions about road safety initiatives.

Miller (1996) has also suggested that 'it seems essential to use compatible values of life and travel time in transport investment analyses'. Since the travel time values normally used for transport decisions reflect consumer preferences, this implies that 'willingness to pay' values of road trauma should be used when travel time savings are valued.

Reflecting this argument, the analysis in this study includes variations on the base scenarios for rural freeways and rural divided roads in which 'willingness to pay' values are used (Table 2). Travel time for all purposes of trip (including leisure trips) is valued in these analyses. It is suggested that this is technically the correct combination of valuations of these two important impacts of the speed limit changes analysed in this study.

Optimum speeds if road trauma valued by 'Willingness to pay'

On the basis of these valuations, 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.

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. However, reliable data on rural traffic levels using each of the four classes of road analysed in this study was not available to calculate the total economic impacts across the rural road network.

CONCLUSIONS

Within the limits of the assumptions made and the data available for this study, a number of conclusions about rural speed limits were reached. In particular, it was assumed that the average speed of each vehicle type is the same as the speed limit, unless their speed is reduced by slowing for curves and stopping in some sections.

1. Increasing the speed limit to 130 km/h for all vehicles on rural freeways would have substantial social costs. The total social cost could be constrained, and even reduced, if trucks were limited to 100 km/h on such roads. A variable speed limit system allowing speeds of 120 km/h for cars and light commercial vehicles during good conditions, but reduced to 100 km/h under adverse conditions, while limiting trucks to 100 km/h at all times, would keep total social costs below current levels. However, all scenarios whereby speed limits are increased for some vehicle types and circumstances are necessarily accompanied by increased road trauma to provide travel time saving benefits.

2. Increasing the speed limit to 130 km/h on rural divided roads would have even greater social costs than the increased limit on freeways. If trucks were limited to 100 km/h, the impact on total social costs would be smaller but they would still increase. Even a variable speed limit like that for freeways described above would be associated with an increase in road trauma costs. The higher crash rate on the divided roads compared with rural freeways will result in any speed limit increase producing even greater road trauma increases than on the freeways, despite lower traffic volumes on non-freeway roads.

3. If the 'willingness to pay' valuations of crash costs reflecting consumer preferences are used, 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 social costs in each environment. However, there would be increases in road trauma on the rural freeways due to the increase in car speeds.

4. There is no economic justification for increasing the speed limit 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 social 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.

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