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THE ENVIRONMENTAL IMPACT OF BUS PRIORITY SIGNALS

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ABSTRACT: The changing nature of urban transport planning brought about by environmental, social and financial constraints has resulted in the emergence of Transport System Management (TSM) as an accepted planning philosophy. Of the many techniques which may be regarded as TSM schemes, one, the priority treatment of certain classes of vehicle, has received particular attention. This paper will concentrate on one type of priority scheme - active bus priority signals - and will examine the energy and air pollution impacts of such a scheme. On the basis of the results of a demonstration project in Melbourne, it will be shown that, contrary to previous speculation, such a priority scheme does not have immediate environmental advantages. The implications of this finding will then be discussed in the light of overall evaluation of the scheme, mode choice impacts of the scheme and the extension of the priority scheme to encompass a route of bus priority intersections.

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BUS PRIORITY SIGNALS

INTRODUCTION

In recent years, a number of inter-related factors have combined forces to change the direction and emphasis of transport planning. The days of seemingly unlimited expansion of the transport system to provide ever-increasing mobility have gone. In its place are the tasks of maintenance and management of the existing transport system to provide more efficient and equitable accessibility at a more reasonable social and resource cost.

The factors which have brought about this change are basically fourfold. The most important of these factors is the economic recession which affected most Western countries in the first half of this decade. Spiralling inflation rates and increasing unemployment were, and still are, the dominant domestic concerns of many governments. In an effort to curtail inflation, a common reaction from many governments has been to attempt to curtail government spending. Since most transport infrastructure is provided with government money, this curtailment has had an immediate and dramatic effect on transport construction projects. Even if, for other reasons, large scale construction of transport facilities were seen to be desirable, there is simply not the money available to pursue that ambition.

However, another factor exists which augurs against the consideration of large scale transport construction. This is the emergence of citizen participation as a viable and necessary planning technique. For many and varied reasons, there has been increased opposition to the plans devised by transport planners. The basic criticism of these plans is that they have been out of scale. Whilst taking an adequate global view of transport problems, the plans have failed to grapple with the effects of proposals on individuals; they have failed to meet the real needs of people as those needs are perceived by the people themselves. Thus even if money were available for large-scale construction, there is no certainty at all that the population in question would accept such construction.

While the above two factors have been the major pragmatic reasons for the change in direction of transport planning, two other factors have initiated a general rethinking of transport needs and goals. The first of these factors is the increased awareness of the magnitude of private transport modes as a consumer of liquid fossil fuels. This awareness has been heightened by energy crises of varying magnitude over the past six years. As a result, many governments, and individuals, are now seeking less energy-intensive means of transport for daily needs. This reduction in energy-intensiveness of daily travel may be brought about in three main ways (Hirst, 1974):

(i) Improvements in Vehicle Design
  - type of vehicle, motive power, weight of vehicle, etc.

(ii) Change in Vehicle Use Characteristics
  - number of trips, trip length, vehicle occupancy, personal driving habits, etc.

(iii) Improvements in Traffic Conditions
  - cruise speed, road surface, grade, idle time, magnitude and frequency of speed changes.

Changes are taking place in all three areas by vehicle designers, vehicle users and traffic authorities.

The final factor affecting transport planning is the role of transport vehicles as mobile pollution sources. Private transport vehicles play a significant part in the emission of carbon monoxide, hydrocarbons and various nitrogen oxides. As with energy consumption, the amount of air pollution emissions may be reduced by focussing attention on either vehicle design, vehicle use characteristics or traffic conditions.

For the above reasons, and possibly others, a reversal in transport planning directions has taken place. One important consequence has been the emergence of Transportation System Management (TSM) as a planning philosophy in its own right. As described by Patricelli (1977), TSM is "pre-eminently a process for planning and operating" whose key objective is the conservation "of fiscal resources, of energy, of environmental quality, and of the urban quality of life".

Whilst TSM has been defined to include a large number of project types, one category of particular interest is the use of traffic management techniques to give priority to high occupancy vehicles (HOV).

This paper will concentrate on one of these priority techniques (namely, active bus priority signals), and will examine the effect of this priority system on the amount of energy consumed and air pollutants emitted at the intersection in question. The implications of these findings will then be discussed in the light of a route of bus priority intersections and the possibility of mode switching to bus. It should be noted that the work reported in this paper constitutes only part of the full evaluation of active bus priority signals. Other aspects of the evaluation may be found in Richardson and Ogden (1978; 1979), Richardson (1978a), and Richardson *et al.* (1978).

