CONSTANT SPEED DRIVING UNDER DYANMIC ADVISORY SPEEDS YIELDS SAFETY, ENVIRONMENT AND ENERGY BENEFITS

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ABSTRACT:

Data taken each second from two multilink road experiments was used to examine the time spent in the main speed-acceleration regions of the test car's operating envelope. These regions were mapped using a three dimensional graphical presentation. Time spent above the speed limit was reduced from 25% of the travel time for 'float' conditions to 1% using advisory speeds, but with the same travel time. The fuel rate experienced when above the speed limit was 55% more than the mean fuel rate. Reductions in accident potential peak roadside noise and vehicle maintenance costs are predicted from the data.

INTRODUCTION

The passage of high volumes of passenger vehicles along major urban arterial roads is one of the least appealing features of modern city life. These vehicles, while consuming a large fraction of the national liquid fuel pool, produce a significant proportion of pollutant emissions, contribute to the perceived high accident level and cause heavy maintenance costs for both road and vehicles. It is generally agreed that smoother traffic flow can help alleviate these problems.

Early attempts to achieve smoother flow by means of advisory speed signs have been documented by Von Stein (1961) and Morrison et al. (1962). Recently, Seiffert (1984) described several foreseeable changes to vehicle and traffic system technology, including the provision of direct advice to drivers to enable better "green wave" conditions. In the project of which this paper is a part, results have been reported of discrete vehicle simulation by Trayford et al. (1984a) and of a network flow model by van Leersum (1984). A single intersection road experiment (Trayford et al. (1984b)) has confirmed these simulation results demonstrating a 15% reduction in fuel consumption and a 50% reduction in stop rate. Wooldridge et al. (1984) reviewed the CSIRO project to this point and outlined the future course of the work. A further two experiments reported by Trayford et al. (1984c) using 7 links on Malvern-Waverley Road, a major arterial road in Melbourne, have shown that in a co-ordinated fixed time signal mode similar gains in the reduction of stops and fuel consumption are possible. This paper analyses the one-second-interval data of these last two experiments in terms of the time spent by the test vehicle in various speed-acceleration regions, to investigate the size and range of potential safety, environment and energy benefits.

METHOD

A general description of the two experiments was reported in Trayford et al. (1984c), while the equipment and the software used in the test car has been reported by Reid (1985). Briefly, the instrumented car was driven along 3.5 km of an arterial road in both peak and off-peak hours under vehicle actuated traffic signals, controlled overall by either a flexible fixed time or an adaptive traffic responsive mode. The ten drivers (eight in the first experiment and two in the second) drove under various conditions of advice. In the first experiment, advisory speeds, when under the fixed time signal mode, and free choice, under both modes, were used. "Following surrounding traffic", achieved with either chase car or floating car methods, and an instructed 'save fuel" mode were adopted in the second experiment. In the "save fuel" mode the drivers were instructed to keep below 60 km/h and to minimise accelerations. The best advice condition of the first experiment suggested a fuel saving of 15% when compared to the chase and floating car conditions reflecting the surrounding traffic in the second experiment.

In addition to the trip summary data reported in Trayford et al. (1984c), the data taken each second was recorded to form a 2 megabyte data base. This data base contained measures of distance, fuel (1 and 0.1 mℓ data channels), elapsed time and events. Acceleration was derived from distance, and thence speed, by a centre difference method. Maps of frequency of occurrence and fuel rate on speed-acceleration grids were constructed using a cell size of 1 km/h x 0.1667 ms^{-2}. A division of time and fuel into major speed-acceleration regions was then made to facilitate more direct comparisons. These regions are shown in Figure 1. The 45-60 km/h constant speed region (0.1667 ms^{-2} wide) delineates the minimum region of the fuel consumption curve expressed in ℓ/100 km. While the boundary at the 60 km/h urban speed limit is obvious, the lower limit for the desirable constant speed operating region is a judgement on the lowest speed a driver may find acceptable. This was set at 45 km/h based on the experimental data of Trayford et al. (1984b).

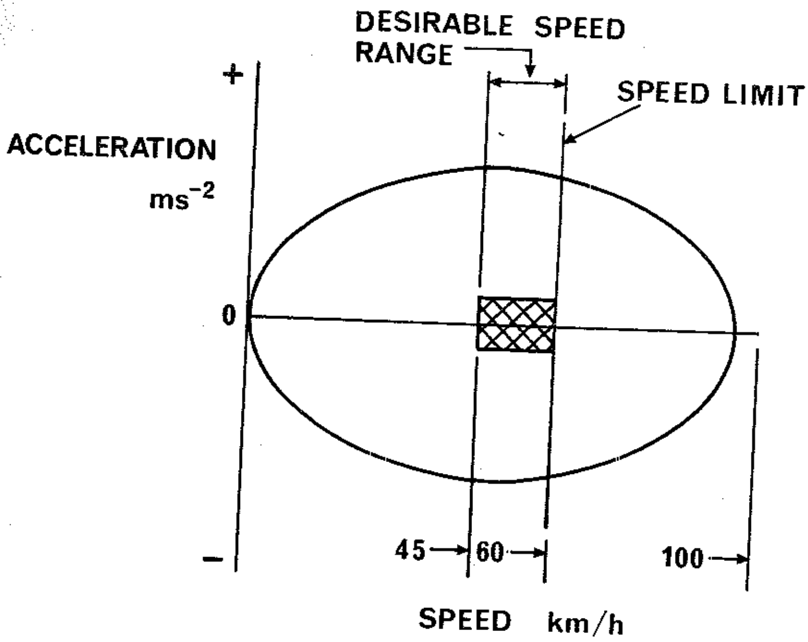


Fig. 1. Major vehicle operating regions on the speed-acceleration map.

