URBAN ENERGY SAVING THROUGH DYNAMIC ADVISORY SPEEDS: THE PROGRESS OF A RESEARCH PROJECT

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ABSTRACT: *Dynamic advisory speeds can be an effective means of saving energy used by urban traffic. The current CSIRO project shows fuel savings of around 15% with large reductions in stops. Adding this to adaptive controls (e.g. SCATS) calls for advance signal and queue information. Driver compliance under Australian conditions is not yet known, but overseas experience is encouraging. High compliance cuts down lane changing and may bring safety benefits. Travel time reduction can be traded with fuel saving if new traffic generation is of concern. The cost should not impose an untoward burden given the short pay-back period.*

INTRODUCTION

Except for proposed fully automated guidance systems where the driver has a monitoring role, in most developed transport systems the pilot, captain or driver is an integral part of a two-way information flow necessary for the safe and efficient conduct of the operation. This is hardly the case for a driver enmeshed in a traffic signal system. Here the driver is forced to carry out the commands (stop and go signals) and plays no cooperative part in optimising its efficient running.

A German traffic engineer, von Stein, however, did develop a system of dynamic advisory speed signs in the 1950's (von Stein 1961, 1978). This is still operating in Dusseldorf and some other European cities. In these systems the driver is given a speed at which to drive, from a roadside display able to show increments of 10 km/h. These are located near the beginning of each link. With this advice a driver, over several links, can improve his performance towards achieving an objective, be it minimum stops, fuel consumption or travel time. Compliance with the signs yields tangible benefits.

Experimental verification of such a system was reported by Morrison et al. (1962). Ellson (1964) reported an unsuccessful experiment designed to increase saturation capacity, but queue lengths were not accounted for in the algorithm and little emphasis was placed on fuel consumption. Hammarstrom (1981), however, found a 10% fuel saving using two systems in different cities in Sweden.

Traffic signal systems have developed along evolutionary lines from isolated signals, through vehicle actuation and fixed time coordination, to adaptive traffic responsive systems such as the Sydney Coordinated Adaptive Traffic System (SCATS). With the advent of research and development in driver navigation devices (the Japanese PILOT and the German ALI, for instance), it seems clear that future advances must bring the driver into an information-control loop situation if the full potential of the road traffic control system is to be realised.

AUSTRALIAN BACKGROUND

The energy crisis of the mid-70's has forced the proponents of traffic management systems to appraise systems not only on their capacity and travel time benefits, but also on the basis of fuel consumption. Concurrently, the Australian traffic signal systems are being modernised. Vehicle actuated response was added to the older isolated signals and then link coordination was obtained, first with fixed time cycles, and more lately with the adaptive system SCATS, which is being introduced into major cities. This period of progressive installation will continue for at least five years.

Considering this emphasis on energy conservation, and the finding of Clark (1975) that 65% of transport fuel was used on urban arterial roads, it could be expected that the search for a more energy efficient driving cycle would be directed at the car/driver/traffic signal interface.

THE CSIRO ADVISORY SPEED PROJECT

The aim of the project is to introduce a driver advisory speed system as an addition to existing traffic control systems.

Modern traffic control systems have been developed by traffic engineers so that vehicles moving within them can be recognised and to a degree accommodated by a system response. Thus the adaptive control system was developed, which is able to handle the wide variations of flow experienced in urban arterial flow over a 24 hour period. However, it responds to the presence of vehicles in a passive way in that the system does not take direct advantage of the capacity of the vehicle driver to respond to its stimuli. It treats the vehicle as a captive element and merely registers its presence as a count within a link of the road network. Frequently drivers operate their vehicles so as to exercise their considerable acceleration potential (including their denial of the speed limit) therefore experiencing considerable variation in speed.

