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PLANNING GUIDELINES FOR BUS PRIORITY SYSTEMS AT SIGNALIZED INTERSECTIONS

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ABSTRACT

In the last decade, the world experienced a renewed interest in using the advanced technology to improve transit service operation, reliability, and image. The development of the Intelligent Transportation Systems (ITS) in the last decade contributed towards this renewed interest in transit services. Providing preferential treatments for high occupancy vehicles (HOV) will make the HOV more competitive with other modes of transportation. This will increase the transit modal split and reduce single occupancy vehicle demand, thus reducing traffic congestion within the urban boundaries.

The study examined various bus priority signal (BPS) strategies for a major corridor in the City of Ann Arbor, Michigan, USA. The BPS process was simulated using TRAF-NETSIM software. The graphic animation feature in the software was used to monitor the bus arrival at the signalized intersection.

The preemption plans of green extension/red truncation with/without compensation, the skip phase, and the conditional preemption were evaluated. The most appropriate preemption plan for each intersection along the study corridor was determined.

The vehicular (vehicles, buses, and carpools) measures of effectiveness (MOE) in terms of travel time and delay were tested under various levels of network traffic volumes and main to cross street traffic ratios for an isolated intersection. The signal priority for carpools was also tested.

The general conclusion that traffic progression is most critical under heavy traffic conditions. Traffic volume guidelines for signal preemption strategies were also established. The study concluded that there are advantages of providing a limited percentage of carpools with the signal preemption capability.

INTRODUCTION AND BACKGROUND

The end of 1980s witnessed the emergence of a new area and application of transportation engineering named the Intelligent Vehicle Highway Systems (IVHS), which was later renamed to the Intelligent Transportation Systems (ITS). This opened the area for applying some of the "old" ideas in transportation engineering that were not practiced any more for several reasons. Some of these reasons were related to the available technologies at the time. One of these practices was the provision of priority treatments for buses (or high occupancy vehicles, HOV). With the success in ITS and its applications, the interest in "bus priority signals – BPS" as preferential treatment for buses and other HOV was renewed.

Bus priority signal (BPS) is a method of providing preferential treatment to buses and other high occupancy vehicles (HOV) by altering the signal timing plan to favor those vehicles.

In general, providing preferential treatment for buses is expected to improve the performance of buses and other traffic on the bus direction. However, delay is expected to increase for traffic on the cross street. In an attempt to reduce reliance on automobile travel, efforts have been made to make public transit more attractive by reducing transit delays, providing more reliable transit schedules, and providing a level of service that might make it competitive with private automobiles. When bus delay is reduced, buses run on a more reliable schedule and their trip time is shorter. This makes transit a more attractive mode of transportation and may increase bus ridership by diverting private automobile drivers. This, in turn, will result in congestion relief and a reduction in exhaust emissions.

There are two main techniques to provide priority treatment for HOV at traffic signals. These are passive and active detection and granting priority (Sunkari et al 1995, Allsop 1977, Nato 1976). Passive priority systems are characterized by the fact that the flow of buses need not be recorded at a particular instant in order to grant priority. Instead, the intensity of bus (or HOV) movements is deduced from historical measurements of traffic flow. This system is based on signal coordination and improved signal timing for all arterial traffic to favor bus traffic. The following are methods for improving transit operation: (1) adjustment of cycle time, (2) splitting phases, (3) area-wide timing plans, (4) gating (metering vehicles), and (5) turning prohibition.

An active priority system is when the passage of an individual bus is detected and priority is awarded to the bus because of this detection. Therefore, the priority treatment is provided only when the bus is present. The followings are methods of active priority treatment:

Green Extension (or Red Truncation): Includes extending the green phase (when the bus arrives at the intersection just after the end of the normal green period) to allow the bus to pass the intersection. It is usually limited to some maximum value.

Phase Recall (early start or red truncation): When the bus arrives at the intersection during the red signal, its green phase started prematurely and all other non-bus phases are terminated. This is usually associated with providing a minimum green time for the phase to be prematurely terminated.

Phase Skipping: To facilitate the provision of the bus priority phase, one or more non-priority phases may be omitted from the normal phase sequence. However, some restrictions may be applied to this treatment, such as no phases with heavy demand are skipped.

