the graphic displays above, various alphanumeric displays are available, including system status, controller status, and intersection status. These displays are provided on the IBM 3277 screen. The system status display provides information on the current mode of operation of the system, broken down by section. The controller status display lists the current mode of operation of each controller in the signal system. Possible modes are on-line, off-line, critical intersection, or controller parameter set. The intersection status display provides the traffic signal timing and traffic flow parameters for a user-selected intersection.

Operator system control is achieved by operator commands selected from a display menu on the IBM 3277 screen. As discussed previously, various options are available. Note that the manual and controller parameter set options permit operator intervention in the automated control of the system; as a result, investigations concerning the possible impacts of manual intervention in automated control can be conducted. The operator's decision to preempt the automated control can be based on the surveillance information displayed on the CRT or any prior information that warrants such intervention. The sequence of operations for operator intervention is shown in Figure 4.

The operator control inputs are accomplished via the IBM 3277 keyboard as shown in the system configuration of Figure 3. The sequence of operator commands and system responses shown in Figure 5 illustrates the selection of several possible modes of control.

SUMMARY

The UTCS simulator described in this paper was developed to support current and future research in first-generation UTCSs. The simulator comprises a traffic simulation component (NETSIM/ICG) and a UTCS component. These components are interfaced through several routines that emulate the communication functions in a traffic control system. To test the UTCS simulator, a test network was coded. Hypothetical peak-period origin-destination volumes were assigned on the network. On the basis of the resulting link volumes, several traffic patterns were identified. For each traffic pattern identified, the TRANSYT signal optimization program (5) was used to find the optimal network signal timing plan. In all, eight histories and four timing plans were generated. The simulator was tested in all modes of control. The ratio of program run time to real time ranges from 1:50 to 1:10 depending on the size of the network, the number of vehicles in the network, and whether or not the graphic display options are used.

ACKNOWLEDGMENT

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Evaluation of a Bus Preemption Strategy by Use of Computer Simulation

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The effects of implementing a bus preemption strategy on an arterial corridor (Monument Avenue) in Richmond, Virginia, were studied. The Urban Traffic Control System/Bus Priority System microscopic traffic simulation model was used to simulate the bus preemption system operation for various bus flow rates and bus stop locations. A benefit-cost analysis found bus preemption to be unjustified for the network. A comparison of benefit-cost ratios for the individual intersections showed a parabolic shape in the corridor. The benefits of bus preemption were found to be limited by the preemption algorithm structure and the bus stop location. A far-side bus stop was found to minimize the negative effects of bus preemption on automobile travel delay. The results were related to the control algorithm studied, and it was recommended that a more sophisticated control algorithm be developed for simulation studies and that similar studies be performed for other control algorithms.

Transportation system management (TSM) strategies have evolved because of the significant increase in travel demand in urban areas, the lack of additional land to expand the transportation system, and the increase in construction costs. These factors have led to the search for methods to improve the level of service of existing facilities with small investment costs. During the past several years, the need to reduce dependence on foreign petroleum imports has become an important fact of American life. The measure of effectiveness, passenger miles per gallon of fuel consumed, can be greatly improved through

TSM strategies that improve the use of transit systems. Bus priority treatments and particularly bus preemption strategies are possible means of improving transit service. These strategies reduce friction between buses and other vehicles in the traffic stream, delay due to traffic signals, and delay caused by the operating characteristics of the bus (acceleration and deceleration).

In general, bus preemption is the changing or maintaining of a traffic signal display in order to reduce the amount of stopped delay or, if possible, to prevent moving buses from stopping. The changing or maintaining of the signal status is referred to as red truncation or green extension. Red truncation refers to the situation in which a bus arrives at a signal that displays red and, because of the presence of the bus, a green display is given earlier than normal. Conversely, green extension refers to the situation in which a bus arrives at the signal just before the signal display turns red and the presence of the bus causes the green signal to be maintained until the bus passes through the intersection.

Bus preemption affects both the delay and fuel consumption of buses and automobiles. A bus aided by green extension will experience a reduction in travel time because it will not be required to wait through a red phase and it will save fuel because it will not experience either the speed-change cycle or the idling time associated with a stop. These benefits are also experienced by passenger cars that travel through the intersection during the green extension. However, the cross-street traffic will incur disbenefits of increased delay (the green-extension time) and fuel consumption. Similar impacts can also be observed for the red-truncation strategy.

The principal goal of this paper is to evaluate traffic performance in a network under the control of a specific bus preemption signalization strategy and to assess such a TSM strategy. To achieve this goal, the following objectives were identified:

1. Evaluate traffic performance under existing demands and operational conditions,
2. Evaluate the system with the bus preemption signalization strategy under changes in bus flow rates and loadings, and
3. Investigate the effect of the design characteristics of the network on traffic performance.