THE DEMONSTRATION PROJECT

The basis of the results reported in this paper emanate from a bus priority demonstration project commenced in late 1977 in Melbourne. In November of that year, the Road Safety and Traffic Authority (RoSTA), in conjunction with the Melbourne Metropolitan Tramways Board (MMTB), installed the first active bus priority signals in Victoria at the intersection of Bell Street and Oriel Road in Heidelberg.

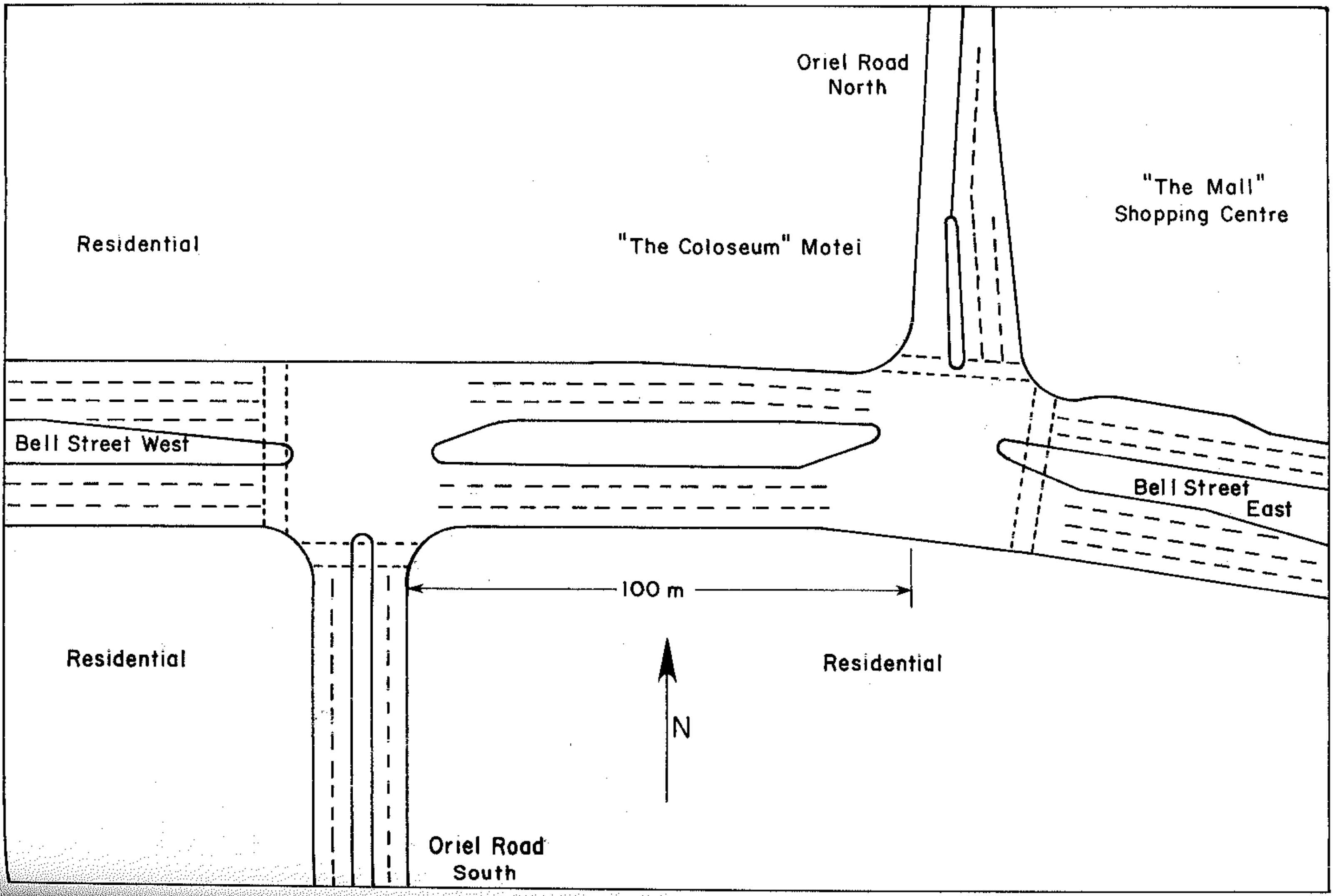
The intersection is located approximately 11 km. north-east of the Melbourne CBD in a predominantly residential area. Bell Street is an important east-west circumferential route linking residential and industrial areas and is the most important non-radial arterial route in this part of Melbourne. Oriel Road is a comparatively minor north-south subarterial route, so far as general traffic is concerned, but it happens to carry a quite substantial flow of buses. The intersection is complicated by way of the fact that it is a staggered twin-tee configuration as shown in Figure 1.

