Prediction of Effects of Bus-Priority Schemes by Using Computer Simulation Techniques

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This paper describes a computer program that predicts the effect of bus-priority measures applied to an urban highway network. The program predicts the travel times of buses and other vehicles along a highway network that has different types of intersection controls, with or without bus-priority schemes in operation. The paper describes how the program will allow transportation planners to assess the likely effects of proposed priority measures from a comparison of travel times through a complex highway system by use of a model that computes the journey times of buses and other vehicles over a network that is composed of highway links that have priority, roundabout, or signal control at the intersections. The model follows the progress of each bus along a given route as it repeats the cycle from one bus stop to the next for various traffic conditions. Details of the master computer program and the associated subroutines are given together with details of validation studies carried out on the outer ring road of the city of Bradford. To demonstrate the practical use of the program, details are given of the effect of bus-priority schemes on average delay, queue lengths, and bus travel times for the following highway and traffic situations: (a) priority intersections where the nearside lane of the minor road is allocated to buses for different traffic flow conditions and different lengths of priority lanes, (b) signalized intersections that have two or three approach lanes where the nearside lane of one approach road is allocated to buses for different traffic flow conditions and different lengths of priority lane, and (c) a 2-km length of bus route, which includes three signalized intersections and eight bus stops for differing traffic volumes and proportions of buses in the traffic flow. Details of the program output are given to demonstrate that the simulation model is flexible enough to study any particular section of a highway that may incorporate bus priority.

All developed countries have experienced growth of private automobile ownership and an increase in the amount of traveling undertaken by the individual. The result has been an increased role for the private automobile and a decreased role for public transport in fulfilling today's transportation demands. In urban areas more vehicles are using the street system, which has caused an accompanying growth in congestion, noise, fumes, and accidents. The resulting decrease in environmental standards has decreased considerably the attractiveness of towns as places of employment, recreation, and residence.

In an attempt to reverse (or at least halt) this trend, a particular effort has been made to make public transportation more convenient, more comfortable, and more reliable and so provide a level of service that is competitive with the private automobile.

A major attempt to restore the level of service of public transport in many cities has been the assignment of priority on the road system to public transport vehicles. These measures include simple traffic management (such as the introduction of a traffic-signal-priority scheme at a junction or a bus-only lane on a small part of the road network) and an extensive scheme that involves the combination of several bus-priority schemes on differing sections of the highway network.

In general, the objective has been to determine the most beneficial scheme for all users of the highway. It is therefore desirable to be able to evaluate such a priority scheme before it is implemented rather than to use the traditional method of comparing before-and-after traffic-flow characteristics.

THE COMPUTER SIMULATION MODEL

Considerable research has already been performed by a variety of research organizations on the effects of affording priority to buses at intersections controlled by traffic signals. Salter and Memom previously reported (1) research on the effectiveness of a curb-side bus-priority lane on a consideration length of a radial highway that had three traffic-signal-controlled intersections. For bus-priority measures to produce significant benefits on an urban bus route, it is frequently necessary for the priority to extend over a considerable length of the route and, with this in mind, we have developed a computer simulation model that will evaluate the effects of a variety of priority measures for the whole or part of the route. The model considers the effects of priority measures both on buses and on their passengers and also on nonbus traffic. Particular attention is given in the model to the consequence of bus priority at intersections that may be priority, rotary, or signal controlled as these are usually the critical parts of the highway network.

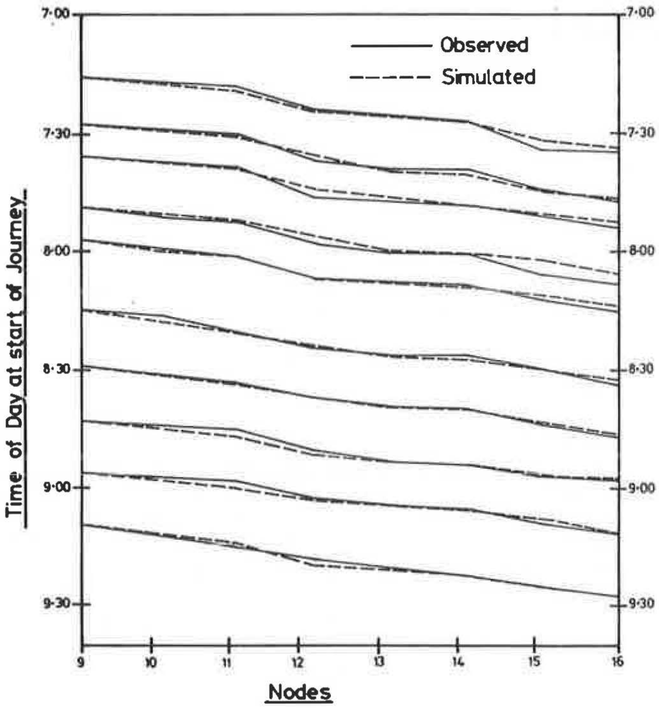
The model follows the progress of each bus in service along a particular route as it moves from stop to stop on the service route. The model incorporates the following distributions:

1. A distribution that represents the distribution over time of passenger arrivals at each bus stop;
2. A distribution of passenger-boarding times and a mechanism that regulates the number of passengers that board in accordance with available space in the bus (if passengers cannot board the first bus then they form the initial queue for the next bus); and
3. A distribution of passenger alighting times (both this distribution and the previous one are varied according to the fare collection system and bus type that are in operation).

As a bus travels along the road network, it accelerates away from a bus stop, travels at the running speed on the highway (provided it does not arrive at a junction), decelerates to the next bus stop, and then remains stationary while passengers alight and board. If passengers are not waiting, then the deceleration and waiting periods are omitted. The running speed for buses between intersections is determined from a speed-flow relation. If, however, a bus has to pass through an intersection, then the progress of the bus ceases to be determined by a speed-flow relation and instead microscopic simulation is employed.

Before the bus reaches the area of influence of the junction, simulation of nonbus vehicles commences and vehicles are generated to predetermined flows and

Figure 1. Observed and simulated time-distance diagram for buses traveling on a section of the Bradford ring road.



turning movements. This ensures that the junction is at the correct level of service as the bus passes through the junction. The program logic prints out delays and queue lengths for buses and other vehicles for each intersection. Vehicles are generated to a predetermined headway distribution at a point distant from the junction, generally the bus stop immediately prior to the junction. Each vehicle is assigned a turning movement, a speed, and an acceleration and deceleration rate. Uniform time scanning is used for this microscopic section of the simulation.

In addition to the more usual consideration of the effect of bus priority at signal-controlled intersections, this program also allows the effect of bus-priority measures at priority and roundabout intersections to be evaluated.

A considerable amount of data have to be input to define the bus route to allow considerable variation in the service routes that can be simulated. This information includes a schedule of bus stops, distance between stops, scheduled departure times, and location of junctions relative to adjacent bus stops. Each bus is given a maximum speed and a speed-flow relation appropriate to the section of the service route on which the bus is traveling together with acceleration and deceleration rates. Parameters that describe the nature of passenger arrival times, boarding and alighting times, and bus capacity are also required.

Details of the highway also have to be input. These include an activity index that describes the traffic char-

Table 1. Observed and simulated bus travel times between bus stops and bus waiting times for bus stops 43-46.

	Bus Stop Numbers											
	43-44 (234 m)				44-45 (123 m)				45-46[a,b] (307 m)			
	Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)		Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)		Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)	
Time (a.m.)	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
7:35	42.33	44.66	12.66	9.66	29.00	29.66	33.66	29.66	48.33	55.00	29.66	25.66
7:45	45.00	43.33	8.00	7.00	25.00	26.00	11.33	10.00	49.00	50.66	11.33	10.00
7:55	42.33	46.66	11.66	9.33	24.33	25.33	8.66	6.00	55.66	56.66	10.33	9.00
8:05	41.66	44.00	13.00	7.00	24.00	25.00	12.00	9.33	44.66	63.00	12.66	10.00
8:15	42.33	43.66	9.33	8.66	25.66	25.33	26.33	18.00	49.00	45.33	12.00	22.00
8:25	41.33	45.00	8.00	7.00	26.33	25.33	11.33	7.66	42.00	43.00	13.00	6.66
8:35	40.00	41.33	14.00	8.66	27.00	24.00	17.00	14.66	52.33	41.66	24.00	18.66
8:45	39.66	41.33	11.00	7.00	23.33	24.66	11.00	12.33	37.33	41.33	12.00	21.66
8:55	46.00	39.00	10.33	9.00	24.00	27.66	8.66	8.00	36.66	42.33	10.00	10.00
9:05	43.00	39.66	8.00	7.00	24.00	27.33	10.66	12.00	43.00	40.00	17.00	21.66

[a]Priority junction.
[b]Distance from the bus stop before the junction to the stop line = 258 m; distance from the stop line to the next bus stop = 49 m.

