bus operations before system service deteriorates significantly.

It is hoped that the use of the model will lead to a fulfillment of its potentials.

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Abridgment

Analytic and Simulation Studies of Factors That Influence Bus-Signal-Priority Strategies

M. YEDLIN AND E.B. LIEBERMAN

Research intended to identify conditions under which the greatest benefits to transit operations can be realized by implementing a bus-signal-priority strategy is described. Two techniques are presented for studying the problem. An analytic model was developed to compare the performance of bus systems operating with and without bus signal preemption. Studies were undertaken to examine the effects and interrelations of several factors in terms of bus operations. These factors include signal density, traffic volume, maximum signal-preemption length, passenger volume, bus headways, signal split and cycle length, station location, and exclusive right-of-way for buses. Insights from the study pertaining to each of these factors are described. In addition, the Federal Highway Administration's network flow simulation (NETSIM) model was modified to incorporate a bus-signal-preemption strategy. Simulation studies produced results that confirmed some of the insights provided by the analytical model and yielded additional insights.

The application of a bus-signal-priority strategy must be part of an overall systems approach to bus operations. Signal strategies do not operate in a vacuum but in a total environment that consists of all other factors that constitute a bus mass transit system.

Although studies have been conducted on bus signal control (1-3), it has not yet been determined which factors are most important to the success of a bus-signal-preemption strategy. The objective of this study was to identify those conditions under which the greatest benefits to transit operations can be realized by implementing a bus-signal-priority strategy.

Two techniques were used in studying this problem. An analytic model was developed to study the behavior of a bus system operating with and without bus signal preemption. Parametric studies were then undertaken with the analytic model to examine the influence of many factors on the operational performance of a bus system. Because of the extensive interrelations among the effects of various factors on bus system performance, graphical representations of the results were prepared. These were carefully examined to determine the significant consequences of the factor interrelations. The most significant combinations of factors affecting system performance could then be identified.

In addition, the network flow simulation (NETSIM) model of the Federal Highway Administration (FHWA) was modified to incorporate provisions for a conditional signal-preemption strategy. Simulation studies were undertaken both to confirm some of the insights obtained by applying the analytic model and to study the effects of additional factors that were outside the scope of the analytic model. Measures of effectiveness (MOEs) generated by the models were used to determine the impact of bus signal preemption under various conditions.

ANALYTIC STUDY

An analytic study (4) was conducted to quantify the sensitivity of various bus operating characteristics of a transit system (stops per mile, travel-time reduction, and percentage of travel-time reduction) to many of the factors that influence bus operations. These factors include signal density (intersections per mile), cycle split, bus headway, cycle length, traffic volume, bus passenger demand, maximum phase extension and truncation time, buses in exclusive right-of-way or in mixed traffic, preemption strategies of green extension only and green extension or red truncation, and station location [such as near side every block, far side every block, and near side every third block (express service)].

This study consisted of the following steps:

1. Developing analytic expressions that relate bus operating characteristics to these contributing factors,
2. Applying these expressions to specified bus environments,
3. Organizing the results in a manner that exhibits the underlying relations, and

4. Deriving conclusions by examining these results.

The set of analytic expressions constituted a macroscopic model of bus operations. Although such a model, by its nature, requires the application of simplifying assumptions, sufficient detail is retained to satisfactorily represent bus operations. Bus trajectories include acceleration and deceleration modes as well as the cruise mode. (On short links buses cannot achieve the cruise mode, and this behavior is properly represented.)

The interaction between adjoining approaches along an arterial is taken into account. Buses that are stopped at the upstream intersection of an approach, either by the signal or to service passengers at a station, experience different trajectories on the subject approach than buses that are not stopped on the upstream approach. The model also estimates the expected value of delay experienced by buses during dwell, in a queue, and as a result of a red signal phase.

As a result of parameter studies using this analytic model, the following insights can be drawn about each factor. Benefits reflect reduced transit travel time and stops. The detailed results of a study conducted over a wide range of all factors considered here are available elsewhere (4).

Vehicle Volume

The incremental benefits of bus signal preemption increase somewhat (less than 10 percent) as traffic volume increases.

Passenger Volume

Wide variations in passenger volume produce little variation in the level of bus-system-related benefits obtained by bus signal preemption, since signal preemption has no effect on dwell times.

Headways

The incremental benefits of bus signal preemption are only marginally influenced by bus frequency.

Preemption Strategy

The incremental benefits of a more aggressive signal-preemption strategy (green-phase extension or red-phase truncation) are more pronounced when buses mix with general traffic than when they have their own right-of-way. When a strategy of green extension of up to 30 s or red truncation is used for buses in mixed traffic, the level of service for buses approaches that attained by removing all signals. The more aggressive (and effective) the signal-preemption strategy, the greater the prospect of disruption to cross-street traffic (4).

Cycle Length

Bus travel time increases with signal cycle length for a given value of cycle split. The influence of signal cycle length on the benefits provided by bus signal preemption is very small.