Traffic signals were first installed and operated in the conventional mode using a Philips PSF2 microprocessor controller unit operating in "group". Following satisfactory operation of these signals in a non-priority manner for approximately two months, bus priority VETAG equipment was installed. The VETAG system comprises:

(a) a vehicle borne semi-passive transponder,

(b) a loop antenna buried in the road surface,

(c) an interrogator, connected to the loop.



[illegible] Bell Street/Oriel Road Site Details

Low power signals are constantly radiated through the loop by the interrogator. As a bus passes over a loop on either approach in Oriel Road, the transponder is activated by the interrogation signals and transmits a vehicle identification code to the interrogator via the loop detector. This code is then decoded by the decoder and, if valid, is passed to the intersection controller as a valid priority demand.

The response of the controller to a priority demand is one of extension or "skip-phase" recall. Extension of the phase is granted by allowing a set time interval after detection to enable the bus to cross the stop line. Compliance with this minimum set time interval may necessitate exceeding the maximum green time on the priority bus phase. The skip-phase recall results in the existing phase being cut short and control moving immediately to the bus priority phase, skipping others along the way. Compensation is provided to Bell Street through traffic by means of two-cycle balancing of green time allocation.

Intersection Survey

To obtain data to perform an evaluation of the priority signal operation, a field survey was performed covering two days of operation. On the first day, the signals operated in conventional non-priority fashion. On the second day, the priority signals were turned on and the survey was repeated.

A number of field surveys were conducted (see Richardson and Ogden, 1978) but for the present paper two surveys are of particular interest. The first was a survey of priority bus operations which recorded the delay incurred by priority buses as they passed through the intersection along with other characteristics such as bus occupancy, bus stop loading and unloading times and the incidence of buses being stopped by the traffic signals.

The second survey of importance was a queue length survey of all traffic passing through the intersection. This queue length survey (Richardson, 1979) was designed to enable the calculation of many intersection performance measures from relatively few input data. The survey method involves recording only four variables per cycle; the time at the start of the green period, the queue length at the start of the green, and either the time at which the last vehicle in this queue crosses the stop-line or the number of vehicles in this queue which are held over to the next cycle.

From the above measurements in each signal cycle, a number of performance measures could be estimated. Specifically, one could derive estimates of vehicular approach delay and variability of delay, pedestrian delay and variability of delay, vehicular flow rate, a complete record of signal phasing and timing, the number of effective vehicular stops and the total vehicular stopped delay.

ENERGY CONSUMPTION

Whilst any of the above performance measures can be used to evaluate the operation of the priority intersection, this paper is primarily concerned with the environmental impact of the signals. In particular it is concerned with the excess energy consumed at the intersection and the air pollutants emitted. Increasingly, these two factors are becoming of greater concern in the design and evaluation of traffic management devices.

As mentioned earlier, energy and pollution can be affected by three aspects of the transport system; vehicle design, vehicle use and traffic conditions. The first two categories will not be appreciably affected by changes in traffic signal design. However, in the third category, the design of an isolated set of signals may have a significant impact on the amount of idle time and the number of speed changes (accelerations and decelerations). These are reflected in the number of effective vehicular stops and the total stopped vehicular delay measured in the survey method.

Recognizing the effect of these two parameters, Courage and Parapar (1975) have proposed an expression for the incremental energy used by a traffic stream in negotiating a signalized intersection such that:

$$E = \alpha D + \beta S \qquad (1)$$

where

E = incremental fuel (energy) consumed due to the signal timing plan

D = stopped delay in vehicle-hours

S = number of stops for all vehicles

α = conversion coefficient in litres per vehicle hour of delay

β = conversion coefficient in litres per vehicle stop.

Others (Evans, Herman and Lam, 1976; Cohen and Euler, 1978) have since questioned the need for including the "number of stops" term in the equation and suggest that, because of the correlation between delay and number of stops, it is only necessary to express fuel consumption as a function of delay (or average travel time per unit distance). However, their recommendations would appear to be more related to area wide measures of fuel consumption rather than a specific intersection, where the definition of travel time per unit distance is open to considerable debate. Also because of the possibility of non-correlation or, at least, change in correlation between the with and without priority situation, the original two-term equation proposed by Courage and Parapar (1975) will be used in this study.