Table 2. Observed and simulated bus travel times between bus stops and bus waiting times for bus stops 46-49.

	Bus Stop Numbers											
	46-47[a,b] (297 m)				47-48 (270 m)				48-49 (258 m)			
	Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)		Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)		Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)	
Time (a.m.)	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
7:35	55.00	46.66	16.00	15.00	35.66	35.33	53.66	50.33	39.00	41.00	13.66	12.33
7:45	60.66	70.00	7.66	7.00	39.66	35.33	18.33	15.33	40.66	33.66	13.66	15.00
7:55	66.00	70.00	13.33	13.33	43.11	45.66	30.00	28.66	39.33	40.33	42.00	36.66
8:05	58.00	66.33	8.00	7.00	39.66	41.33	7.66	20.00	40.66	36.33	7.00	7.00
8:15	57.33	55.00	9.66	9.33	34.66	38.00	23.66	18.66	38.66	39.00	15.00	19.00
8:25	56.33	60.33	8.00	7.00	42.33	33.60	7.00	12.33	35.00	34.66	14.33	7.66
8:35	73.33	63.33	11.00	8.66	35.66	36.66	22.66	16.66	39.33	40.00	2.00	13.00
8:45	68.00	67.00	11.00	12.00	39.66	40.33	22.68	24.66	40.00	39.33	29.00	10.00
8:55	62.33	62.66	8.00	7.66	40.33	41.33	18.00	22.33	36.66	38.33	12.33	16.33
9:05	56.66	59.66	11.00	27.00	42.10	40.00	22.33	13.00	36.33	37.66	21.33	33.00

[a]Signalized intersection.
[b]Distance from the bus stop before the junction to the stop line = 240 m; distance from the stop line to the next bus stop = 57 m.

Table 3. Observed and simulated bus travel times between bus stops and bus waiting times for bus stops 49-53.

	Bus Stop Numbers															
	49-50[a,b] (253 m)				50-51 (310 m)				51-52 (345 m)				52-53[a,c] (314 m)			
	Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)		Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)		Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)		Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)	
Time (a.m.)	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
7:35	41.33	49.33	55.66	52.33	45.33	47.66	20.66	17.00	42.00	44.33	12.66	11.00	58.33	41.00	7.66	7.00
7:45	51.00	40.66	19.00	21.00	48.33	49.33	17.66	17.00	42.66	43.33	9.33	10.00	37.33	45.66	20.00	14.33
7:55	47.66	66.33	31.00	28.66	46.33	49.00	10.66	9.00	41.00	47.66	27.33	12.00	38.66	38.33	9.00	7.00
8:05	40.66	38.00	8.66	9.00	47.00	46.66	7.66	7.00	43.66	62.66	30.66	19.66	56.33	42.66	32.00	25.00
8:15	54.00	46.33	13.66	17.00	43.00	43.00	7.33	7.00	47.33	41.33	24.00	18.66	55.33	60.33	12.00	0.00
8:25	72.00	68.00	14.00	8.66	41.66	47.33	11.00	7.66	41.66	41.66	32.66	28.00	61.33	60.00	77.00	34.00
8:35	59.66	59.00	27.66	24.00	45.66	51.00	14.33	19.66	49.66	47.33	32.66	28.66	53.33	57.00	10.33	8.66
8:45	49.66	48.66	29.00	30.66	47.00	49.00	21.66	24.66	46.00	47.33	33.00	32.66	47.66	59.00	10.00	32.66
8:55	47.00	62.33	13.33	9.00	42.66	47.33	10.33	19.33	43.00	44.66	19.00	13.33	65.33	63.00	10.00	9.66
9:05	60.00	54.33	29.00	25.00	45.66	47.00	19.33	33.00	40.66	42.66	33.00	13.00	43.00	65.00	10.00	8.00

[a] Signalized intersection.
[b] Distance from the bus stop before the junction to the stop line = 218 m; distance from the stop line to the next bus stop = 35 m.
[c] Distance from the bus stop before the junction to the stop line = 252 m; distance from the stop line to the next bus stop = 62 m.