Cycle Split

The incremental benefits of bus signal preemption on arterials where signals exhibit lower G/C ratios are greater than on arterials where the signals exhibit high G/C ratios (G = green time and C = cycle time).

Bus Right-of-Way

The incremental benefits of bus signal preemption are far greater when buses mix with general traffic than when they have an exclusive lane. When there is no exclusive bus lane, the incremental benefits of signal preemption are far greater when the bus system has near-side stations than when it has far-side stations. The provision of an exclusive lane for a bus system with far-side stations cannot be justified by an improvement in bus performance, either with or without bus signal preemption. Hence, an exclusive bus lane is more effective for systems with near-side bus stations.

Signal Density

The incremental benefits of signal preemption increase with signal density, regardless of all other factors.

Bus Stations

Bus signal preemption seems more effective for systems with near-side bus stations than for those with far-side stations; travel times for bus systems with far-side stations are about 10 percent less than those with near-side stations. The effectiveness of bus signal preemption is independent of station spacing.

In general, bus signal preemption offers improvements by reducing both travel time and the number of stops due to signal control. For example, bus signal preemption provides approximately a 1.8-min improvement in bus travel time over a distance of 1 mile for a signal density of 8 signals/mile, when the maximum extension-truncation is 15 s, stations are near side, buses mix with traffic, and traffic volume is moderate.

SIMULATION STUDIES

In order to confirm and supplement the results of the macroscopic analytic studies, several experiments were performed by applying the microscopically detailed NETSIM model. For this application, traffic operations on both the main-street and cross-street approaches were considered.

The NETSIM program was modified to incorporate a responsive bus-signal-preemption strategy. This algorithm scans all approaches to each intersection of the analysis network to determine whether buses are "within range" of the signal control so that decisions can be made concerning signal timing. This preemption strategy permits either an extension of the current phase or a truncation of the current signal phase, depending on conditions. These decisions are constrained by limitations on minimum phase duration and maximum green extension so as to replicate a realistic strategy. In addition, truncation of a phase is not permitted if the prior phase was extended and vice versa.

Three different network configurations were executed by using the modified NETSIM model:

1. Case 1--An isolated intersection where buses traverse both directions along the main street and there are no buses on the cross streets,
2. Case 2--An isolated intersection where bus traffic exists on all approaches (unlike case 1, the buses compete for the signal preemption), and
3. Case 3--An arterial section, consisting of seven streets and intersections, along which bus traffic is routed while the cross streets contain only general traffic and no bus activity.

The signal control timing was designed in each case by assigning cycle lengths and splits according to Webster's criteria (5).

Table 1. NETSIM case studies.

Case	Volume[a] (vehicles/h/lane)	Bus Headway		Preemption Condition	Bus Delay	Total Person Delay
		Main Street	Cross Street			
1	250	5 min, 3 min	—	No preemption (min)	12	1 311
				Preemption (min)	4	974
				Change (%)	-67	-26
2	250	5 min, 3 min	5 min, 3 min	No preemption (min)		
				Main Street	47	3 929
				Cross Street	30	
				Preemption (min)		
				Main Street	41	3 377
				Cross Street	24	
				Change (%)		
				Main Street	-13	-14
				Cross Street	-20	
	500	70 s, 40 s	80 s	No preemption (min)		
				Main Street	250	19 276
				Cross Street	138	
				Preemption (min)		
				Main Street	210	17 460
				Cross Street	138	
				Change (%)		
				Main Street	-16	-9
				Cross Street	—	
3	250	5 min, 3 min	—	No preemption (min)	70	7 976
				Preemption (min)	24	3 686
				Change (%)	-66	-54

[a] All directions.

Bus Signal Preemption at an Isolated Intersection

Main-Street Buses Only

Case 1 examined an isolated intersection with moderate traffic volumes of 250 vehicles/h/lane in all directions. Buses appeared on the main street only, at headways of 3 min in one direction and 5 min in the opposing direction. These conditions corresponded to a volume/capacity ratio of approximately 0.33 for each intersection approach.

By using the modified NETSIM model, it was found that a bus-signal-preemption strategy could significantly reduce bus delay and overall person delay while not significantly affecting other traffic operations. Assuming 1.3 persons/automobile and 40 persons/bus, Table 1 gives a reduction in person delay of 26 percent. In addition, buses along the main street actually experienced reductions in delay of 67 percent. Delay to all vehicles on all approaches showed a very slight (3 percent) improvement.

Buses on All Approaches

In case 2, in which cross-street buses competed with main-street buses for signal preemption, preemption caused no disruption of general traffic and no significant shift in service equity between main- and cross-street approaches while providing a moderate improvement in the performance of buses. As data given in Table 1 show, total person delay was reduced by bus signal preemption by approximately 14 percent when buses competed for service compared with the earlier value of 26 percent without such competition.

A variation of this case explored the performance of bus signal preemption under conditions of high traffic volumes, frequent bus arrivals, and buses competing for service at an intersection. Here, traffic volumes were increased to 500 vehicles/h/lane. Bus headways were 70 and 40 s on main-street approaches and 80 s on cross-street approaches.