DATA PROCESSING

The data from the one-second-interval data base were processed in two stages. First, the numbers of the runs corresponding to the desired test conditions were extracted from the master data base and the one-second-interval data from each of these runs pooled to form an appropriate subset. The data comprised readings from the odometer, fuel meter and master clock logged at one second intervals. Average acceleration, speed and fuel flow rate were derived from these inputs. Average speed was taken as the distance covered between samples divided by the elapsed time. This speed was then arbitrarily ascribed to the centre of the sample period. The speeds at the start and end of the sample were obtained by linear interpolation between this centre value and those of the two adjoining samples, with acceleration being determined from the difference in these speeds and the elapsed time.

The second stage involved the sorting of the derived values into the cells or bins according to speed and acceleration ascribed to each sample. Three arrays, each 100 by 45, were constructed and filled with frequency or fuel counts. Each bin represented a velocity between 0 and 100 km/h in increments of 1 km/h and an acceleration between -3.75 ms^{-2} and +3.75 ms^{-2} in 45 increments of 0.167 ms^{-2}. A count was added to the appropriate bin for each sample to yield a frequency array, while the fuel counts were added to their bins to determine the total fuel consumed in each bin. Division of either of the fuel arrays by the frequency array converted this to fuel flow rate data.

In order to examine this quantity of data, programs were written to plot the various arrays as 3-dimensional solids and to rotate and translate these images to facilitate examination from any angle.

RESULTS

The various driving conditions of the two experiments can be pictured as a three-dimensional plot with frequency in the vertical plane. Figure 2 gives the speed-acceleration frequency maps for the conditions of the surrounding traffic in the off-peak period as determined by the test car, using both a chase car technique and a floating car, zero passing count method. The stop cell or bin (0-1 km/h, ± 0.0833 ms^{-2}) overwhelms the rest of the diagram, running off scale. However, stop results have been reported in Trayford et al. (1984c) and the purpose of this paper is to concentrate on the higher speed features, especially in the region of the cruising speed "ridge". The higher frequencies are grouped in a speed band (± 0.083 ms^{-2}) extending from 55 km/h to 80 km/h, with no one peak predominating. Speeds exceeding the speed limit (60 km/h) are common.

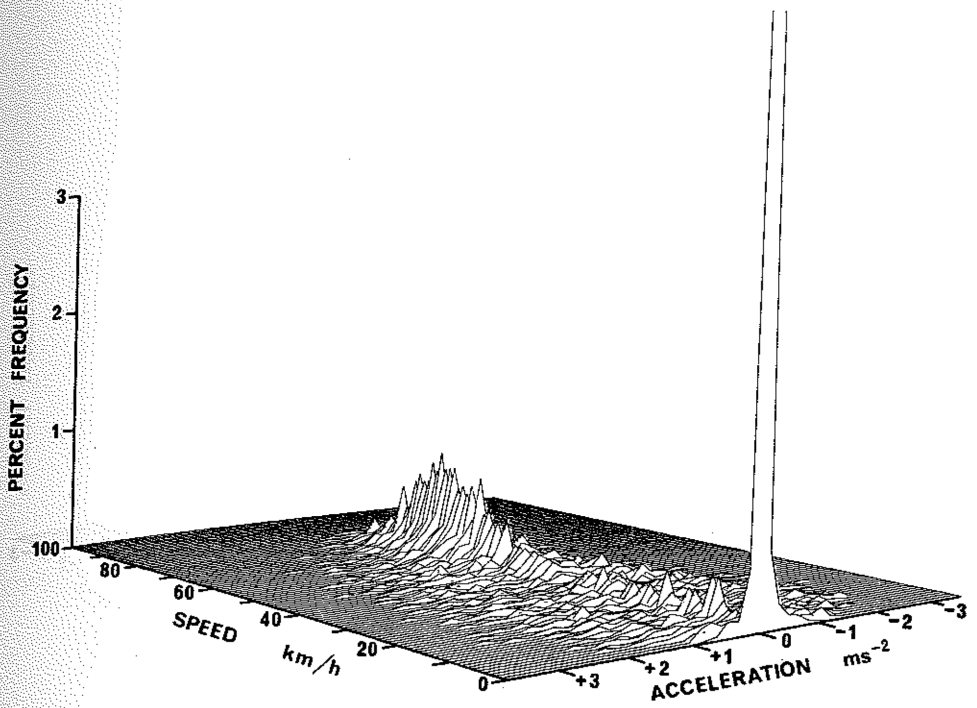


Fig. 2. Surrounding traffic frequency counts as measured by the test car in the off-peak period.