Without sacrificing the present degree of control, the introduction of dynamic advisory speeds allows the driver the knowledge of how best to use them to achieve a smooth flow through the network, reducing the acceleration produced speed variations presently experienced. In the light of the modern ability to communicate exact and timely information to the driver, a reduction in number of stops and in fuel consumed should be experienced which will be perceived as a positive benefit. This should constantly reinforce driver response leading to a high compliance over all drivers. This in turn should lead to less stressful and safer driving, and will consume less fuel.

Attention in the project has been directed at giving the driver up-to-date driving information to allow him to drive through a system at near the minimum fuel consumption speed (≈ 50 km/h according to Johnston et al. (1977)), remembering that the mean speed of inter-suburban travel is much less than this figure. A literature search as outlined earlier showed that prior work had not emphasised energy saving and this aspect became the prime motivation for the work.

The CSIRO project has embraced a combination of computer simulation, which enabled a larger number of cars to be simulated in a traffic system, and road experiment, which provided real data but has the limitation of using one or at the most, very few cars. For the road experiment a four cylinder, front wheel drive, automatic hatch-back was bought and equipped with fuel and distance sensors. Output from these was fed to an 8 bit, 64 k microcomputer with 2.6 Mb diskette storage. An accurate system clock allowed synchronization with the signal system and real time programs were prepared to capture the data and calculate the advisory speeds. The input data for these calculations was provided by a prepared data base, signal timing information and the output of the distance sensor, which gave the location of the car on the road to within $\pm 0.2\%$ (i.e. $\pm$ 10 m over a 5 km road section). A complete description of the hardware and software involved will be the subject of a separate paper.

SIMULATION AND ROAD EXPERIMENT

Algorithm Development

A prerequisite for both simulation and experiment is the algorithm for calculation of the advisory speeds. As discussed by Doughty et al. (1984) and Gipps et al. (1984), several options are available. Always advising the speed required to meet the start of the green phase was the starting point for algorithm development. In the work described below allowance was made for variations in strategy dependent on the time elapsed in the current signal cycle. The presence of stationary queues, the state of several intersections downstream and the mean pre-advised speed of the traffic can now also be taken into account.

Discrete Vehicle Simulation

Discrete vehicle simulations were run using program MULTSIM, described by Gipps and Wilson (1980), to test the effects of various percentages of vehicles in the traffic stream complying with advisory speeds. Details of these are discussed by Trayford et al. (1984a). A one-way idealized road with uniform link lengths of 500 m and no entering or leaving traffic was tested first. Then data from the previously outlined experiment on Military Road was used to simulate the experimental section as realistically as possible.

The idealized road results showed fuel and travel time savings due to advisory speed signs to be a function of both compliance and coordination speed, at low and high volumes. At lower coordination speeds savings vary better than linearly with compliance, while at high coordination speeds higher compliances are needed for a useful gain.

Low coordination speeds of 30 or 40 km/h yield fuel savings around 20%, with little time saving, while coordination speeds of 60 or 70 km/h reduce the fuel savings considerably, but allow travel time savings of 30 to 40%. The transition is roughly linear, showing significant fuel and time savings at intermediate coordination speeds around the minimum fuel consumption speed of 50 km/h. The number of stops was greatly reduced at compliance levels above 75%, and the amount of lane changing was virtually unchanged up to 50% compliance but dropped linearly to near zero at 100% compliance.

The two directions on Military Road were simulated separately, and the results combined on a volume weighted basis. These combined results showed fuel savings at all of the coordination speeds tested (from 30 to 70 km/h) at 100% compliance, as shown in Table 1. Signals were coordinated primarily for the "to Sydney" peak flow direction. Time savings ranged from near zero, at the low coordination speeds, to 22% at 70 km/h coordination. Stops were reduced by 40 to 70% and lane changing by 15 to 50% over the coordination speed range. Fuel consumption reductions ranged from 12% at 30 km/h coordination speed, through to 7% at 50 km/h and 5% at 70 km/h.