PREVIOUS RESEARCH

The earliest known bus preemption experiment was conducted in August 1967 by Wilbur Smith and Associates and the Bureau of Traffic Research, Los Angeles Department of Traffic, under a study financed by the U.S. Department of Housing and Urban Development (1). Two intersections in Los Angeles were studied: Broadway and First and Broadway and Second. The signals were preempted to give priority to buses traveling on Broadway. In discussing this experiment, Evans and Skiles (2) indicated that traffic signal delay constituted 10-20 percent of the average bus trip time. They concluded that signal delay would be the easiest type of bus travel time delay to reduce.

In 1975, Levinson, Adams, and Hoey (3) suggested the following warrants for bus preemption:

1. Reduction in total person delay as a result of bus preemption;
2. During the peak hour, a minimum of 10-15 buses carrying 400-600 passengers;
3. A minimum daily volume of 100 buses; and
4. Reducing the cross-street green while still providing the necessary clearance time.

During the late 1970s, many papers were written evaluating bus preemption and various preemption control strategies that used simulation models. Wood (4) used the microscopic Bus Priority Assessment Simulation (BUSPAS) program to test two bus preemption control strategies. Wood tested an inhibit strategy and a compensation control strategy. The inhibit strategy did not permit a phase that lost green time due to preemption to be preempted in the following cycle; cycle lengths remained constant. Under the compensation strategy, the green time was increased by a predetermined value in the cycle following a preemption in order to compensate for the green time lost to a preemption. The study concluded that inhibiting cycles could reduce the delay caused to other traffic by preemption. If inhibition did not reduce the added delay sufficiently, then compensation could.

Another study was done at the Transport and Road Research Laboratory (TRRL) in England by Vincent, Cooper, and Wood (5). Their study examined five variations of preemption strategy: (a) green extension only; (b) green extension, red truncation, inhibit; (c) green extension, red truncation, compensation; (d) red truncation, inhibit; and (e) red truncation, compensation.

The experiment considered four cases of different volumes, saturation flow rates, and signal timings. Several bus detector placements were also investigated. The researchers reported that the effects of green extension and red truncation were approximately additive. For this reason, strategies B and C proved to be far superior to D and E in reducing the average delay per bus.

Lieberman, Muzyka, and Schneider (6) reported on a simulation study that used the SCOT model. This study evaluated a network in Minneapolis under a fixed-time signal timing plan generated by SIGOP-II to minimize person delay and under a bus preemption control strategy. The bus preemption control strategy could call for (a) green extension, (b) red truncation, (c) the signal to cycle rapidly to reinstate the normal green phase, or (d) the signal to cycle to reinstate the green phase after satisfying other phase duration minimums. Although both strategies reduced delay over the existing case, the bus preemption system reduced delay by 42.5 passenger-h/h more than the signal timing strategy.

ANALYSIS

To evaluate the performance of the bus preemption control strategy, a benefit-cost analysis was conducted on an arterial corridor (Monument Avenue) in Richmond, Virginia, for the morning and evening peak-hour traffic conditions. Monument Avenue is a major east-west arterial that connects the suburbs with the central business district (see Figure 1). The study area consists of a 1.3-mile segment of Monument Avenue between the intersections of Roseneath Road and Staples Mill Road (see Figure 2) with a bidirectional average daily traffic (ADT) of approximately 25 000 vehicles. There are 14 at-grade intersections along this section. Six of the intersections are controlled by a traffic signal, and the remainder have two-way stop sign control of the cross street as shown in Figure 2. East of the Hamilton Street intersection is an access ramp to southbound I-195 for eastbound Monument Avenue traffic.

Bus stops are generally located 20 ft upstream of each intersection, as shown in Figure 3. The two exceptions are the far-side stops for westbound buses at Hamilton Road and Chantilly Street. An average dwell time of 30 s was assumed for the analysis. The Greater Richmond Transit Company (GRTC) operates bus service for the Monument Avenue corridor. GRTC route 1 serves the corridor with 6 buses/h during the peaks for an average bus headway of 10 min.

The estimated investment cost to provide bus preemption in the corridor was $62 400 for an optical detection system. The cost estimate was based on phase selectors and detectors for six intersections at $6000/phase selector and 12 bus emitters at $1100/emitter. Maintenance costs were assumed to 10 percent of the capital cost. After an assumed service life of 15 years, the equipment terminal value was assumed to be zero.

Travel time delay and fuel consumption were used as measures of road user cost. These measures were derived for all bus and automobile traffic. Passenger travel time delay cost was estimated at $5.50/passenger-h, and fuel consumption costs were estimated at $1.50 and $1.30/gal for gasoline and diesel fuel, respectively. The estimates of travel time delay and fuel consumption were developed by using two computerized microscopic traffic flow simulation models: the Urban Traffic Control System-Bus Priority System (UTCS-BPS) model (7-9) and NETSIM (10).

