Abridgment

# BUS PRIORITY SIGNAL CONTROL: SIMULATION ANALYSIS OF TWO STRATEGIES

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A study to evaluate the effectiveness of two bus priority strategies using a validated traffic simulation program is described. The test network, which is located in the Central Business District of Minneapolis, Minnesota includes two major arterials, each with a contraflow bus lane. The first control strategy consists of a fixed-time traffic signal pattern generated by the SIGOP-II model, which is designed to minimize passenger-delay, rather than vehicle-delay. The second control strategy is a real-time policy which preempts the fixed-time control to provide preferential treatment for approaching bus vehicles. The simulated results for each strategy were compared with those reflecting the existing fixed-time signal control. This study indicated that, for this application, the reduction in delay for bus passengers as predicted by the simulation program provided by both strategies outweighted the additional delay experienced by passengers in private vehicles; the preemption strategy provided greater improvement in performance than did the other. The study also demonstrates that a validated simulation model is an effective tool for evaluating alternate design configurations prior to field demonstration.

With attention focusing on techniques for encouraging the general public to increase its usage of mass transit facilities, several experiments have been undertaken to improve the performance of bus operations. One approach for evaluating strategies is to develop a preliminary design which is subsequently implemented in the field. This approach is both costly and time-consuming (1). Furthermore, should the preliminary design produce a degradation in traffic performance, there exists the prospect that the experiment will be terminated before refinements can be implemented.

Another approach is to develop the "best" preliminary design possible prior to field implementation by exploring different candidate designs. Each is then tested in a manner which replicates the proposed traffic environment. An effective methodology for such experiments, which has received increasing usage in recent years, is the application of traffic simulation techniques.

This paper describes the application of a microscopic simulation model of urban traffic, named SCOT(2,4) to a network in the central business district in Minneapolis. On each of two adjoining parallel, one-way arterials, a contraflow bus lane has been implemented. The purpose of this study was to identify the "best" preliminary design. Specifically, the following tests were conducted:

1. Evaluation of traffic operations on the network with the existing fixed-time control timing plan.
2. Evaluation of traffic operations with a fixed-time signal timing plan specifically designed to minimize person-delay.
3. Evaluation of traffic operations with a real-time bus preemption control.

The operational characteristics of general traffic and of bus traffic are specified as input to the simulation program separately. For general traffic, queue discharge headways, free-flow speed and turn movement percentages are specified for each link. Bus traffic is specified in terms of their respective route structures and the bus stations serviced. All bus stops are located appropriately and their respective [curb] capacities and observed bus dwell times are specified.

The traffic control is specified in terms of signal interval durations and signal offsets, at each node (intersection) of the network. For the on-line bus preemption control, detectors were specified in the locations where they would be installed in the pavement, and the control was specified in terms of minimum phase duration for the cross streets. The actual real-time pattern of signal indications was determined by internal logic.

The physical street system is represented as a network, as shown in Figure 1. Each north-south arterial services general traffic in one direction with a single bus contraflow lane. The cross-flow streets all service one-way flow, as indicated.

The urban portion of the SCOT simulation model moves individual vehicles along the network links (streets) and through the nodes (intersections) in response to the signal control. This portion is essentially synonomous with the UTCS-1 model (3) which was validated on a network servicing bus traffic. Statistics describing traffic operations are accumulated and listed for each link in the network; bus statistics are maintained separately.

## Control Plans

The existing fixed-time control system exhibits a common cycle length of 90 seconds, relative offsets are zero for all links, and the signal split at each intersection is set at a G/C of 0.5, approximately. Right-turn-on-red is permitted for most approaches. General traffic may turn left across the bus contraflow lane.

The SIGOP-II model (5) was employed to obtain new signal timing plans. A small modification was introduced into this model specifically to replicate bus traffic operations and the dwell time experienced while servicing passengers at bus stations. The difference in passenger occupancy between buses and general traffic vehicles (40 vs. 1.3, respectively) was represented. This effectively transformed the objective function in the SIGOP-II model from "vehicle-delay" to "person-delay." The signal cycle length was retained at the current value of 90 seconds (4).