Table 4. Observed and simulated bus travel times, bus waiting times, and average bus speeds for a section of the route.

Time at Start of Journey (a.m.)	Total Bus Running Time (min)		Total Bus Waiting Time (min)		Total Bus Travel Time (min)		Average Speed (km/h)	
	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
7:35	7.272	7.242	4.27	3.83	11.52	11.07	14.25	14.83
7:45	7.32	7.30	2.27	2.11	9.59	9.41	17.12	17.45
7:55	7.41	8.00	3.23	2.66	10.64	10.66	15.43	15.40
8:05	7.27	7.77	2.32	2.02	9.59	9.79	17.12	16.77
8:15	7.46	7.29	2.55	2.31	10.01	9.60	16.40	17.10
8:25	7.67	7.65	3.27	2.11	10.94	9.76	15.00	16.82
8:35	7.93	7.69	2.93	2.69	10.86	10.38	15.12	15.82
8:45	7.31	7.63	3.17	3.47	10.48	11.10	15.66	14.79
8:55	7.40	7.81	2.00	2.08	9.40	9.89	17.46	16.60
9:05	7.23	7.56	3.02	3.21	10.25	10.77	16.01	14.24
Mean	4.73	7.59	2.90	2.65	10.33	10.24	15.96	15.98
SD	0.218	0.25	0.656	0.65	0.69	0.624	1.06	1.12

Figure 2. Simulated average delay to minor road vehicles at a priority junction that incorporates a bus lane.

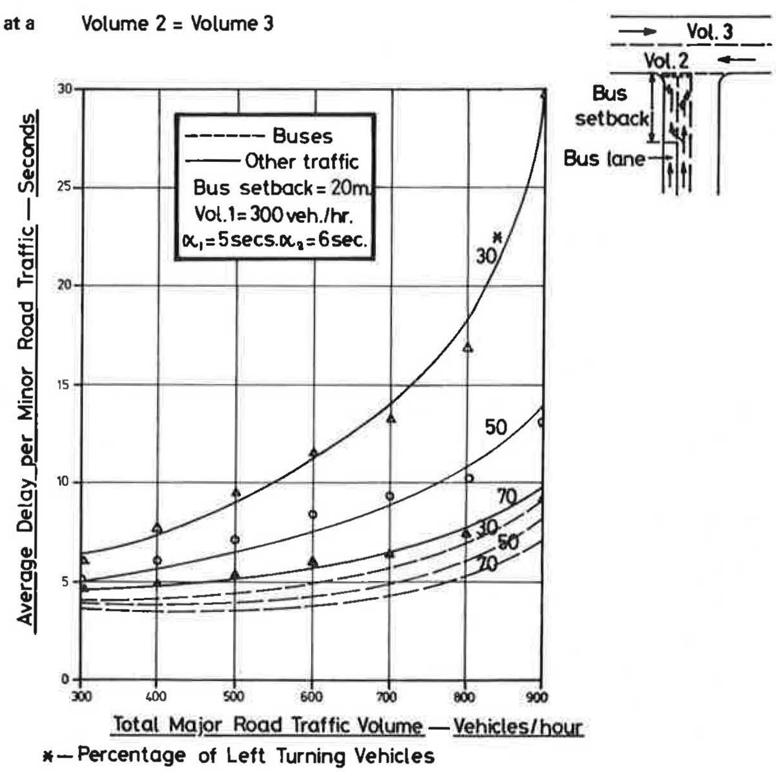


Figure 3. Schematic plan of bus route 1 between bus stop 46-53.