In this equation, the number of stops is defined to be the number of complete stops from an initial cruising speed to rest. However, at an actual intersection many vehicles slow down without coming to a complete stop. To account for these incomplete stops, and the energy consumption associated with them, an adjustment is made in the survey analysis procedure (see Richardson, 1979) such that an effective number of complete stops is calculated which allows for the number of partial stops.

The coefficients α and β to be used in the energy consumption equation depend primarily on the composition of the traffic and the approach speeds. It is difficult to find Australian data, or indeed other relevant data, to provide values for these coefficients. Courage and Parapar (1975), and Bauer (1975), in the absence of specific data bases, use the results of Claffey (1971). As a representative condition, they use Claffey's "composite vehicle" (or average vehicle in the traffic stream) with an approach speed of 30 mph (49 kph). Under these conditions, the values of α and β are 0.60 US gallons per vehicle hour and 0.010 US gallons per vehicle stop respectively (2.28 litres/vehicle hour and 0.038 litres per vehicle stop).

The translation of these values for 1971 American cars into values for 1979 Australian cars is not simple. Complicating factors include the weight of the vehicle, the fuel consumption characteristics and the type of transmission system. It would be expected that, on the basis of all of these factors, the appropriate values for 1979 Australian conditions would be substantially lower. Just how much lower is difficult to determine. It should be noted, however, that the important feature of these values is not their absolute values but their relative values. The ratio of the values gives the equivalency between delay and stops when designing or evaluating signal systems for minimum fuel consumption. Using Claffey's values for the "composite" vehicle, it can be seen that one vehicle stop is the equivalent of one minute of vehicular delay. Thus the minimization of stops would appear more important than the minimization of idle time if fuel conservation is the primary design objective.

Another interesting implication results from a consideration of the coefficients α and β for a bus (or medium weight truck, which is the most similar vehicle reported on by Claffey). Claffey gives values of $\alpha = 0.65$ US gallons (2.47 litres) per hour of vehicle delay and $\beta = 0.020$ US gallons (0.075 litres) per vehicle stop. This results in an equivalency of one bus stop being equal to 1.85 minutes of bus delay, and more importantly, one bus stop being worth only two "composite vehicle" stops. Thus whereas in bus priority evaluations using passenger travel time a bus carrying 40 passengers is worth approximately 30 cars carrying 1.3 people each, a 40 passenger bus is worth only two cars in terms of energy consumption due to vehicle stops. Thus stopping cars to allow free passage to buses may be more difficult to justify in terms of energy consumption than it is in terms of passenger delay. This is in direct contradiction to the suggestions made by Moore (1978) who implies that, while active bus priority cannot be justified in terms of travel time savings, it can be justified in terms of energy reductions.

Given these general thoughts on signal operation and fuel consumption, what, then, is the impact of the bus priority signal demonstration project on total intersection fuel consumption? The total change in fuel consumption can be estimated by using the above mentioned equivalencies. That is, one car stop is equivalent to 60 seconds of car delay, one bus stop is equal to 110 seconds of bus delay and one bus stop is equal to two car stops. Using results from the Bell Street intersection surveys (reported fully in Richardson and Ogden, 1978) and using the above equivalencies, the changes in fuel consumption, as reflected in equivalent vehicle stops, at the intersection are shown in Table 1. The vehicle movement numbers used in Table 1 are shown in Figure 2. Northbound buses (both Melbourne Metropolitan Tramways Board (MMTB) and Ivanhoe Bus

Company (IVAN)) follow the same path as movement 6, whilst southbound buses follow the same path as movement 3.