The bus preemption strategy is designed to alter the fixed-time sequence of signal phasing so as to provide preferential service for bus traffic. Briefly, the algorithm is based on a design where a bus station on a street is always located upstream of the detector which issues a "call" for signal preemption at the downstream signal. That is, there is no bus station between the detector and the stop line. Based on the projected arrival of a detected bus at the stop line, the algorithm determines whether to truncate the RED phase or extend the GREEN phase, or cycle rapidly to reinstate GREEN phase, or cycle rapidly to reinstate the GREEN phase subject to minimum phase duration constraints. The objective is to minimize bus delay. When competing buses vie for the GREEN phase, the algorithm resolves the conflict by implementing that strategy which minimizes total bus delay, subject to certain constraints.

The preemption strategy was programmed and integrated into the SCOT simulation model.

## Experimental Results

The existing control was treated as the "base case." A total of 15 bus routes traversed the test network; each route exhibited an average headway of about 2 minutes. Hence, a bus entered the network every 8 seconds. Results describing the overall performance of bus traffic for the new signal timing plan are presented in Table 1, while those for general traffic appear in Table 2.

As indicated, the buses along the major arterials benefit significantly, while those along the cross streets experience sharp degradation in performance. General traffic experiences a moderate fall-off in operational performance. The overall bus performance experiences improved service as measured by a 12 percent reduction in the total delay relative to the base system. On the basis of the observed occupancies of 40 passengers per bus and 1.3 per auto, the net effect over a 15-minute period is a decrease of 395 passenger-minutes. Extrapolating this figure over the peak hour yields a net reduction in delay of 26.3 passenger-hours per hour.

Results describing the overall performance of bus operations for the bus preemption strategy are presented in Table 3, while those for general traffic appear in Table 4. The pattern of these results is similar to those described above for the new signal timing plan. As expected, buses along the main arterials benefit significantly while other components of the traffic stream experienced increased delay.

For this 15-minute time period, delay experienced by general traffic increased by 498 vehicle-minutes, while delay for buses decreased by 42 vehicle-minutes. Employing the same occupancy figures as previously, the net effect is a decrease of 1032 passenger-minutes in the test period or 68.8 passenger-hours per hour.

## Conclusions

This paper has described a study employing traffic simulation to evaluate design alternatives to improve urban bus operations. The major conclusions are:

1. Strategies designed to improve bus operations involve a blend of several types of improvements. For each facility, it is advisable to explore several candidate strategies prior to the demonstration phase.

2. Simulation has been demonstrated as a viable tool for conducting such evaluations to identify that strategy (or limited set of candidate strategies) which exhibits the highest potential for a successful demonstration project.

3. On the basis of this study, it appears clear that any preferential bus strategy in an urban environ must include consideration of signal control. Furthermore, such consideration should be based upon people-movement measures as opposed to vehicle-movement measures exclusively.

## Acknowledgments

This paper was based upon a more detailed report (6). Dr. James Woo applied the SIGOP-II model to generate the new fixed-time signal patterns for this study.

Table 1. Simulation results for bus system
Bus progression strategy
4:30 - 4:45 P.M.

| Performance Measure | Base Case | Priority Case | % Change |
|---|---|---|---|
| Number of Buses | 116 | 117 | +1 |
| Total Delay (Bus·Minutes) (Dwell Time Excluded) | 232.7 | 204.6 | -12 |
| Mean Trip Time (Minutes) (Dwell Time Excluded) | 3.19 | 2.94 | -8 |
| Mean Speed (MPH) | 6.8 | 7.3 | +8 |
| Number of Intersection Stops | 265 | 217 | -18 |
| Total Duration of Intersection Stops (Minutes) | 108.8 | 88.5 | -19 |