With no advisory speeds, a coordination speed of 50 km/h produced the lowest fuel consumption, but with adherence to advisory speeds a 60 km/h coordination speed provided additional savings in both fuel and travel time. This indicates how advisory speeds might operate in concert with an area traffic control system such as SCATS to produce greater benefits.

Table 1
Combined Effects of 100% Compliance for Both Directions on Military Road

		Percentage change			
		Fuel consumption	Travel time	Stops	Lane changes
Coordination speed (km/h)	30	-12	+6	-73	-55
	40	-9	+3	-39	-39
	50	-7	-10	-48	-48
	60	-7	-18	-42	-25
	70	-5	-22	-44	-16
	Mean	-8	-10	-53	-37

Road Experiment

To ascertain the effect of advisory signs by road experiment an instrumented car was used, with dynamic advisory speeds calculated by an on-board computer and relayed to the driver verbally at the prospective roadside sign positions. In the first designed experiments, of which details are given by Trayford et al. (1984b), the car was driven through a fixed time cycle, signallized T-intersection on an arterial road. The traffic stream allowed reasonable freedom of movement and lane changing so the one car should have given an indication of the advantage possible with advisory signs, despite the interference caused by the remainder of the unadvised traffic.

Each trip involved two passes through the intersection, from about 500 m upstream of the intersection to 100 m downstream, with one pass in each direction. For the first experiment, speed advice was given 100 m past the entry point, and the effect of the advice was determined.

The advice given can be divided into two main types; (i) calculated advisory speeds and (ii) speeds based on the speed of the surrounding traffic.

The calculated advisory speeds reduced fuel consumption by 16% over the other speeds, and the stop frequency was almost halved. These differences, shown in Table 2, were significant at the 5% level. There were significant differences between drivers in fuel consumption, but not in stop frequency or travel time. Also, the benefits of advisory speeds may be driver dependent, as one driver of the four saved almost no fuel. The road was straight on one approach to the intersection and curved on the other, giving visibility of the signals for much further on the straight (northbound) section. However, fuel consumption was higher on the northbound runs, possibly due to grade, but there was no significant effect on stop frequency or travel time. A speed range of 30 to 80 km/h was used in calculating the advisory speeds, but relatively few speeds above 60 km/h were called for.

A second experiment tested the effect of setting different preferred speeds, or "bias speeds", into the speed calculation algorithm and of giving a new advisory speed to the driver 200 m after the first speed was given.

Table 2
Speed Advice Results

Advice	Fuel (ℓ/100km)	Stops (/pass)	Speed (km/h)
Advisory speeds	7.9	0.27	40.5
Surrounding traffic speeds	9.4	0.52	40.6
(Standard error of differences)	(0.45)	(0.12)	(2.9)

In this second experiment, fuel consumption was 5% lower when advice was given at two points along the road, rather than one, and 8% lower when the bias speed was set at 50 km/h rather than 60 km/h. Such savings would be worthwhile, but neither result was statistically significant and further investigation is required. The experiments also indicated that drivers adhered most closely to the advised speeds when the speeds were near 60 km/h.

Two multiple link experiments have recently been completed which cover 6 intersections one way and 7 the other. These experiments have further tested the factors explored in the first two experiments.

Network Simulation

The traffic network simulation program TRANSYT 8, described by Vincent et al. (1980), was modified by van Leersum (1984) to incorporate an advisory speed model, enabling simulation of a typical urban road network. The network was that of the TRANSYT User Manual example, but with successive downstream signal timings (offsets) optimized on the basis of fuel consumption alone.

With the same offsets used for 0 and 100% compliance, the fuel consumption was reduced by 19% when all drivers complied. With optimized offsets used at each compliance level, the fuel saving with 100% compliance was 13%, stops were reduced by 38% and travel time by 7%.

The above experimental and simulation results are summarized in Table 3.