Compensation: To limit the adverse effects priority has caused to the non-priority traffic, one may choose to compensate for the time lost (skipped or cut) from the other non-bus phases in the next cycle. This involves allocating extra green time to these phases to make up for time lost during signal preemption.

The provision of signal priority each time it is requested could be disruptive to the cross-street traffic. Therefore, it would be better to subject preemption to certain conditions, which determine when or if the signal priority will be granted to the bus. These conditions may be related to the bus being behind schedule, bus occupancy, cross-street traffic conditions, and time between consecutive preemptions (other conditions may also be used).

In this research, the active priority system was adopted. Several combinations of these various treatment schemes are tested.

METHODOLOGY

Several active priority strategies were tested such as green extension, phase recall, phase skipping, compensation (for green time cut), and conditional priority (if the bus is behind schedule). The study examined bus priority signal (BPS) strategies for a major corridor, as a case study, in the City of Ann Arbor, Michigan, USA.

The study corridor is approximately 5 ¼-kilometer long with 13 signalized intersections. Existing geometric conditions, peak hour traffic volume, signal timing, bus operation characteristics of the study corridor were obtained. The corridor was coded and then signal timing parameters (green split and off sets) were optimized using TRANSYT-7F software. The optimized signal settings were then simulated using TRAF-NETSIM software.

The graphic animation feature of TRAF-NETSIM was used to monitor the bus progress at the signalized intersection. The program has the capability of simulating fourteen time-period plans in each run. These periods were used to change the signal timing at a specific intersection to grant the BPS, as needed (Al-Sahili and Taylor, 1996).

The software also provides measures of effectiveness (MOE) in terms of delay and trip time for vehicles, buses, and persons. The effectiveness of the system in terms of MOE for all types of vehicles and persons were measured.

The traffic volumes at isolated intersection were altered, and the impact of BPS for different levels of traffic volumes was tested.

STUDY CORRIDOR

Washtenaw Avenue East, which is one of the major corridors in the City of Ann Arbor, Michigan, was used as the study corridor. This study corridor is approximately 5-1/4 kilometer long with 13 signalized intersections, from Golfside Street on the east to South University Street on the west.

Most signals of the study corridor had two phases with permissive left turns and 60-second cycle lengths. The exceptions were: at Golfside Street (4 phases with a 120-second cycle), and at Huron Parkway and Carpenter Street (4 phases actuated). Preemption was not provided for the two actuated signals.

The Ann Arbor Transit Authority bus route serves this corridor at a 15-minute frequency rate during the peak hours of operations.

The study corridor was coded into TRAF-NETSIM as links and nodes. The network contained thirteen intersections along Washtenaw Avenue and one intersection on each side along the across street (if present). The existing geometry and traffic flow characteristics (peak hour traffic volume, traffic signal timing, and bus schedule) were coded into the simulation software.

CALIBRATION AND SENSITIVITY ANALYSES

The model was calibrated against the average and maximum queue length measures obtained in the field, both manually and by video camera, until it reached a fair level of conformity with field data. The sensitivity of the model to several variables including change in green time, percentage of trucks, and presence of buses in the network was tested. It was concluded that TRAF-NETSIM is sensitive to these variable.

CASES OF STUDY

The study investigated the impact of BPS treatments for the following basic cases on the existing corridor:

1. Base Case – No Preemption. The optimal signal settings were simulated and no preemption was granted to any bus. All other cases were compared against this reference case.
2. Case 1: Green Extension, Red Truncation, and No Compensation. In this case, no compensation was gives for the phase intervals that had been reduced.
3. Case 2: Green Extension, Red Truncation, with Compensation. In this case compensation was given for phase intervals that were reduced and were in high need to make up for capacity loss during preemption.
4. Case 3: Skip Phase without Compensation. In this case, a phase (or phases) may be completely skipped for one entire cycle, i.e., green time was extended for one full cycle.
5. Case 4: Skip with Compensation.
6. Case 5: Selective Plans. Based on the results obtained from the first four BPS plans, the most suitable plan (the plan(s) that did not cause excessive delays) for each intersection was selected.

7. Case 6: Conditional Preemption. In this case, the bus progression against its scheduled arrival time at different stations was compared. The most selective BPS plan (case 5) was awarded if the bus was late.