Accelerations out to 2 ms^{-2} are present, many of which occur above the speed limit. On the braking or deceleration side a similar large area is seen with a maximum deceleration near 2 ms^{-2} at around 20 km/h.

By contrast Figure 3, a similar plot of data for a driver using advisory speeds, also taken in the off-peak, shows a much narrower ridge with a single peak near 55 km/h. Counts in cells above 60 km/h are scarce. The extent of the acceleration field appears to be less, especially at the higher speeds, and the localized peaks are also less prominent. It should be noted that for all plots a random selection of data has been taken from each case so that each illustrates the same number of counts as well as uniform scaling.

Figure 4, a plot of the test car running under advisory speeds in the peak hour, shows a similar narrow ridge with one prominent speed peak, also at 55 km/h. It is evident that under advisory speed conditions the speed-acceleration "drive cycle" for the test car differed little between off-peak and peak conditions.

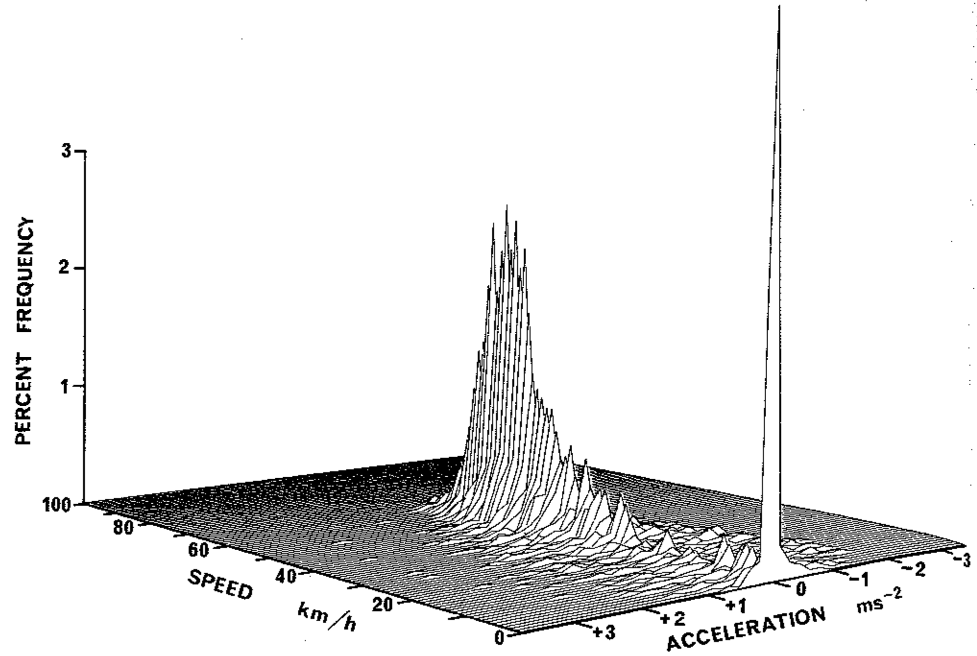


Fig. 3. Off-peak advisory speed frequency counts.

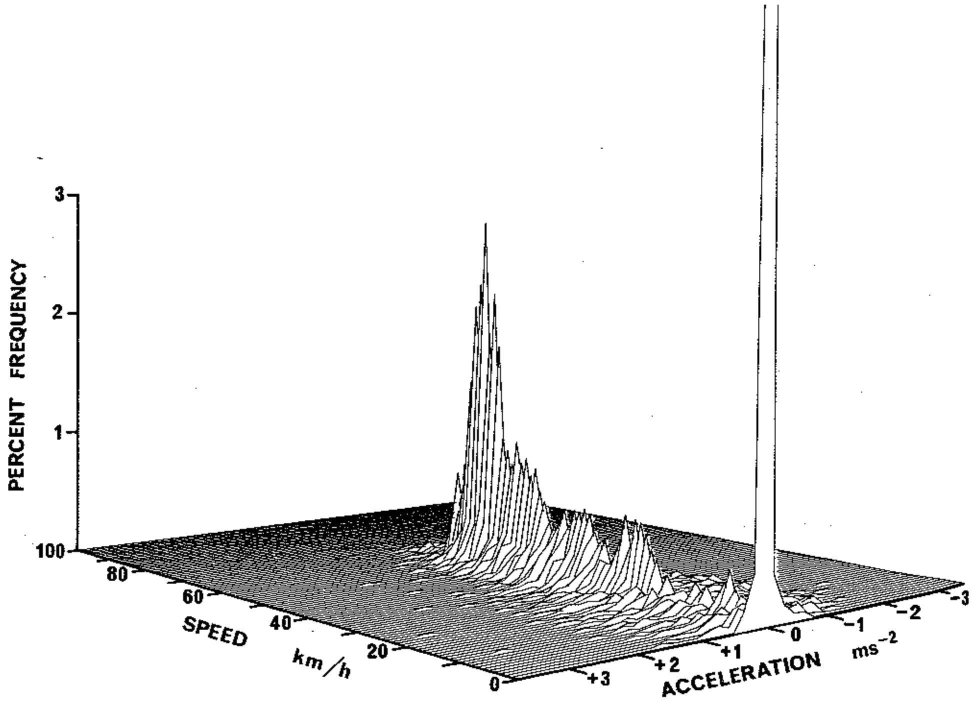


Fig. 4. Peak hour advisory speed frequency counts.