Table 2. Simulation results for network general traffic. Bus progression strategy
4:30 - 4:45 P.M.

| Performance Measure | Base Case | Priority Case | % Change |
|---|---|---|---|
| Vehicle Miles | 1035 | 1028 | -1 |
| Vehicle Trips | 3537 | 3522 | 0 |
| Vehicle Minutes | 5325 | 5873 | +10 |
| Average Speed(MPH) | 11.7 | 10.5 | -10 |
| Stops per Vehicle | 1.56 | 1.77 | +13 |
| Delay per Vehicle (Sec) | 47.9 | 57.6 | +20 |

Table 3. Simulation results for bus system.
Bus preemption strategy.
4:30-4:45 P.M.

| Performance Measure | Base Case | Priority Case | % Change |
|---|---|---|---|
| Number of Buses | 116 | 117 | +1 |
| Total Delay (Bus·Minutes) (Dwell time excluded) | 232.7 | 190.7 | -18 |
| Mean Trip Time (Minutes) (Dwell Time Excluded) | 3.19 | 2.98 | -7 |
| Mean Speed (MPH) | 6.8 | 7.3 | +7 |
| Number of Intersection Stops | 265 | 235 | -11 |
| Total Duration of Intersection Stops (Minutes) | 108.8 | 90.9 | -16 |

Figure 1. Study network

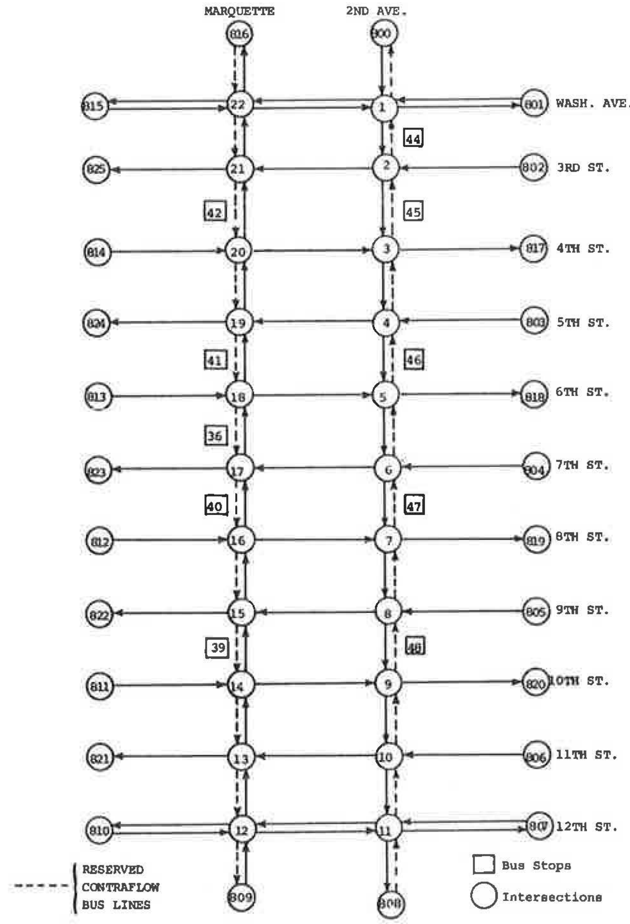


Table 4. Simulation results for network general traffic. Bus Preemption Strategy
4:30 - 4:45 P.M.

| Performance Measure | Base Case | Priority Case | % Change |
|---|---|---|---|
| Vehicle Miles | 1035 | 1022 | -1 |
| Vehicle Trips | 3537 | 3507 | -1 |
| Vehicle Minutes | 5325 | 5808 | +9 |
| Average Speed (MPH) | 11.7 | 10.6 | -9 |
| Stops Per Vehicle | 1.56 | 1.78 | +14 |
| Delay per Vehicle (Sec) | 47.9 | 56.8 | +19 |

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