8. Changing Traffic Volume. The study also investigated the impact of a change in traffic volume on the main and cross streets on BPS results. Several ratios of main to cross street (from as low as 2:1 up to 5:1) were tested.

9. Preemption for Carpools. The study further investigated the impact of providing certain percentages of carpools, ranging from no carpool up to 10 percent, with preemption capabilities.

BPS SIMULATION RESULTS AND ANALYSIS

The first five basic cases (no preemptions and cases 1 through 4) of BPS treatments were simulated for the study corridor. The average vehicular delay results for cases 1 through 4 at each intersection were analyzed. The most appropriate preemption plan for each intersection was determined. After that, cases 5 and 6 of BPS plans were also simulated using TRAF-NETSIM. The summary of MOE for these preemption plans is summarized in Table 1.

Table 1: Summary of MOE for the Study Corridor

Case	Avg. Veh. Delay (Min./Veh-Trip)	Avg. Person Delay (Sec/Person-Trip	Avg. Bus Travel Time (Sec/Bus)	Avg. Bus Delay (Sec/Bus-Trip)
No Preemption	2.83	48.4	1361.6	79.6
Case 1	2.90	49.0	1361.8	79.6
Case 2	2.89	49.2	1326.3	78.6
Case 3	3.00	49.6	1296.1	79.1
Case 4	3.15	52.3	1288.0	76.1
Case 5	2.94	49.6	1301.4	77.6
Case 6	2.97	50.6	1342.6	82.9

The no preemption (the optimum setting) case provided the least amount of overall vehicular delay for the study network, as expected. BPS case number 5 was the “best” because it provides a balance between vehicular, persons, and bus travel time and delays, (selective preemption plans).

The impact of various traffic volumes at the network level was tested by changing the volume from 20 percent below up to 20 percent above the existing level, with a 10 percent incremental change for each case. For each volume level, signal settings (green splits and offsets) were optimized using TRANSYT-7F program. Case 5 preemption was then applied for these cases because it was determined that it is the best preemption case for the corridor. The results were then compared with results for the exiting traffic volumes. The summary of results is shown in Table 2.

Table 2: Cumulative Network MOE, With and Without Preemption

Volume Levels	Preemption?	Average Delay (Min/Veh-Trips)	Average Delay Sec/Person	Bus Travel Time (Min)	Average Bus Delay (Sec/Trip)
+20% Volume	With Preemption	5.23	90.3	131.9	102.9
	W/Out Preemption	5.23	90.2	126.8	97.6
+10% Volume	With Preemption	4.03	67.3	121.2	83.1
	W/Out Preemption	4.25	67.9	124.0	84.9
Base Volume	With Preemption	2.83	48.4	127.4	79.6
	W/Out Preemption	2.94	49.6	129.3	77.6
-10% Volume	With Preemption	1.95	33.6	122.4	73.9
	W/Out Preemption	1.98	34.2	119.3	70.9
-20% Volume	With Preemption	1.76	29.7	121.6	74.6
	W/Out Preemption	1.76	28.3	122.3	73.6

The results showed there was little impact of preemption, in terms of vehicular delay, at high (+20%) and low (-20%) volume levels. Bus travel time and delay decreased with the decrease in volume up to a certain low point and then started to level off.

Increasing carpools will reduce traffic volume and, thus reduce overall vehicular delay. It was also proposed in this study to provide certain percentages of carpoolers with preemption capabilities because carpooling is more attractive to users than buses. As such, 5 percent and 10 percent of vehicles throughout the network were converted to carpools. The total number of persons using the network was kept the same using the carpool auto occupancy rates of 3.5 and the average private vehicle occupancy of 1.3 (these were defaults used by TRAF-NETSIM). Therefore, the higher the carpool percentage the lower the network traffic volume.

The network signal settings were then optimized for each case of carpool percentages. BPS strategies were then applied to the network for each case of the carpoolers. The summary of results is shown in Table 3.