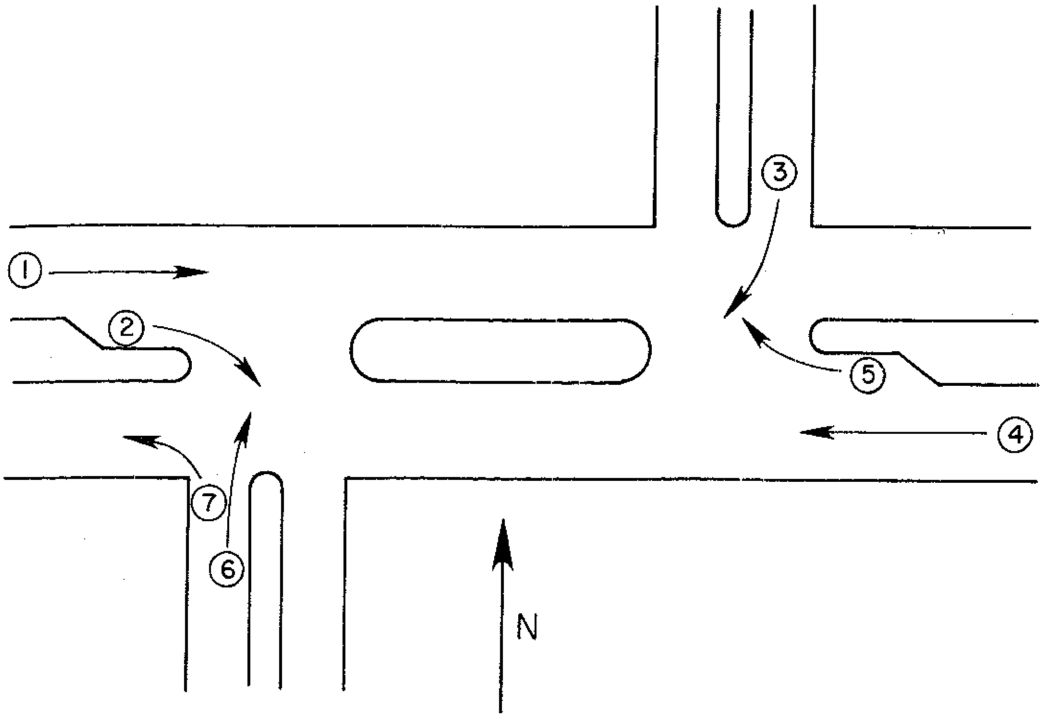


Fig. 2 Vehicle Movement Numbers

	VEHICLE GROUP							BUS GROUP				TOTAL CHANGE IN EQUIV. STOPS
	1	2	3	4	5	6	7	NB MMTB	SB MMTB	NB IVAN	SB IVAN	
7.15 → 8.15												
Δ Veh. Stops	+99	-12	-79	+429	-4	-3	0	+1	-6	+1	-4	
Δ Veh. Delay (secs)	+1790	-886	-3715	+17279	+496	-11	-281	-285	-700	+53	-266	
Δ Equiv. Stops	+129	-27	-141	+717	+4	-3	-5	-4	-24	+2	-12	+636
8.17 → 9.15												
Δ Veh. Stops	+56	-1	-44	0	-6	-22	+37	0	0	-1	0	
Δ Veh. Delay (secs.)	+1824	+983	-3308	-4310	-461	-1645	+1362	-108	-148	-30	-47	
Δ Equiv. Stops	+86	+15	-99	-72	-14	-49	+60	-2	-3	-2	-1	-81
11.00 → 1.200												
Δ Veh. Stops	+75	+2	-1	+43	-12	-4	-4	0	-1	-1	-1	
Δ Veh. Delay (secs)	+3465	+1078	-255	-3531	+689	-408	+266	-89	-177	-56	-25	
Δ Equiv. Stops	+133	+20	-5	-16	-1	-11	0	-2	-5	-3	-2	+108
1.30 → 2.30												
Δ Veh. Stops	+117	-6	+10	+57	+9	+6	+6	-2	0	+1	-1	
Δ Veh. Delay (secs)	+5490	-217	+278	+1862	+484	+888	+182	-243	-88	+26	-25	
Δ Equiv. Stops	+209	-10	+15	+88	+17	+21	+9	-8	-2	+2	-2	+339
3.35 → 4.45												
Δ Veh. Stops	-32	+5	-10	+38	+4	-84	+15	-3	+1	-3	+3	
Δ Veh. Delay (secs)	-1664	+2191	+1262	+1471	+986	-4553	+1389	-294	-153	-282	+112	
Δ Equiv. Stops	-60	+42	+11	+63	+20	-160	+38	-12	-1	-12	+8	-63
4.45 → 5.45												
Δ Veh. Stops	+301	+26	-14	+44	+6	+152	+35	-5	+5	-2	+3	
Δ Veh. Delay (secs)	+19466	+3735	+285	+690	+1531	+8173	+1965	-613	+15	-92	-21	
Δ Equiv. Stops	+625	+86	-9	+55	+32	+288	+68	-21	+10	-6	+6	+1134

Table 1 Summary of Changes in Energy Consumption (as measured by equivalent stops).