The UTCS-BPS program simulates traffic flow by modeling the movement of an individual vehicle (automobile, truck, or bus) in a network of links (streets) and nodes (intersections). The velocity-time trajectories, location, status, and moving and delay time of each vehicle are stored in a vector and updated every second. The vehicles are gener-

Figure 1. Monument Avenue study area.

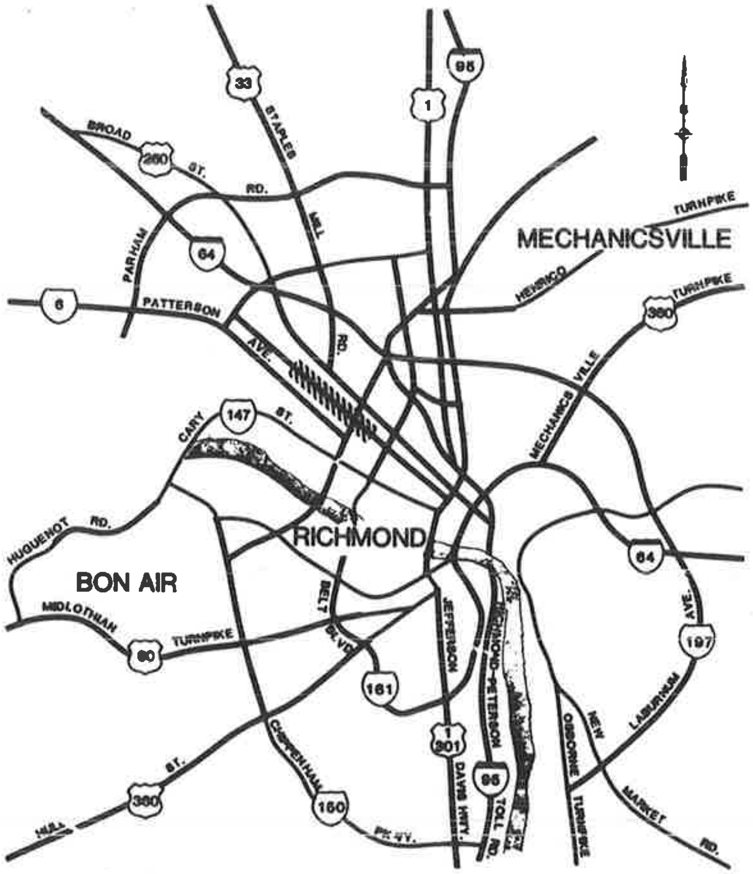


Figure 2. Monument Avenue corridor.

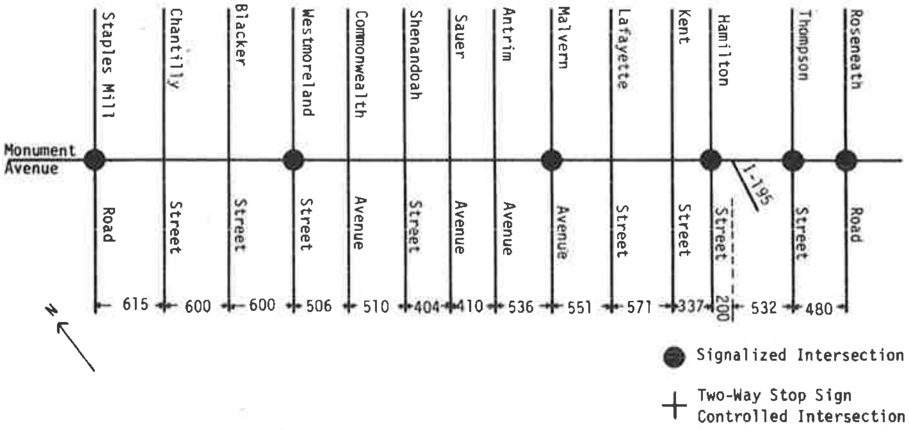


Figure 3. Link-node diagram of Monument Avenue corridor.