Table 3
Summary of Dynamic Advisory Speed Benefits at 100% Compliance

	Overall Savings (percent)	
	Fuel Consumption	Stops
Discrete simulation - Military Road	8	53
Network simulation - TRANSYT example	13	38
Road Experiment - 1/2 km, equal phase split	16	49

FUTURE TRAFFIC SYSTEM REQUIREMENT

For further improvement in the performance of traffic signal systems, better organization of the traffic is required. The compacting of platoons, made feasible by advisory speed signs, would allow coordinated adaptive signal systems to reach a stable condition most suitable for the smooth passage of the compacted platoons. This would be of particular benefit in the commonly found irregular grid networks where the difficulties of cross-coordination are compounded by platoon dispersion. Implementation of advisory signs in such systems calls for advance knowledge of cycle and offset times, at least on a probablistic basis with high certainty. It also requires a speed calculation algorithm which takes account of queues, the "storage" requirement of some intersections, information on the state of several intersections downstream and of saturation conditions.

COSTS

The additional cost of displaying roadside advisory speeds will be a minor fraction of the cost of the existing system. Based on some 5000 traffic signals Australian wide the capital cost would be, say $25,000 per intersection (an extra 50%), totalling $125 million. This is well balanced by a total saving of over $200 million per year, based on a 10% saving of the fuel consumed on urban arterials. This quantity of fuel is assumed to be about half the 15 Gigalitres of petrol sold annually in Australia each year in the period 1980-83 (A.B.S. statistics). The payback period of less than one year would be exceptional in transport projects.

DISCUSSION

Driver Behaviour

Specific driver behaviour experiments to test short and long term driver performance with advisory speeds are yet to be done, although some pointers have emerged from the road experiments so far. Some work, however, has been reported. The implication from Morrison et al. (1962) is that 75% of drivers cooperated with the system, and experience in Dusseldorf shows the compliance there is also quite high.

In a multi-link experiment recently completed by the authors, and to be reported elsewhere, it was observed that drivers carried over the fuel saving habits learned in the advisory speed runs to the free choice runs when the advisory runs were not spaced amongst runs using random spot speed advice. There was quite a contrast from these free choice runs and those where, in a later experiment, drivers were forced to keep with surrounding traffic.

It is argued that behavioural change by means of persuasion is not required for the utilization of an advisory speed system. What is required is action on the driver's behalf pursuant to receiving accurate advisory speed information. If as a result of this information the motorist finds that his driving task immediately becomes easier (his perception), through a reduction in stops, this will give immediate reinforcement for him to continue to take the information given and to use it.

A discussion of behaviour is properly the field of a psychologist and it is hoped that the project will contract research in these areas. Driving and traffic behaviour is in general, of course, not devoid of beneficial behaviour changes, albeit mainly long term. Examples are seen in the wearing of seat belts and attitudes to drink driving. It will be true that a minority of drivers will not comply to advisory speed signs. The results so far indicate that their influence will only be in proportion. In low volume flows the freedom to overtake allowed by the overall density will not affect complying drivers. In high volume flows opportunity to overtake will be severely restricted (just as it is in existing high volume flows) and not only will the complying driver be unaffected, but the minority of faster drivers who do not wish to comply will be forced into involuntary compliance, given the environment of the more densely packed platoon (non-dispersive but not lower headway). Non-complying platoon leaders will have the negative reinforcement of more frequent stops.

Side friction, which is treated in MULTSIM, and which could include trams, will inevitably degrade any system. An advisory speed system does better than current systems by giving advance information to the driver, such that corrections can be made so the driver can navigate with a much better expectation of arriving and passing through the green phase. To emphasize; at any absolute level of congestion an improvement will result with advisory speeds. Advanced features with queue accounting and look ahead algorithms will enhance this.