From Table 1 it can be seen that in four of the six time periods there was an overall increase in the total number of equivalent vehicle stops (i.e. all bus and car delay and stops converted to car stops). These increases are in the range of 100 to 1000 vehicle stops per hour (approximately). Using Claffey's β value of 0.010 US gallons (0.037 litres) per car stop, these increases are of the order of 3.7 to 37 litres per hour. Thus it appears that there has been a significant increase in fuel consumption as a result of the introduction of active bus priority signals at this intersection.

However, the above result should not be taken as a general finding for a number of reasons. Firstly, the complicated nature of the intersection at Bell Street/Oriel Road made the introduction of bus priority at that site rather difficult. For example, each time a bus priority phase was called up it was necessary to allow 8 seconds clearance time after the Bell Street lights had turned red to enable all vehicles to clear the central portion of the staggered intersection. This extra lost time has a deleterious effect on intersection performance, especially during congested conditions. A more straightforward four leg intersection would not have this problem.

Secondly, and more importantly, this particular intersection may be atypical in that the bus flow was on the minor leg of the intersection. Thus, the major flow had to be halted every time a bus priority phase was granted. A more common situation would be for the bus flow to be on the major leg of the intersection. In this situation, priority bus phases would not have as severe a disruptive effect on other traffic (buses would not receive such substantial benefits in this case either).

Thus the results obtained at the Bell Street site do not necessarily apply to other sites. A range of intersection geometry, control and traffic flow types needs to be studied before general findings can be reported. This work is continuing using a simulation model of an active bus priority signal intersection.

AIR POLLUTION

Transport vehicles are a major mobile source of air pollution. U.S. estimates show transport to be the source of approximately 40% of all emissions (by mass). Of the transport air emissions, the largest components are carbon monoxide (75%) and various hydrocarbons (15%) (Wark and Warner, 1976).

Whilst many transport air pollution studies have considered the overall network distribution of mobile pollutant sources, increasing attention is now being paid to the localized, microscale problems of road traffic pollution "hot-spots". These hot-spots generally occur near locations where traffic congestion, slow speeds and driving mode changes cause high emission densities. One such location is in the immediate vicinity of signalized intersections.

In a series of articles, Patterson (1975;1976) considered the effects of a number of intersection control strategies on the emission of pollutants by vehicles negotiating that intersection. Basically he found that strategies which satisfied other criteria (e.g. the minimization of vehicular delay) did not necessarily minimize the emission of pollutants. The model which he used to estimate excess pollutant emissions is very similar to form to that used by Courage and Parapar (1975) to estimate excess energy consumption. It is:

$$P = \rho D + \mu S \qquad (2)$$

where P = excess grams of carbon monoxide emissions as a result of the signal timing plan;

D = stopped delay in seconds;

S = number of vehicular stops;

ρ = conversion coefficient in grams of CO per second of stopped delay;

μ = conversion coefficient in grams of CO per vehicular stop.

For an approach speed of 30 m.p.h. (49 k.p.h.) the values of ρ and μ given by Patterson (1975) are 0.234 gm/sec and 6.406 gm/stop. As with the fuel consumption figures of Claffey (1971), care should be taken in directly transferring these figures, which are from a 1974 U.S. nationwide average mix of vehicles, to the 1979 Australian situation. Obviously, factors such as vehicle type, motive power, type and efficiency of emission control devices will all influence the actual coefficients in operation in Australia.

However, once again, from the point of view of this study the important feature of these coefficients is not their absolute value but their relative value, or ratio. Using the values given above, one vehicular stop is equivalent to approximately 27 seconds of stopped time with respect to the emission of carbon monoxide. Unfortunately, Patterson does not give emission factors for different vehicle types (e.g. buses). As a result, it is necessary to use the same equivalency for all types of vehicle.

Given this equivalency, it is possible to analyse the intersection survey data in much the same way as was done for energy consumption. The results of this analysis are shown in Table 2. It should be noted that this analysis gives the total amount of emissions (or more specifically, carbon monoxide) due to priority signalization of the intersection. It makes no assumption about the temporal or spatial build-up or diffusion of the pollutant. If more detailed information is required, then a more complex evaluation of the type report by Patterson (1976) must be performed.