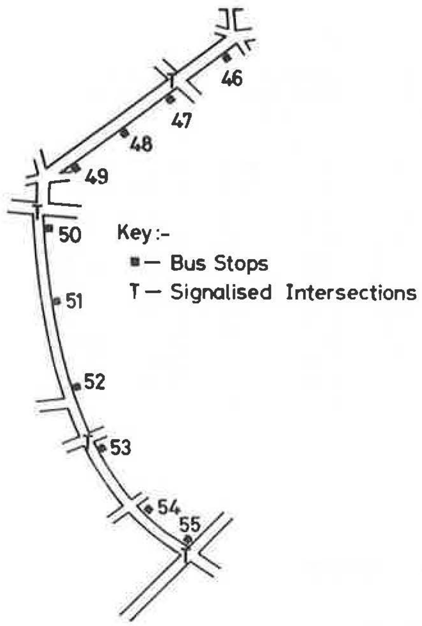
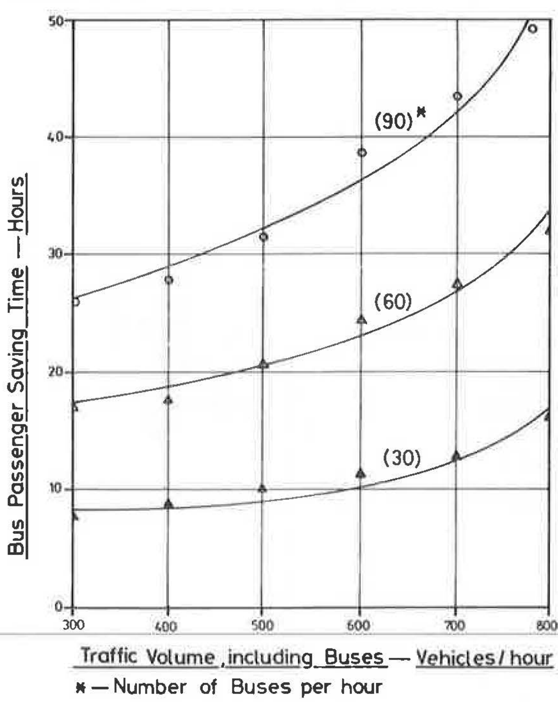
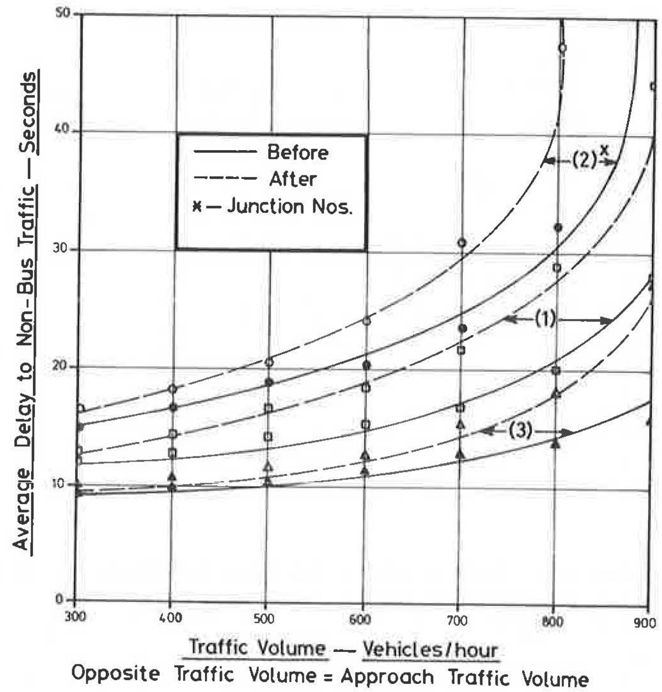


Figure 4. Time saving for passengers during 1 h of bus operation between bus stops 46 and 53, assuming 45 passengers/bus and a bus setback distance at signalized intersections of 40 m.



acteristics of the route and influences the speed-flow relationship and the traffic flows on each of the links together with maximum, mean, and minimum speed on each of the links. For each of the junctions it is necessary to define the proportions of turning vehicles and the type and size of the junction. For priority junctions, including rotary intersections, details of the gap acceptance distribution are required. For signal-controlled junctions the cycle time and the effective green times for each installation are required.

Figure 5. Average delay to nonbus traffic at signalized intersections before and after the introduction of the bus-priority scheme.



After the simulation is complete, the program outputs information relating to the performance of the simulated system. Included in the normal output of the program are

1. Bus travel time between successive bus stops,
2. The number of passengers that board and alight at each stop together with the maximum queue length that occurs at the bus stop during the simulation period,
3. Bus occupancy along each part of the service route,
4. A measure of the variation of the actual bus time schedule from the input schedule, and
5. A listing of delays and queue lengths for buses and other vehicles at intersections.

The program has been used for an investigation of the effects of hypothetical bus-priority measures on the outer ring road of the city of Bradford. This ring road forms the service route for a bus service that has a route length of 17 km. During a complete orbit of the route a bus passes through 10 signalized intersections, four priority junctions, and five roundabouts.