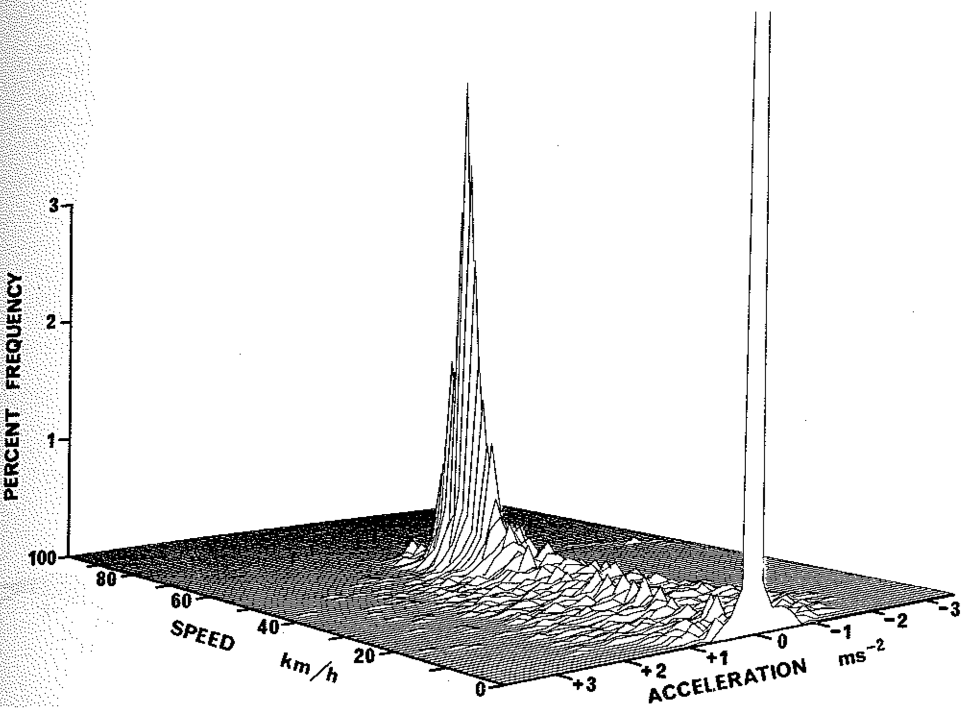


Fig. 5. Off-peak save fuel mode frequency counts.

Moving to Figure 5, which represents the "save fuel" condition, it can be seen that the resultant frequency plot is similar to the previous advisory speed plots. Here, in the off-peak period, the drivers were operating with no dynamic speed advice, but were instructed to keep their speed below the speed limit and to try where possible to drive at constant speed. In Trayford et al. (1984c) the fuel consumption results given for the "save fuel" condition were near the fuel consumption results for the advice conditions, reinforcing this similarity.

In Figures 6 and 7 the frequency plots for the best two of the four advice conditions tested are illustrated. These two conditions were discussed by Trayford et al. (1984c). Each advice condition was given either with a display increment of 2 or 10 km/h and was given once per road link (just downstream of the previous intersection) or continuously (to within 150 m of the next intersection). The two best combinations were the 2 km/h increment given continously and the 10 km/h increment given once. An examination of the plots shows that the "2, continuous" plot has one predominant speed peak at 55 km/h whereas the "10, once" plot has peaks just below 50 km/h and 60 km/h.

DISCUSSION

Fuel Consumption

It has already been reported (Trayford et al. 1984c) that a 15% reduction in fuel consumption is possible using dynamic advisory speeds.