The results shown in Table 2 indicate that the priority signals have, in four of the six time periods, resulted in an increase in the total amount of carbon monoxide emitted by vehicles negotiating the intersection. The increase, in terms of equivalent vehicle stops, is in the range of approximately 100 to 2000 vehicle stops per hour. Using the μ coefficient value of 6.406 gm of carbon monoxide per vehicle stop, these increases are of the order of approximately 0.6 kg to 12.0 kg of carbon monoxide per hour.

It thus appears that for the same reasons as discussed when considering energy consumption, the introduction of the priority system has, at this intersection, resulted in an increase in the level of air pollutants at the intersection. However, the same provisos as to the adequacy of the pollution modelling procedures, the adopted coefficients and the generality of the results must be borne in mind when interpreting

	VEHICLE GROUP							BUS GROUP				TOTAL CHANGE IN EQUIV. STOPS
	1	2	3	4	5	6	7	NB MMTB	SB MMTB	NB IVAN	SB IVAN	
7.15 → 8.15												
Δ Veh. Stops	+99	-12	-79	+429	-4	-3	0	+1	-6	+1	-4	
Δ Veh. Delay (secs)	+1790	-886	-3715	+17279	+496	-11	-281	-285	-700	+53	-266	
Δ Equiv. Stops	165	-45	-217	+1069	+14	-3	-10	-10	-32	+3	-14	+920
8.15 → 9.15												
Δ Veh. Stops	+56	-1	-44	0	-6	-22	+37	0	0	-1	0	
Δ Veh. Delay (secs)	+1824	+983	-3308	-4310	-461	-1645	+1362	-108	-148	-30	-47	
Δ Equiv. Stops	+124	+35	-167	-160	-23	-83	+87	-4	-5	-2	-2	-200
11.00 → 12.00												
Δ Veh. Stops	+75	+2	-1	+43	-12	-4	-4	0	-1	-1	-1	
Δ Veh. Delay (secs)	+3465	+1078	-255	-3531	+689	-408	+266	-89	-177	-56	-25	
Δ Equiv. Stops	+203	+42	-10	-88	+14	-19	+6	-3	-8	-3	-2	+132
1.30 → 2.30												
Δ Veh. Stops	+117	-6	+10	+57	+9	+6	+6	-2	0	+1	-1	
Δ Veh. Delay (secs)	+5490	-217	+278	+1862	+484	+888	+182	-243	-88	+26	-25	
Δ Equiv. Stops	+320	-14	+20	+126	+27	+39	+13	-11	-3	+2	-2	+517
3.45 → 4.45												
Δ Veh. Stops	-32	+5	-10	+38	+4	-84	+15	-3	+1	-3	+3	
Δ Veh. Delay (secs)	-1664	+2191	+1262	+1471	+986	-4553	+1389	-294	-153	-282	+112	
Δ Equiv. Stops	-94	+86	+37	+92	+41	-253	+66	-14	-5	-13	+7	-50
4.45 → 5.45												
Δ Veh. Stops	+301	+26	-14	+44	+6	+152	+35	-5	+5	-2	+3	
Δ Veh. Delay (secs)	+19466	+3735	+285	+690	+1531	+8173	+1965	-613	+15	-92	-21	
Δ Equiv. Stops	+1022	+164	-3	+70	+63	+455	+108	-28	+6	-5	+2	+1854

Table 2 Summary of Changes in Air Pollution (as measured by Equivalent Stops).

the results. As well, it is not clear just what the detrimental effects of the extra pollutants would be. It may well be that even with the extra emissions, the level of pollution at the intersection is still below a threshold level above which pollution may be considered a nuisance or danger.

PLANNING IMPLICATIONS

The results presented above, whilst being interesting in their own right, are of greater significance when viewed as part of an overall planning approach for transport system management. In particular, three aspects of this study are important in the evaluation of active bus priority signal systems.

The first aspect is the role which environmental impacts should play in the overall evaluation of a bus priority intersection. For the Bell Street/Oriel Road intersection, it has been shown (Richardson and Ogden, 1978) that the net present value of this isolated intersection treatment is between - $70,000 and - $110,000 (depending on the definition of travel time savings used in the analysis). Thus a considerable loss in resources results from the implementation of the scheme mainly in the form of increased fuel consumption. Because of the energy intensiveness of vehicular stops, a priority intersection will only be justified (in terms of fuel consumption) if a compensation method can be found which makes up for the increased number of stops caused by priority bus demands. Present compensation systems aim to equilibrate green time allocation in the hope that this will balance the additional delay caused by priority bus demands. This concept must be extended to ensure compensation for the additional number of vehicular stops caused by priority bus demands.