The propensity of drivers to trade off stops for travel time is also a behavioural area. This can be addressed by experiment, both for reductions and increases in travel time for a typical journey. As a starting point, the conduct of a thought experiment can reveal clear numerical limits on the drivers' behaviour upon which the performance of the advisory speed system can be overlaid. Once a quantitative basis can be defined for these limits this immediately yields an estimate of the increment in stop rate (a measure of the encouragement or discouragement) for operating at particular trade-offs for travel time reductions and increases. Thus the system gives the traffic authority a means of taking decisions on the balance between stops and travel time.

Safety Aspects

The reduction in lane changing, to be expected, and confirmed by the MULTSIM simulations, and accompanying reduction in the speed differential between adjacent vehicles, should lead to a lower incidence of accidents.

Overseas experience

The value of overseas experience has to be recognised. Substantial credit must be given to a system which has been maintained for a decade (cities in Sweden and the Netherlands) and for 25 years (as in Dusseldorf). The data on fuel consumption is however, scarce, with only Hammarstrom (1981) providing recent evidence (a 10% saving). At present, data for the area wide experiment needed could only be provided from a city in Europe such as Dusseldorf.

Planning options

Many traffic management schemes aim to increase capacity and it has been commonly argued that when successful these will cause traffic generation because of the decrease in travel time. Dynamic advisory speeds, although not increasing the capacity at saturation, could reduce travel times at smaller levels of flow. But lower travel times need not be offered. An alternative is lower fuel consumption and a lower number of stops. If a traffic authority makes a conscious decision to use the scheme to lower travel time, then traffic generation may indeed result given the appropriate economic and social conditions. However, if this trade-off is not made and similar travel times are allowed, with resulting lower fuel and stops, then the resulting traffic generation should be negligible. That is, the scheme has similar types of benefits and trade-offs for a traffic control authority as do other traffic management schemes.

Financial considerations

The cost of the system, as with all public systems, should be viewed as the weighing of a government sector cost against a private sector gain. In this instance, the benefit of the private gain (lower fuel costs) versus the public cost, was stated earlier to give a payback period of less than one year. A staged introduction of the system would allow its merits to be demonstrated in competition with other public projects across the socio-economic spectrum.

CONCLUSIONS

1. The CSIRO dynamic advisory speed project has demonstrated the potential for a specific energy saving in urban traffic in Australia.

2. The work on the development of algorithms for advisory speed calculation has accounted for safe approaches to stoplines or the rear of queues, and for realizing the minimum energy requirement when traversing multi-link road sections, including cases where the platoon is split.

3. The discrete vehicle simulation model MULTSIM and the network model TRANSYT have both been modified to include advisory speeds. MULTSIM has yielded results on idealized and realistic arterial roads and TRANSYT has given results on the network of the standard user example.

4. An instrumented microcomputer equipped car has demonstrated, through a set of 4 experiments (2 single intersection and 2 multi-link) using 14 drivers covering some 2000 km in total, fuel savings of up to 16% and reductions of as much as 50% in stops. The results are driver dependent and have led to further behavioural experiment.

5. The results of the experimental and the simulation work are self-consistent and show fuel savings of 8 to 16% and stop reductions of 40 to 50%. Travel time is shown to reduce when the trade-off of less fuel saving is made.

6. Behavioural questions are of concern to potential users and this area needs further investigation, using the specialized knowledge available through contract research. The wider question of system requirements and costs will continue to receive attention.

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INVESTMENT IN LOCAL GOVERNMENT ROADS IN TASMANIA
A PUBLIC CHOICE MODEL

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ABSTRACT: *The object of this paper is to develop a public choice model that will explain Local Government road expenditure. The model, which will be developed in this paper, treats Local Government roads as public goods and views public choice as the outcome of majority voting at the municipal ballot box.*

The effect of intergovernmental grants and the difficulty of measuring the output of roads necessitates considerable modification of the traditional voting model found in the public finance literature.

At this stage no estimations have been undertaken. However, it is hoped that the model will explain annual road expenditures rather than the overall size of the road network and develop estimates of the price elasticity of roads.

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