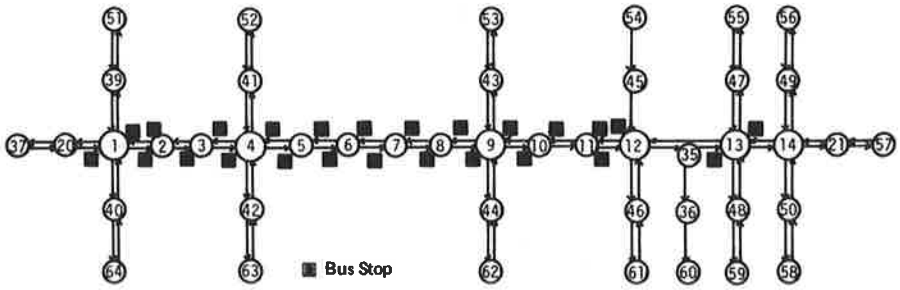
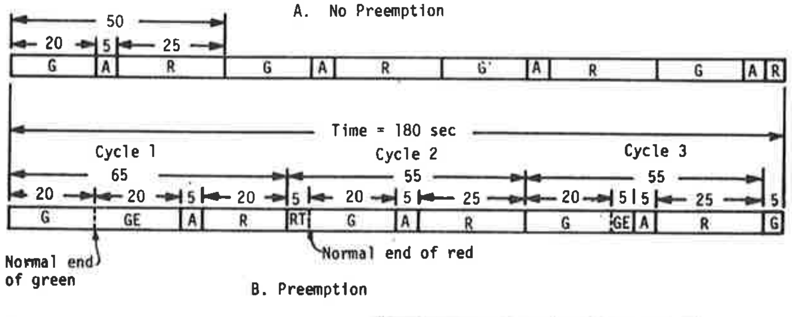


Figure 4. Effect of bus preemption on a two-phase signal.



Approach	Green + Amber Time No Preemption	Preemption
Main Cross	100 80	110 70
Total	180	180

ated stochastically, and headways are assigned according to a shifted negative exponential function. The generated vehicles are assigned to an entry link and when conditions permit they are emitted onto the network links. Statistics are not collected for a vehicle until it occupies a network link. The bus and automobile travel time delays are included in the UTCS-BPS output. NETSIM read the velocity-time trajectories produced by UTCS-BPS and used a table look-up procedure to determine fuel consumption.

Five simulations were made of both the no-preemption case and the preemption case. The results for each case were averaged before inclusion in the benefit-cost model. Each simulation replicated 30 min of real time.

BUS PREEMPTION ALGORITHM

The UTCS-BPS model updates a node's signal status once every second. The approaches to a node are checked to determine the possibility of bus preemption only if certain conditions are met. For red truncation, these conditions are

1. The current phase has been active for a minimum period of time (20 s),
2. At this time the current phase is not being extended, and
3. A previously computed time for red truncation to occur at the node is less than or equal to the present time in simulation.

For green extension, the conditions are

1. A bus must be within the detector zones of the intersection or network and
2. A red truncation must not be scheduled to occur at the node at this time.

The algorithm is capable of granting signal preemption to any one of four approaches to an intersection. However, for the purpose of this study, buses were only simulated on the arterial.

The possible effects of bus preemption on a simple two-phase signal cycle are shown in Figure 4. The bar charts indicate the signal aspect for a bus preemption instrumented intersection approach. Case A shows the normal repetition of a 50-s cycle with 50-50 splits for a pretimed controller. Case B indicates how the signal cycle can be altered by the granting of a green extension, a red truncation, and another green extension to buses on the approach.

It is clear from the bar graphs that a green extension has greater potential to reduce bus signal delay than a red truncation. A green extension can reduce delay by the length of the preceding red period whereas a red truncation can only save the normal red phase time minus the minimum phase duration.

BENEFIT-COST MODEL

Because the two alternatives examined in this study are mutually exclusive, an incremental benefit-cost analysis model is used. The relation is given by

$$B/C = [-(U_P - U_B) - (K_P - K_B)]/[-(I_P - I_B)(CR_{i,n}) + (T_P - T_B)(SF_{i,n})] \quad (1)$$

where

B/C = benefit-cost ratio (on an equivalent uniform annual basis);
U_P = annual user cost for the preemption case;
U_B = annual user cost for the "do-nothing" case (base case);
K_P,K_B = annual maintenance and operations cost for the preemption and the base case, respectively;
I_P,I_B = investment cost for the preemption and the base case, respectively;

$CR_{i,n}$ = capital recovery factor for vest charge rate i and analysis period n (years), given by

$$CR_{i,n} = i(1 + i)^n/[(1 + i)^n - 1] \quad (2)$$

T_p, T_B = terminal value of the equipment for the preemption and the base case, respectively; and

$SF_{i,n}$ = sinking fund factor for vest charge rate i and analysis period n (years), given by

$$SF_{i,n} = (i)/[(1 + i)^n - 1] \quad (3)$$

Given the previously stated assumptions, Equation 1 reduces to

$$B/C = [-(U_p - U_B) - K_p]/(-I_p\, CR_{i,n}) \quad (4)$$

SIGNAL TIMING

A signal timing plan was generated for the Monument Avenue network in order to minimize vehicle delay in the no-preemption case. The timing plan was developed for the morning and evening peak hours by using the Signal Operations Analysis Package (SOAP) (11) and the Traffic Network Study Tool (TRANSYT) (12). Each of the signalized intersections was modeled by SOAP to determine the phasing pattern and cycle length required to minimize vehicle delay and excess fuel consumption. The SOAP analysis also determined optimal cycle length for the individual intersections. The signal phasing chosen for the morning simulation was two-phased at all intersections except for Staples Mill Road, which had an exclusive left-turn phase on Monument Avenue. For the evening simulation, a two-phase operation was selected for the Roseneath, Thompson, and Malvern intersections, a three-phase operation for Hamilton and Staples Mill, and a four-phase sequence for Westmoreland. At all intersections the cross-street traffic was served by a single phase.