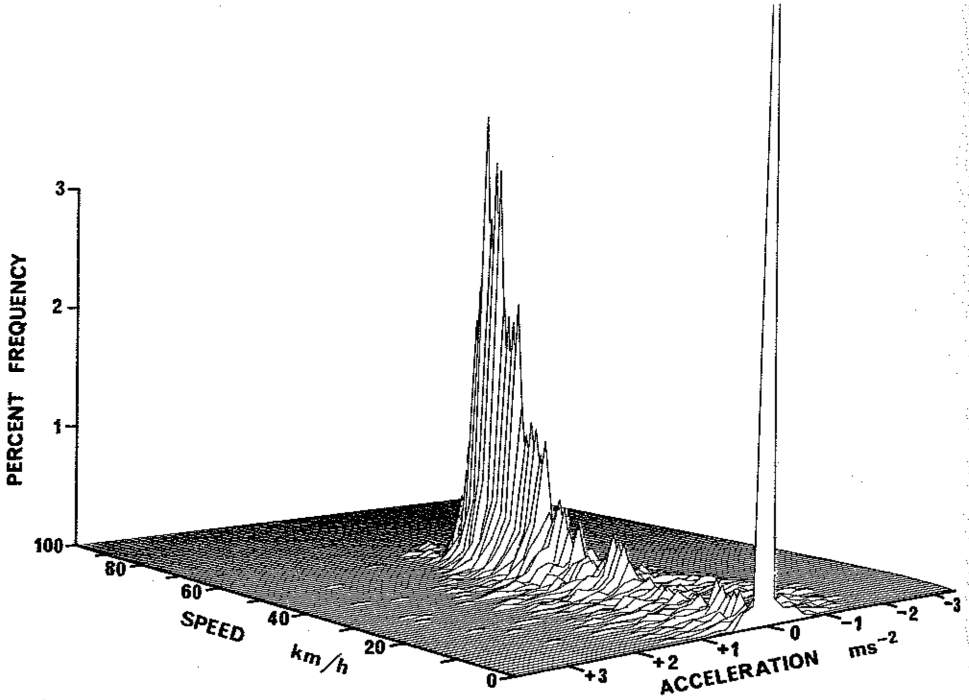


Fig. 6. Two km/h display increment, continuous advisory speed frequency counts for both periods.

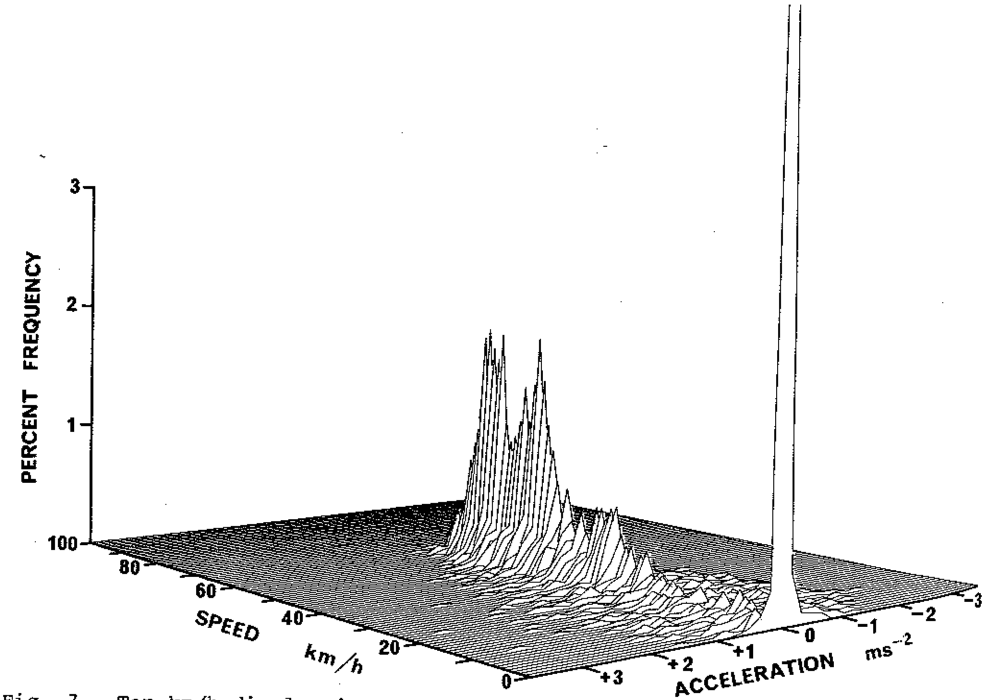
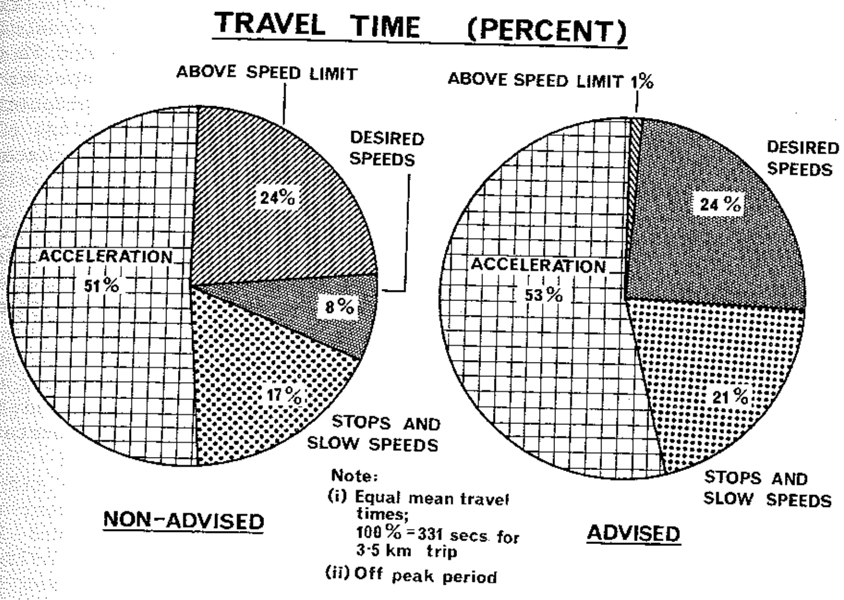