Table 3: Summary of Impact of Preemption for Carpools

Case	Avg. Veh. Delay (Min./Veh-Trip)	Avg. Person Delay (Sec/Person-Trip	Avg. Bus Travel Time (Sec/Bus)	Avg. Bus Delay (Sec/Bus-Trip)
Optimum Case	2.39	40.8	1208.4	82.1
W/ Preemption	2.39	40.6	1200.9	81.6
5% Carpool	2.26	38.1	1136.0	78.8
W/ Preemption	2.27	38.0	1113.0	78.9
10% Carpool	2.13	35.9	1110.7	78.6
W/ Preemption	2.42	39.8	1114.0	76.8

The results indicated that for each case of a carpool percentage, there was little impact at the overall network vehicular level for providing preemption for up to certain number of carpoolers. Results shown in Table 3 indicate that this percent is between 5 and 10 percent.

Carpoolers themselves benefited from preemption, although no carpool statistics could be obtained from TRAF-NETSIM. However, the benefit of providing preemption for carpoolers that it encourages carpooling. Therefore, the overall network vehicular traffic will be reduced. As a result, the overall vehicular delay will also be reduced as evident in Table 3.

On the other hand, buses generally benefited from carpool preemptions because the frequency of preemption calls increased. Therefore, as the bus arrived at the intersection, there was a high chance that a preemption call was already placed by a carpool. Thus preemption for buses was also granted.

The sensitivity of BPS to specific peak hour volumes and the ratio of main/cross street traffic volume was also evaluated. The simulations for these cases were conducted at an isolated intersection because of limitations of TRAF-NETSIM. Traffic volumes in TRAF-NETSIM are entered at the entry nodes only; therefore, intersection volumes cannot be controlled throughout the network.

Traffic volume ratios ranging of 2:1, 3:1, and 5:1 were selected. The main street volume was chosen to range from 1000 to 2000 vehicles per hour (VPH). The possible combinations of cases are shown in Table 4.

Table 4: Cases of Main Street to Cross Street Volume Ratios

Ratio	Main Street/Cross Street Volume (VPH)
Upper 2:1 (U 2:1)	1750/875 (*)
Middle 2:1 (M 2:1)	1500/750
Lower 2:1 (L 2:1)	1000/500
Upper 3:1 (U 3:1)	2000/667
Middle 3:1 (M 3:1)	1500/500
Lower 3:1 (L 3:1)	1000/333
Upper 5:1 (U 5:1)	2000/400
Middle 5:1 (M 5:1)	1500/300
Lower 5:1 (L 5:1)	1000/200

(*) The 1750 VPH was used instead of 2000 for the main street because network reached over saturation and queues accumulated. Therefore, preemption was not possible.

All nine cases were simulated first without preemption using the optimum green split for a simple two-phase signal with a typical 10 percent turning right and left. Then these cases were tested for various preemption strategies of green extension/red truncation, skip phase, compensation, and no compensation.

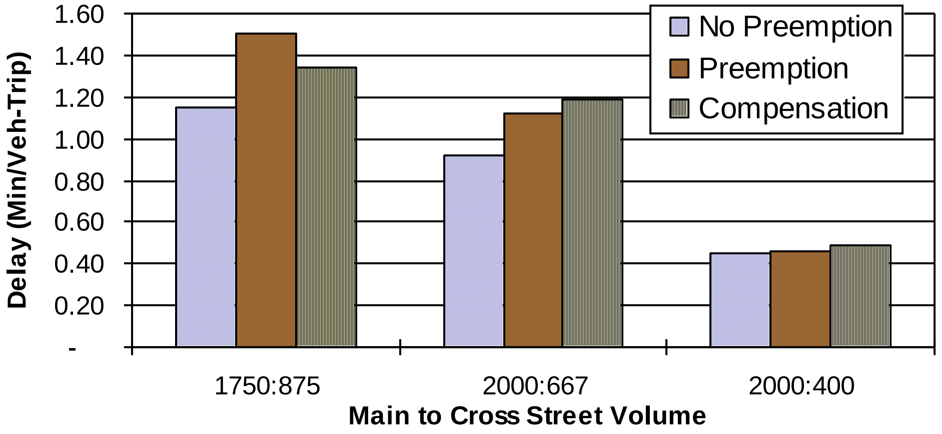
The average overall vehicular delays, the average person delays, and the bus delays were investigated as shown in Table 5. The results of vehicular and bus statistics are shown in Figures 1 and 2, respectively.