The TRANSYT model was then used to simulate traffic in the network macroscopically by using the phasing pattern results from SOAP. A range of cycle lengths were tested to determine the one that minimized a performance index (PI). The PI was a function of vehicle delay and the number of vehicle stops made. The range of cycle lengths tested was based on the results of the SOAP analyses. The results of the TRANSYT analyses are given below (X = cycle length not tested):

	Performance Index	
Cycle Length (s)	Morning	Evening
45	43.43	X
50	39.18	X
55	40.15	X
60	41.07	112.75
65	41.88	X
70	42.75	X
75	43.79	88.93
80	45.83	X
85	48.12	84.24
90	X	86.71
95	X	87.73
100	X	88.00
105	X	89.83
110	X	91.90
120	X	95.75

The cycle length, offsets, and splits generated by the TRANSYT program for the morning and evening peak hours, which minimized the PI, were used in the UTCS-BPS simulations. The morning cycle length was 50 s, and the evening peak hour used an 85-s cycle length.

The offsets were maintained throughout the no-preemption case simulations. However, the traffic signal control algorithm in UTCS-BPS could not maintain or reestablish the proper offset after a cycle at an intersection had been preempted.

ANALYSIS RESULTS

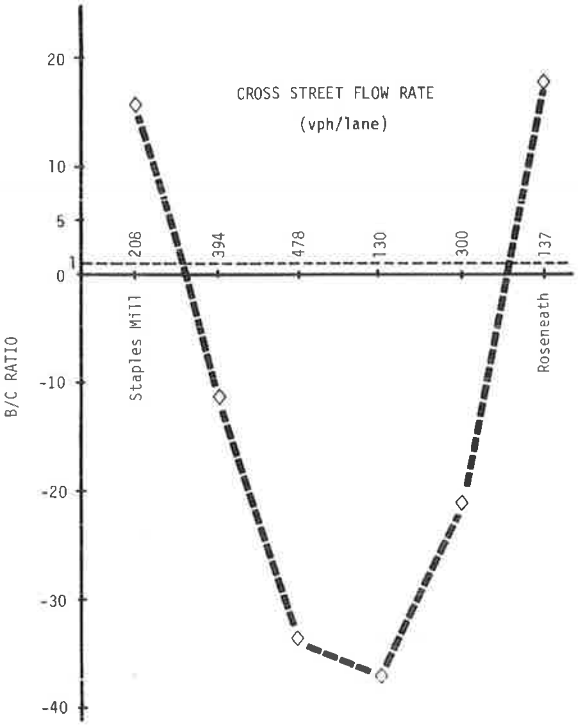
Both the morning and evening peak-hour analyses resulted in negative benefit-cost ratios for the network, which indicated that bus preemption caused higher road user costs than no preemption. A value of -12.042 was computed for the morning analysis and -15.399 for the evening. To determine possible causes for the negative benefit-cost ratios, the morning peak-period data were analyzed on an intersection-by-intersection basis.

The individual intersection benefit-cost ratios calculated from the morning simulation results are shown in Figure 5. The results were plotted according to the location of the intersection irrespective of cross-street automobile flow rates. The higher of the two opposing cross-street automobile flow rates at each intersection is shown in the figure.

A parabolic shape is apparent from the plot in Figure 5. A statistical analysis showed that the road user cost measures over the total network were not significantly different for the no-preemption and preemption cases at the 95 percent confidence level. However, the analysis showed that automobile delay was significantly different for the no-preemption and preemption cases at the three intersections with the lowest benefit-cost ratios.

The bus preemption control algorithm was reviewed as a possible cause of the negative benefit-cost ratio. The logical structure of the program grants priority to red truncation over green extension. Because the green extension form of preemption can provide greater benefits to buses than red truncation, the algorithm structure limits the benefits of bus preemption.

Figure 5. Benefit-cost ratio versus cross-street flow rate: morning peak period.