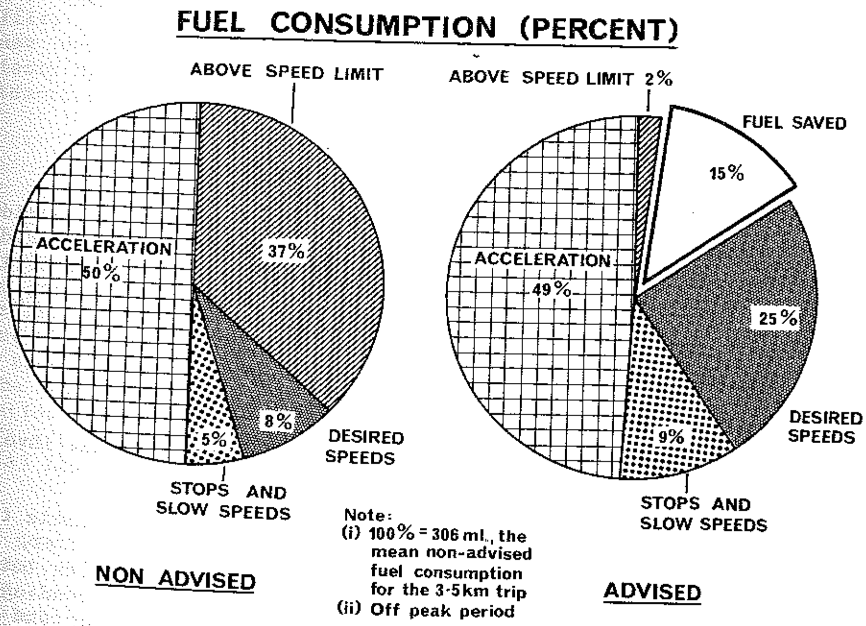
Fig. 7. Ten km/h display increment, once only advisory speed frequency counts for both periods.

Figures 8 and 9 represent the time spent and fuel consumed in each of the vehicle's major operating regions. The times are derived from the one second frequency data given in the results and the boundaries of the speed-acceleration regions used are as stated earlier, noting that the acceleration regions contain all the accelerations $> \pm 0.084\ \mathrm{ms}^{-2}$ below the speed limit of 60 km/h.



Note:
(i) Equal mean travel times; 100 % = 331 secs for 3·5 km trip
(ii) Off peak period

Fig. 8. Time spent in major speed acceleration regions.



Note:
(i) 100% = 306 ml., the mean non-advised fuel consumption for the 3·5 km trip
(ii) Off peak period

Fig. 9. Fuel used in major speed acceleration regions.

The most noticeable contrast between the advised and non-advised conditions is the amount of time spent above the speed limit. In Figure 8 the surrounding traffic, as measured by the test car, spent 23.5% of the trip time above the speed limit while for the test car, under advisory speeds, this was only 1.1%. This difference in exposure to above speed limit speeds carries important safety implications as discussed later. Two other differences show. The proportion of time spent in the constant speed region is higher for advisory speeds; 25% for speeds 45-60 km/h and 14% for slower speeds as against 8% and 5% for the surrounding traffic. Stopped time was lower for advisory speeds; 7% compared to 12%. There was little difference in the overall proportion of time spent below the speed limit in accelerating and braking. The corresponding fuel diagrams (Figure 9), show similar contrasts except, of course, for the presence of a fuel saving of some 15%.

Table 1 shows the relative fuel usage rates for each operating region. Each is the ratio of the mean fuel consumption rate in a particular operating region to the mean rate taken over all regions. During the time spent in the above-speed-limit region there is a greater fuel usage of 1.55 times the mean fuel rate for the trip .

Therefore Table 1 shows how the emphasis for fuel saving must be placed on firstly reducing over speed limit conditions, and then accelerations, given that the total time for the trip is held constant.

Table 1

Ratios of Operating Region Mean Fuel Rate to Mean Fuel Rate for the Whole Trip

Above Speed Limit	Acceleration (below speed limit)	Desirable Constant Speeds	Slow Constant Speeds	Deceleration (below speed limit)	Stops
1.55	1.35	1.03	0.53	0.43	0.2

Accidents

Sanderson and Cameron (1982) have commented on accident severity related to speed, in terms of injury rate per 100 accident involved vehicles, based on data from Solomon (1964). A fit of this data found the following exponential law to be suitable.

$$y = 14.7\, e^{0.0148x}$$

$$R^2 = 0.84 \quad 0 > x > 130$$

where y is the injury rate in persons per 100 accident involved vehicles and x is the speed in km/h.

Spot speeds, which include a greater selection of vehicle types than that afforded by the "float" conditions of the test car, were measured on the experimental arterial road. These spot speeds between intersections gave a mean of 71 km/h for the traffic surrounding the test vehicle, whereas the equivalent most frequent speed for the test car under advisory speeds was 55 km/h. The 60 km/h speed limit was rarely exceeded. Using the above expression the injury severity rate at 71 km/h is 42.0 persons and at 55 km/h it is 33.2, a reduction of 20%.