The implementation of bus signal preemption under these conditions provided no benefits for the buses on the cross streets and a 16 percent reduction in bus delay on the main street. The net benefits expressed in terms of total person delay were less than 10 percent.

Bus Signal Preemption Along an Arterial

Case 3 considers arterial travel marked by moderate volumes of 250 vehicles/h/lane and bus headways of 3 and 5 min, respectively, in the two directions. Here, as Table 1 indicates, the bus-signal-preemption strategy reduced bus delay by a highly significant 66 percent along the arterial. Person delay was reduced by 54 percent.

It is of interest to relate these results to those of the intersection in case 1. Although the two cases are not directly comparable (the cross-street volumes differ), it is seen that the benefits for a single intersection are substantially lower than those of the arterial: 26 versus 54 percent reduction in person delay. This implies that the installation of signal-preemption capability on a system of intersections may provide a compounding benefit. The reduction in bus travel time is approximately 1.5 min/mile, compared with the approximately 1.8 min/mile obtained with the more macroscopic analytic study for similar conditions.

CONCLUSIONS

Application of the NETSIM model to a limited number of cases produced results that confirmed those provided by the macroscopic analysis and provided some additional conclusions:

1. When bus arrivals on competing approaches are serviced by a signal-preemption policy, there is a net benefit to the buses. This benefit is significantly less than the benefits that would accrue if buses were not competing for service.
2. Bus signal preemption is most efficient when bus arrivals are less frequent than one per signal cycle, since there is a greater opportunity to respond to discrete arrivals. When bus volume is very heavy, strong consideration should be given to providing an exclusive right-of-way (lane) for that period of time.
3. Signal systems equipped with bus-signal-preemption capability may provide greater benefits than

would be provided by applying signal preemption to isolated intersections. There appears to be a "compounding" of benefits along arterials that are so controlled.

In summary, analytic and simulation modeling of transit operations controlled by a bus-signal-preemption policy indicates that under well-defined conditions significant benefits may accrue in terms of reduced travel time without disrupting general traffic. The particular conditions and factors that promote these incremental benefits have been identified.

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Transportation for the 1980 Winter Olympics: A Retrospective Look

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A review of transportation planning for the 1980 Winter Olympics in Lake Placid, New York, and the implementation of the plan is presented. The many events that led up to the Olympics, such as the purchase of land for parking lots, the planning of the bus system, and the reconstruction of highway facilities, are described briefly. The operation of the bus system during the Olympics is examined closely. Both newspaper accounts and first-hand knowledge are used to ensure an accurate representation of events. The roles of and relations between the New York State Department of Transportation and the Lake Placid Olympic Organizing Committee are examined.

When Lake Placid, New York, was selected as the site of the 1980 Winter Olympics, the world wondered if a small town could run them successfully. Several critical problems were immediately realized. One of the greatest areas of concern was the problem of moving an estimated 50 000 people within an area that usually had 3000 residents. Limited housing made this issue even tougher, since 20 000-30 000 people would have to arrive and leave every day.

The Lake Placid Olympic Organizing Committee (LPOOC), a private corporation made up mostly of local Lake Placid citizens, turned to the New York State Department of Transportation (NYSDOT) for answers to the transportation questions. NYSDOT was asked to design a feasible plan to transport visitors. The plan, after review by LPOOC, was to be implemented by the organizing committee. The Olympic Transportation Plan (1) met the various environmental constraints, minimized the impact to local residents and spectators, and yet allowed tens of thousands of people to witness the 1980 Winter Olympics.

The plan's five basic elements were (a) restriction of automobile access into the area, (b) parking in peripheral parking lots for spectators arriving by automobile, (c) provision of transportation in the Olympic area by means of a shuttle-bus system, (d) enforcement of speed traffic controls, and (e) sale of 50 percent of all event tickets available to the public only as part of a charter bus, train, or air package.

NYSDOT and transportation consultants hired by LPOOC thoroughly tested and reviewed the plan by means of a series of computer programs. Assuming that all of the above basic elements would be conscientiously implemented, these professionals were confident that, except for possibly a few peak hours at the largest events, delays would be minimal and travel in the area possible.

PLANNING THROUGH 1976

The LPOOC planning efforts were endorsed by a local referendum in 1973, by a joint resolution of the New York State Legislature in 1974, by a concurrent resolution of the U.S. Congress in 1975, and by actions of Presidents Nixon, Ford, and Carter and New York State Governors Wilson and Carey. LPOOC requested NYSDOT to examine existing facilities and determine what actions were required. One of the state's first steps was to inventory the transportation facilities as well as other areas that would affect transportation (2). A series of program information reports (PIRs) was issued. These reports included inventories of highways, lodgings, and restaurants.

Highway access to the Lake Placid area consisted of three 2-lane rural facilities, a winding and mountainous route with roads that approach from the south, west, and north. Two rail facilities serve