Data were input into the program to represent the layout of the ring road and the bus service along the route. Observations were made to determine bus running times, passenger arrival distributions at bus stops, and alighting and boarding times. The model was then run to test its ability to reproduce actual bus journey times under nonpriority conditions.

A comparison between observed and simulated bus journey times over a section of the ring road during the morning peak hour is shown in Figure 1. Good agreement can be noted between observed and simulated values in this nonpriority case.

A second comparison was made between the observed and simulated bus travel times. In this case a relatively small part of the bus route was taken into account. This part of the highway (2.74 km in length) includes three signalized intersections, one priority junction, and 11 bus stops. The first bus stop (bus stop number 43) is a timed bus stop, which makes it possible to record the exact departure time of buses from this bus stop.

Observations were carried out during morning peak periods (7:30-9:00 a.m.) to consider bus waiting times at each bus stop and bus travel times between each two successive bus stops. Three different observations were carried out for each bus departure time from the first bus stop on different weekdays. Subsequent simulation results were obtained from the model under the same conditions as were observed, and the results were compared with observed data in Tables 1-4.

This comparison shows that the observed and simulated data are quite close to each other and that the model is adequate to represent their vehicle behaviors according to the purpose of the study.

The model is able to predict the effects on all vehicles of bus-priority measures at intersections. In addition to the usual form of bus-priority measures at traffic-signal-controlled intersections, the model also has the ability to predict the effects of bus-priority measures at priority junctions. Figure 2 shows the simulated variation of average delay to buses and other vehicles at a priority junction when the priority bus lane terminated 20 m from the "give way" line. The mean gap accepted was input as 5 s for left-turning vehicles and 6 s for right-turning vehicles. Equal flows were assumed in both directions on the major road and the simulation was carried out with 30, 50, and 70 percent of left-turning vehicles (left-hand rule of the road).

A section of bus route 1 along the ring road was selected for study in order to assess the usefulness of the program in estimating the effect of a bus-only lane on bus and passenger travel times. The part of the route chosen was located between bus stops 46 and 53 (as shown in Figure 3). It had a length of approximately 2 km and included three signalized intersections and eight bus stops. A curb-side bus-priority scheme was introduced along this section of the ring road. The priority lane terminated 40 m from the signal stop lines.

Reductions in bus-passenger journey times between bus stops 46 and 53 due to the introduction of the priority scheme for the three cases of 30, 60, and 90 buses/h in each direction are shown in Figure 4. Frequently when bus-priority schemes are introduced travel time is increased for nonbus vehicles. Figure 5 shows the increase in delay at the three signalized intersections along the priority route after the introduction of the bus-priority scheme.

We believe that the model has demonstrated its ability to simulate the effects of bus-priority schemes on travel time and delay. We intend to continue the work and evaluate future priority schemes.

REFERENCE

1. R. J. Salter and A. A. Memon. Simulation of a Bus-Priority Lane. TRB, Transportation Research Record 626, 1977, pp. 29-32.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Evaluation of Active Bus-Priority Signals

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This paper describes the development and application of a methodology for the evaluation of an active bus-priority signal system. Results from a demonstration project show the impact of a bus-priority scheme on intersection delay and delay variability. Two new measures, perceived delay and budgeted delay, are introduced and are shown to have important implications in the evaluation of bus priority and other transportation system management schemes. We conclude that active bus priority is justified under a wider range of conditions than has hitherto been considered to be the case.

In recent years, a number of interrelated factors have combined forces to change the direction and emphasis of transportation planning. The days of seemingly unlimited expansion of the transportation system are gone. In its place are the tasks of maintenance and management of the existing transportation system. Although some may consider that these tasks are not as exciting as the previous growth phase, they are nevertheless equally, or perhaps more, demanding of initiative and intellectual effort.

The factors that have brought about this change are basically fourfold:

1. The increasing awareness of the magnitude of private transportation as a consumer of liquid fossil fuels,
2. The role of transport vehicles as mobile pollution sources,
3. The economic recession that affected most Western countries in the first half of this decade and has caused spiralling inflation rates and increasing unemployment to be the dominant domestic concerns of many governments, and
4. The emergence of citizen participation as a feasible and necessary planning technique.

For these reasons, and possibly others, this reversal in 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 (1), TSM is "preeminently 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".