A further favourable effect must be considered. The mean absolute speed deviation of vehicles, as noted by Sanderson and Cameron (1982), is a measure of accident involvement. Expressed as the standard deviation of spot speeds, as measured in the experiments, this is 11 km/h for the surrounding traffic and about 4 km/h for the test car under advisory speeds. Using the data collated by Sanderson and Cameron (1982), the involvement rate per million vehicle miles (1.6×10^6 km) falls from 1.5 to about 0.7, a reduction of 50%, when the difference in speed deviation falls from 15 km/h to 4 km/h. These figures are without slow speed turning vehicles in the data. The addition of slow speed turning vehicles increases markedly the absolute accident involvement rate.

Simulation work reported by Trayford et al. (1984a) has also shown that lane changing would be reduced 40% by the use of advisory speeds. A reduction in lane changing implies a reduction in speed deviation between adjacent vehicles, i.e. those vehicles physically placed to be in a possible collision situation. The three factors above, involving speed, are not likely to be additive but they are likely to be favourably interactive.

The reduction in stops observed (some 50%) cannot be related directly to changes in safety. In so far as a fall in the number of stops implies lower overall accelerations, it can be equated to a lower speed deviation. Solomon (1964) specifically reports on the speed deviation between vehicles prior to rear end crashes compared with the speed deviations of non-involved traffic. Rear end collisions formed the largest proportion of collisions (> 40%) below travel speeds of 80 km/h. In his data, 32% of the rear end crash vehicles had a speed difference of more than 48 km/h, compared with only 1% of the other traffic. Rear end crashes frequently occur at the rear of stopped queues upstream of intersections. With a reduction in stops for advisory speed operation, it could be expected that up to half of these incidents could be avoided.

Noise

A factor of concern to road authorities and the public is the noise generated by vehicles on urban roads. Lay (1984) quotes a sound pressure level logarithmically dependent on the speed, for road surface noise. Using this to form a comparison it is argued that a fall in the mean spot speed from 71 to 55 kmh will result in a decrease of 3 dB(A) in the peak noise level beside the roadway. However, as the standard deviation of the speed distribution is likely to decrease from 11 to 4 km/h a further fall might be expected making the overall decrease over 3 dB(A) from this source.

As well as the predicted fall in mid-link roadside noise, the noise generated around intersections, due to the 50% predicted reduction in stops, would need to be considered. The decrease in acceleration and braking, considering also larger vehicles, such as trucks, should contribute to a similar fall in the peak noise generated by the traffic near intersections.

According to Samuels (1982) the prediction of noise and the associated community annoyance in the case of interrupted flow i.e. at intersections, is so far immature and no accepted method is available. However, a reduction in measured peak sound levels may not result in a fall in community annoyance levels because of the dominant influence of successive vehicle to vehicle noise fluctuation, as used in the noise annoyance criteria. Based on simple calculations from data supplied by Rogers (1984), these levels could be expected to remain much the same, making even a 3 db(A) reduction hard to demonstrate.

Pollution

It is also difficult to ascribe a change in the amount of emitted pollutants to the use of advisory speeds. The non-linear relationship of emission with speed of the three major pollutants, carbon monoxide, hydrocarbons and oxides of nitrogen (each measured as grams per kilometre), precludes a useful overall index relationship with speed being derived. It is clear, however, that the reduction in fuel used will reduce the emitted pollutants in kind, or by around 15%.

Mole (1982) has reported the modal fuel and emission breakdown for a standard drive cycle, using a car similar to the test car (a Laser 1.5 ℓ), except that it had a manual rather than an automatic transmission. Using these figures, the ratios of emissions to fuel used were determined in the following modes: above speed limit, acceleration, constant speed and idle, for each of carbon monoxide, hydrocarbons and oxides of nitrogen. As the idle or stop time was only a small fraction of the trip time in the authors' experimental data, the overall mean emission rates per unit of fuel were used for these times. The emission to fuel ratio for the above-speed-limit condition was assumed to be the combined rate for acceleration, cruise and deceleration, as quoted. Knowing the time breakdown for the advised and non-advised condition, the emissions were calculated as shown in Table 2.

The calculated reductions of 16, 17 and 12 percent in carbon monoxide, hydrocarbons and oxides of nitrogen respectively are in line with the fuel reduction of 15%. Similar reductions in emissions might be expected from larger cars, such as the Falcon 4.1 ℓ, quoted by Mole (1982), but they may not be related directly to the fuel saving. Although larger cars have a higher fuel consumption, the allowable emissions can only be slightly greater than that of a smaller car, as both are designed to meet the same emission rates in grams per kilometre, as set by regulation.

Depending on the proportion of urban roads placed under advisory speeds these reductions in emissions could have a significant impact on total urban emissions.