The review also indicated that the multiple phasing and the short cycle lengths combined minimize the benefits of preemption to buses. The short cycle lengths meant that the phase lengths were shorter. When preemption consisted of green extension, the current green phase length could be doubled in duration. But extending a 20-s phase another 20 s does not provide the added passage time that doubling a 40-s phase does. The extra passage time from a longer cycle length would greatly assist a bus in peak-hour traffic. For the red truncation form of bus preemption, a minimum phase duration of 20 s was required before the red signal display could be truncated. For example, if a bus were stopped by a red phase with a normal duration of 25 s, the maximum possible benefit to the bus if red truncation were granted would be 5 s. Obviously, with longer phase durations the possible benefits to bus passengers would be greater.

The inability of the algorithm to reestablish offsets once a signal preemption occurred may also have adversely affected road user costs. A platoon of vehicles traveling down the arterial receives important travel time benefits due to signal coordination in the no-preemption case. However, when a signal preemption occurs the signals are no longer coordinated and an approaching platoon of vehicles may experience excessive delays, depending on when they arrive at the uncoordinated signal. As more signals on the arterial are preempted, the benefits of any adjacent coordinated signals disappear and vehicle delay increases.

Another factor that may have affected the ability of the bus preemption system to perform well enough to generate a positive benefit-cost ratio was the bus stop location. All of the stops were near-side stops except two, of which only one was at a signalized intersection. While boarding and alighting passengers at a near-side stop within an approach detection zone, a bus would cause red truncations and green extensions of the signal. These preemptions occurred even though the bus was not ready to depart the stop and reenter traffic. These preemptions caused delay to cross-street automobiles while the bus did not experience any reduction in travel time delay.

The problem is not with the control algorithm alone. This is an actual problem encountered with the bus preemption hardware. One report (13) recommends that, in installing the bus preemption optical detection system, all bus stops be moved to far-side locations, if practical. The report estimates the cost of moving a bus stop in New Orleans at approximately $5500. The cost depends on the quality of the facilities at the stop, such as a shelter or the amount of signing. The cost of providing new locations or moving stops could be prohibitive. It was therefore decided to analyze higher bus flow rates over the Richmond network and to compare the results with those obtained from simulations with the bus stops outside the detection zones. Bus flow rates of 15 and 25 buses/h were studied along with the 6-buses/h flow rate.

One simulation run was made for the no-preemption case. Five runs were made of the preemption case and the results were averaged. The evening peak-period conditions were adopted, and comparisons were made of the changes (no-preemption delay minus preemption delay) in automobile travel time delay and bus travel time delay. Figure 6 shows these comparisons. Line a indicates where automobile passenger delay increases (disbenefits) between no preemption and preemption are equally offset by bus passenger delay reductions (benefits) at an automobile occupancy rate of 1.4 passengers/automobile and a bus occupancy rate of 35 passengers/bus. Data points in the area below and to the left of the line indicate that total passenger travel time delay increases from the no-preemption to the preemption case. Points above and to the right of the line indicate a decrease in total passenger travel time delay.

Only one case showed a decrease in total passenger delay. This was the 25-buses/h main street bus flow rate with bus stops located at midblock. The worst case was also the 25-buses/h flow rate, but the bus stops were located at the near side of the intersection. It was decided to review the control algorithm and its operation with multiple-phase signals again.

Multiple phases minimized the benefits of preemption under the control algorithm. Extra phases meant shorter phase durations and therefore shorter green extension or red truncation periods. The control algorithm also did not have the capability to skip phases. This meant that a bus, arriving during a red period and eligible for red truncation at a signal with a four-phase sequence, would have to truncate the three remaining phases before being served by the early call to the normal green phase for its approach.

To assess the impact on bus preemption of two-phase signals with different bus stop locations, another series of simulations was performed. Bus flow rate and bus stop location were varied under a two-phase signal operation while the same cycle length as the original evening peak-period signal timing plan was maintained. Again, one 30-min simulation was done of the no-preemption case while the average of five preemption case simulations was used to determine the changes in passenger car and bus travel time delays. Figures 7 and 8 show the results.

Figure 6. Effect of bus stop location on changes in delay: multiphase signal operation.