The second feature of considering the environmental impact of bus priority signals is the role which they play in the evaluation of an extended route of bus priority intersections. Using the definition of perceived, budgeted time savings (Richardson & Ogden, 1979; Richardson 1978a) it can be shown that the value of time savings accruing to bus passengers will increase at a greater than linear rate as they proceed through a number of bus priority intersections. However, fuel consumption increases will accrue at only a linear rate with each additional bus priority intersection. Hence, it has been shown (Richardson, 1978a) that there exists a crossover point at which bus priority intersection routes become viable even though the individual priority intersections are not themselves viable. This crossover point has been suggested to lie between seven and twenty priority intersections on a route, depending on assumptions of bus loading distribution along the route and the viability of individual intersections along the route.

The third feature of bus priority signal environmental impacts is that, while bus priority may have negative environmental impacts at an intersection, it has been suggested (Moore, 1978) that this may be more than counterbalanced by having bus priority induce a shift in mode usage from private car to public transport for an entire trip. Because of the greater overall energy efficiency of public transport, this shift would then bring about an overall decrease in energy usage.

However, for isolated bus priority intersections there is unlikely to be any induced mode shift because of three factors. Firstly, although there has been an improvement in the level of service for bus passengers and there has been a general degradation in the level of service for car drivers, this alone is not enough to induce mode shifting. Unlike a bus lane situation in which cars and buses are jostling for the same road space in a common corridor, in the case of priority intersections the competing movements are travelling in different corridors with vastly different origin and destination patterns; the buses are running North-South whilst the delayed cars are running East-West. Hence although buses have a relative improvement in the level of service, there will be no mode switching between the disadvantaged and advantaged group because of the vast differences in their origin-destination patterns.

Secondly, the traffic movement which is most likely to have a similar origin-destination pattern to the bus passengers (e.g. the Oriel Road car drivers) also have a slight increase in their level of service. This increase, however, is not as great as that obtained by the bus passengers and hence, relatively speaking, they are disadvantaged with respect to the bus passengers. Hence, on this basis, some of these car drivers might, perhaps, be expected to switch to bus travel to gain even greater benefits from the priority system. However, according to the satisficing theory of choice (Brand, 1974; March and Simon, 1958; Richardson, 1978b) a tripmaker is unlikely to consider choosing a new mode unless his present mode has been adversely affected or he has had a drastic change in his trip pattern. On the basis of the first criterion, it can be assumed that present car drivers on the bus route will continue to use their cars, since not only has their mode not been adversely affected, it has, in fact, most likely received a small advantage (as demonstrated at the Bell Street/Oriel Road site). The second criterion, however, holds some hope for long-term increases in bus patronage. If the level of service offered by bus can be improved, such that it offers a viable alternative to the private car for the trips it serves, then in the long run when new tripmakers along this route choose their mode of travel, they may in fact choose the bus more often than is presently the case.

The third factor supporting the argument of zero short-term mode switching is the fact that the changes in the level of service offered by a single intersection improvement are very small, especially when compared with the total length of the trip. At best, it is offering a 30-second improvement on a trip lasting probably 30 minutes. According to the theory of small time savings (Hensher, 1976; Richardson, 1978c) such a small improvement would, most likely, go unnoticed and hence not affect mode choice. However, as mentioned earlier a route of bus priority intersections may have sufficient impact to be noticed and hence affect mode choice.

CONCLUSION

The granting of priority to buses at signalized intersections is one way of increasing the person-carrying capacity of urban road networks. However, whilst it can be shown that person travel time improvements can be effected by such priority schemes, the environmental impacts of such schemes have been less well defined.

It has been shown on the basis of a demonstration project survey of operating conditions, that the granting of priority to buses at signalized intersections can result in substantial increases in energy consumption and air pollution emissions at the intersection. However, because of possibly atypical conditions at the demonstration project site it is unclear just how well these conclusions apply to other possible priority intersection sites. It is recommended that further research be continued to evaluate the environmental impacts of bus priority signals at other sites, both by means of field surveys and computer simulation.

It is also recommended that attention be paid to the measurement of fuel consumption coefficients under Australian conditions, to the investigation of the worth of bus priority signal routes and to the effect of long and short-term demand changes on total energy consumption.

Only with this knowledge can a balanced assessment of bus priority signals be made with regard to both traffic operating conditions and environmental impacts.

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