Operating Costs

The cost of operating the vehicle under the proposed driving conditions needs to be considered. The rate of wear and tear on a vehicle, as measured by annual maintenance costs, will fall if the vehicle is driven under advisory speeds. The lower maximum speeds, lower rates of acceleration and halving of the number of stops can all influence the maintenance of the vehicle transmission and braking system. A medium sized passenger car completing 20,000 km annually in urban driving can be expected to experience one to two stops per

TABLE 2

Reduction in Emissions Using Advisory Speeds from Modal Analysis of Two Mean Trips

	Advised							Non-Advised							
Mode	ACC	ASL	DCS	Sl	DCC	St	TOTAL	ACC	ASL	DCS	Sl	DCC	St	TOTAL	Reduction %
Fuel ℓ	0.117	0.005	0.076	0.024	0.034	0.004	0.259	0.124	0.111	0.025	0.008	0.030	0.007	0.306	15
CO g/ℓ	163	143	133	133	148	158		163	143	133	133	148	158		
g	19.1	0.7	0.1	3.2	5.0	0.6	38.7	20.2	15.9	3.3	1.1	4.4	1.1	46.0	16
HC g/ℓ	15	13.1	10.6	10.6	19.6	14.3		15	13.1	10.6	10.6	19.6	14.3		
g	1.76	0.07	0.8	0.25	0.67	0.6	3.61	1.86	1.45	0.27	0.08	0.59	0.01	4.35	17
NO_X g/ℓ	22.8	21.3	24.2	24.2	15.2	20.5		22.8	21.3	24.2	24.2	15.2	20.5		
g	2.67	0.11	1.84	0.580	0.52	0.08	5.80	2.83	2.36	0.61	0.19	0.46	0.14	6.59	12

Trip length 3.538 km   Travel time 331 s

ACC = Acceleration, ASL = Above speed limit, DCS = Desired constant speed
Sl = Slow constant speed, DCC = Deceleration, St = Stop time.

kilometer which amounts to 20,000 to 40,000 stops per year. The standard Australian urban drive cycle AS2077 has 1.5 stops per kilometre. In the arterial road experiments reported by Trayford et al. (1984c) the stop rates for the non-advised conditions varied from 1 per km, for off-peak conditions, to 1.5 per km for the city bound flow over the 90 minute morning peak period. One American estimate of the cost of stops is quoted in the biennial report of the California Energy Commission (1983) at U.S.$32 per 1000 stops. A consideration of Australian maintenance costs by Agnew (1984) gives a lower figure of A$15 per 1000 stops. With a 50% savings in stops this yields a $150 to $300 annual saving over the assumed 5 year investment life for the vehicle for travel on roads where advisory speeds would be applied.

Lastly, driver acceptance of dynamic advisory signs will be motivated by the rewards and comfort of the driving conditions. Given the rewards of a reduction in stops and of fuel consumption the driver will also respond to a lower variability in travel time by maintaining compliance with advisory speeds. The standard deviation of travel times was 86 s for the surrounding traffic, and 63 s for the advisory condition, with the same mean travel time of 326 s. This reduction of 27% in the coefficient of variation gives the driver more predictable driving times and it seems likely that this would be desired by the driving population. By this measure, bus services could also be expected to be more reliable, with bunching of buses and therefore waiting time reduced. Unlike schemes designed solely to improve bus services, though, advisory speeds would increase the reliability of transport for both car and bus travellers.

CONCLUSIONS

Data taken each second from two multi-intersection dynamic advisory speed experiments points to several safety and environmental benefits, as well as confirming the 15% fuel and 50% stop savings reported earlier. The summary conclusions are:-

1. Test car drivers under advisory speeds spent only one-twentieth of the time above the speed limit compared with that spent by surrounding traffic in that region, but took the same mean travel time per trip.

2. The proportion of time spent at constant speeds below the speed limit was three times that of surrounding traffic.

3. The time spent stopped was 40% lower when advisory speeds were used.

4. Time spent travelling above the speed limit used over one and a half times the fuel per unit time compared to the mean fuel rate. Therefore fuel consumption can be reduced by keeping below the speed limit which in turn is facilitated by the use of advisory speeds.

5. Two measures of accident severity and involvement show reductions of 20 and 50% respectively for cars driven under advisory speeds, based on the single test car speeds recorded. Lane changing reductions of 40% reported earlier also support a reduction in accident involvement. These measures cannot be expected to be additive but they may interact favourably.

6. The reduction in maximum speeds observed would bring at least a 3 dB(A) fall in the peak roadside noise in mid-link. Near intersections a fall in peak roadside noise should occur because of the reduction in stops and accelerations. However these reductions may not result in a fall in community noise annoyance levels because of the predominant effect of the vehicle to vehicle noise fluctuations within the traffic stream.

7. The major emitted pollutants, carbon monoxide, hydrocarbons and oxides of nitrogen, are likely to be reduced in line with the reduction in fuel consumption, i.e. the 15% experienced in the experiments.

8. Maintenance costs on a medium passenger vehicle travelling 20,000 km per year on future advisory speed routes may be reduced $150 to $300 annually because of less wear and tear on the transmission and brakes, caused primarily by the 50% reduction in the number of stops.

ACKNOWLEDGEMENT

The authors wish to thank the officers of the Traffic Division of the Road Traffic Authority of Victoria for their help in running the signal modes employed and for valuable discussions.

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