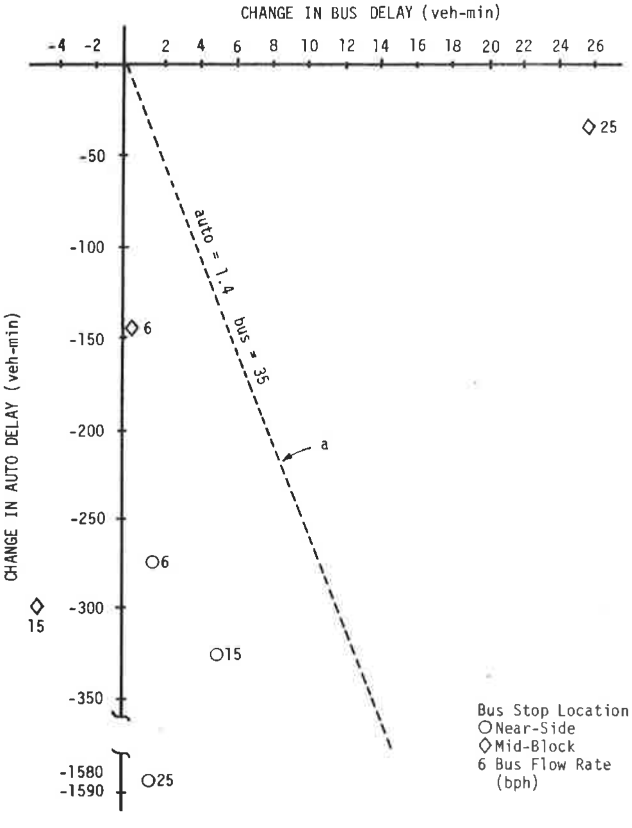


Figure 7. Effect of bus flow rate on changes in delay: two-phase signal operation.

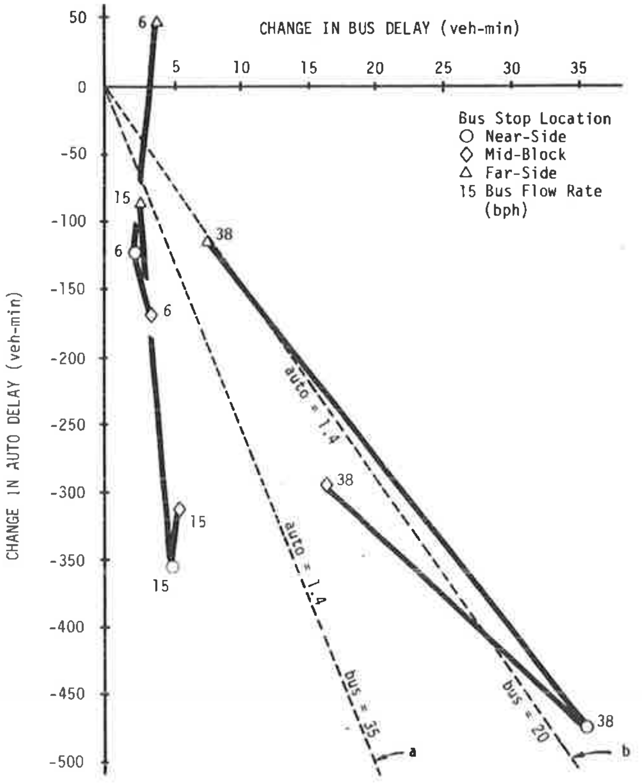


Figure 8. Effect of bus stop location on changes in delay: two-phase signal operation.

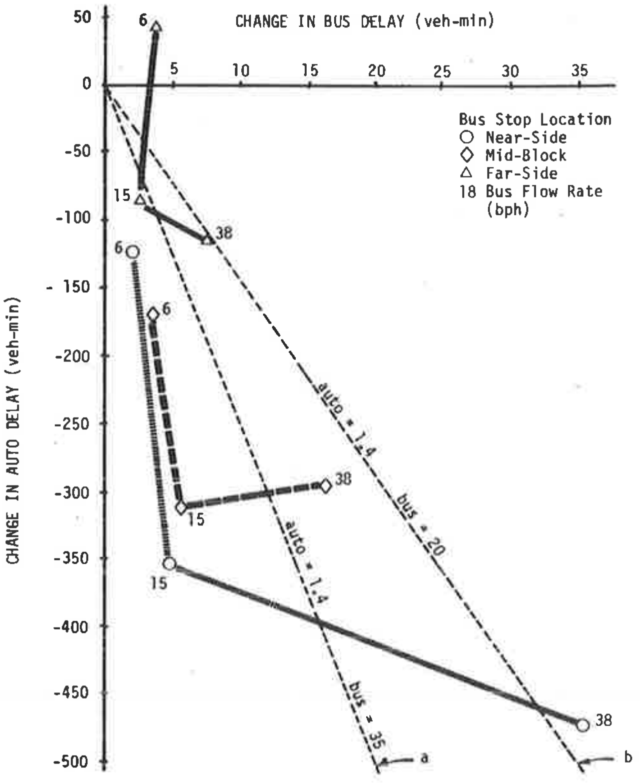


Figure 7 shows the results plotted with a constant bus flow rate and varying bus stop location. A comprehensible pattern does not emerge from the results. Lines a and b represent the points at which the changes in bus and automobile passenger travel time delays are equal for the occupancy rates shown. The 38-buses/h main street bus flow rate indicates that bus preemption can decrease total passenger delay if bus loads exceed 35 passengers. In general, if the bus passenger load drops to 20 passengers, bus preemption increases total passenger delay. The 6-buses/h flow rate with a far-side stop location decreases total passenger delay under either loading, whereas the far-side stop with a 15-buses/h flow rate appears to increase total passenger delay slightly.

Figure 8 shows the results plotted with a constant bus stop location and varying bus flow rate. A more definitive pattern becomes visible. As expected, the near-side stop location has the most negative impact on the change in passenger car delay. The far-side stop has the least impact. These results indicate that the far-side bus stop may have the best possibility, of the three stop locations, of providing a benefit-cost ratio greater than one under the bus preemption control algorithm and a two-phase signal. This finding supports previous findings that recommend far-side bus stop locations for use with bus preemption systems (13). This does not mean that preemption cannot be effectively accomplished with near-side or midblock stop locations. The findings only indicate that preemption can reduce total passenger delay more readily with far-side bus stop locations than with near-side stop locations.

CONCLUSIONS AND RECOMMENDATIONS

The analysis of the Richmond network indicated that bus preemption was not cost effective. The analyses revealed that the near-side bus stop locations and multiple signal phasing combined to reduce the benefits of preemption. The problems associated with bus stop location and multiple signal phasing were related to the bus preemption control algorithm. The algorithm was not sophisticated enough to simulate the signal system operations that are possible with technology available today. The results may vary under other control algorithms.

During the performance of this research, several items of concern have been noted regarding the data and methodologies used. The following recommendations are offered for further consideration:

1. Microscopic traffic simulation programs should be programmed to simulate several types of bus preemption control strategies. The preemption control algorithms should be sufficiently sophisticated to (a) simulate bus preemption at fully actuated traffic signals, (b) simulate bus preemption under a coordinated signal system in which coordination of the signals is reestablished after a bus preemption by phase skipping or smoothing of the signal cycle length, and (c) allow phase skipping when a bus preemption call is made.

2. A similar research effort should be performed for other control algorithms to determine how the algorithm affects the cost-effectiveness of bus preemption.

3. An investigation should be performed to determine whether or not automobiles tend to platoon around buses where bus preemption systems exist. An interior network intersection was simulated as an isolated intersection under the same traffic conditions. Bus preemption provided more user benefits under the isolated scenario than under the network scenario for the intersection. This may indicate

that vehicle platoons may be adversely affected by preemption in a network under this control algorithm.

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Heuristic Programming Approach to Arterial Signal Timing

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A heuristic programming approach to minimum-delay arterial street signal timing plan optimization is presented. The selection of a good heuristic solution for phasing sequence, cycle length, and green splits is demonstrated. The approach demonstrates a procedure for use by the traffic engineer in selecting the phase sequence, cycle length, and offsets for an arterial street for developing a minimum-delay signal timing plan from existing computer programs. The heuristic procedure is to use the PASSER II computer program for maximum bandwidth progression optimization to select the phasing sequence and the initial starting point for use in the TRANSYT 6 computer program to develop a minimum-delay performance index solution. This permits all signal timing variables to be optimized. Comparisons are made between this heuristic solution and the best signal timing plan developed (considering all possible combinations a priori) by the TRANSYT program. An evaluation of use of the PASSER II green split routine versus the TRANSYT STAR1 routine on the program solution was performed. The heuristic procedure, when restricted to the minimum-delay cycle length, resulted in at least a good solution versus a TRANSYT best solution that used a measure index. A comparison of the PASSER II green splits and the TRANSYT STAR1 routine produced mixed results.

The primary emphasis of this paper is on fixed-time, common-cycle, coordinated traffic signals with multiple-phase control for arterial streets. A heuristic programming approach to minimum-delay optimization of signal timing for arterial streets is presented. The area of application is a linear system of high-type signalized intersections.

Improving the effectiveness of traffic-control variables has been thought to contribute to reducing congestion and relieving those conditions that impede the flow of traffic. Selection of a signal timing plan is complicated by the large number of available alternatives and the interrelations among the signal timing variables (1). Considerable research has been done on the coordination of traffic signals on arterial streets (2). Efforts have been directed toward computerized signal timing optimization procedures, strategies, and techniques that would provide for signal timing plans superior to those in use. Improvements in operational efficiency and safety have been consistent long-term goals.

Despite the various methods available to determine arterial signal settings, a maximum bandwidth progression solution has historically been the approach preferred by traffic engineers (3-5). This arises in part from the lack of computational complexity in use and the ability to visualize the goodness of the results.

Although progression has been widely accepted and used, questions have arisen concerning whether it provides a good arterial solution at the expense of the cross-street traffic. Other methods for coordinating signals have been proposed in which the objective of optimizing is an index of performance,