Table 5: Summary of Overall Statistics for the Volume Sensitivity Test

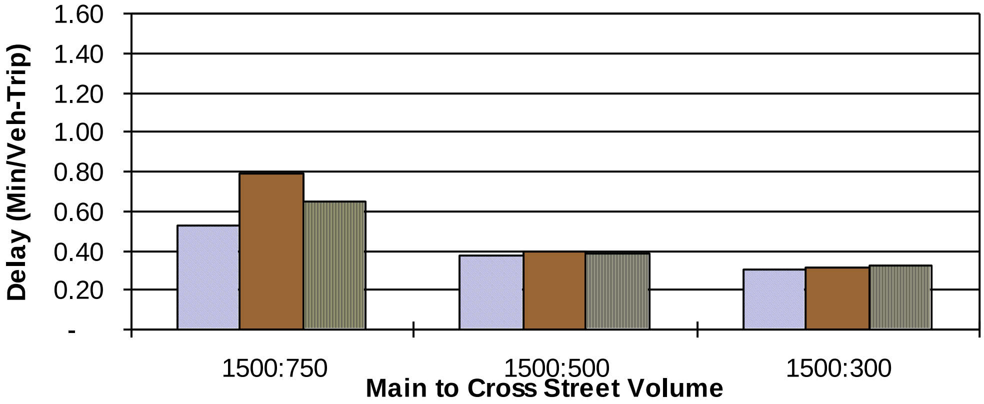
Volume Ratio (hourly volume)	With/out Preemption	Avg. Veh. Delay (Min/Veh-Trip)	Avg. Person Delay (Sec/Person-Trip	Avg. Bus Delay (Sec/Bus-Trip)
1500:750 (2:1)	No BPS	0.53	25.5	44.5
	BPS, no Comp.	0.79	40.0	38.8
	BPS w/ Comp.	0.65	32.3	39.2
1500:500 (3:1)	No BPS	0.37	16.6	43.1
	BPS, no Comp.	0.39	17.6	37.8
	BPS w/ Comp.	0.38	17.1	38.1
1500:300 (5:1)	No BPS	0.30	13.0	40.2
	BPS, no Comp.	0.31	13.5	37.1
	BPS w/ Comp.	0.32	13.7	37.4

Vehicle delay generally increased with preemption. The adverse effects of preemption (in terms of delay) were high at the lower volume ratios (2:1), and it became negligible at the upper ratio (5:1) and for low cross street volume. The preemption with compensation was better for low volume ratio (2:1) because of the high percentage of cross street ratio. However, compensation for (skipped phases) at very high volume ratios (5:1) added more delay to the intersection.

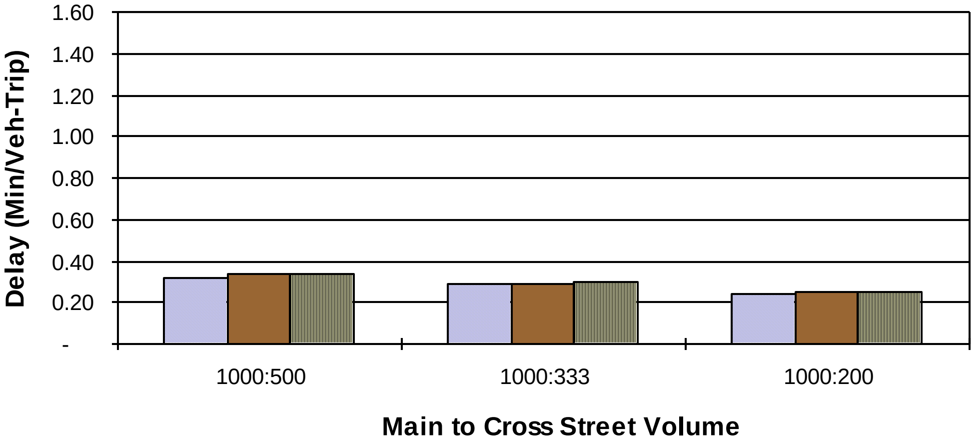
Furthermore, the average MOE for four cycles before preemption and four cycles after preemption (including the preemption cycle) were obtained for every preemption. The cycle length was set at 60 seconds and the bus headway was set at 5 minutes. The minimum time



A. High Volume



B. Medium Volume



C. Low Volume

Figure 1: Network Average Vehicle Delay

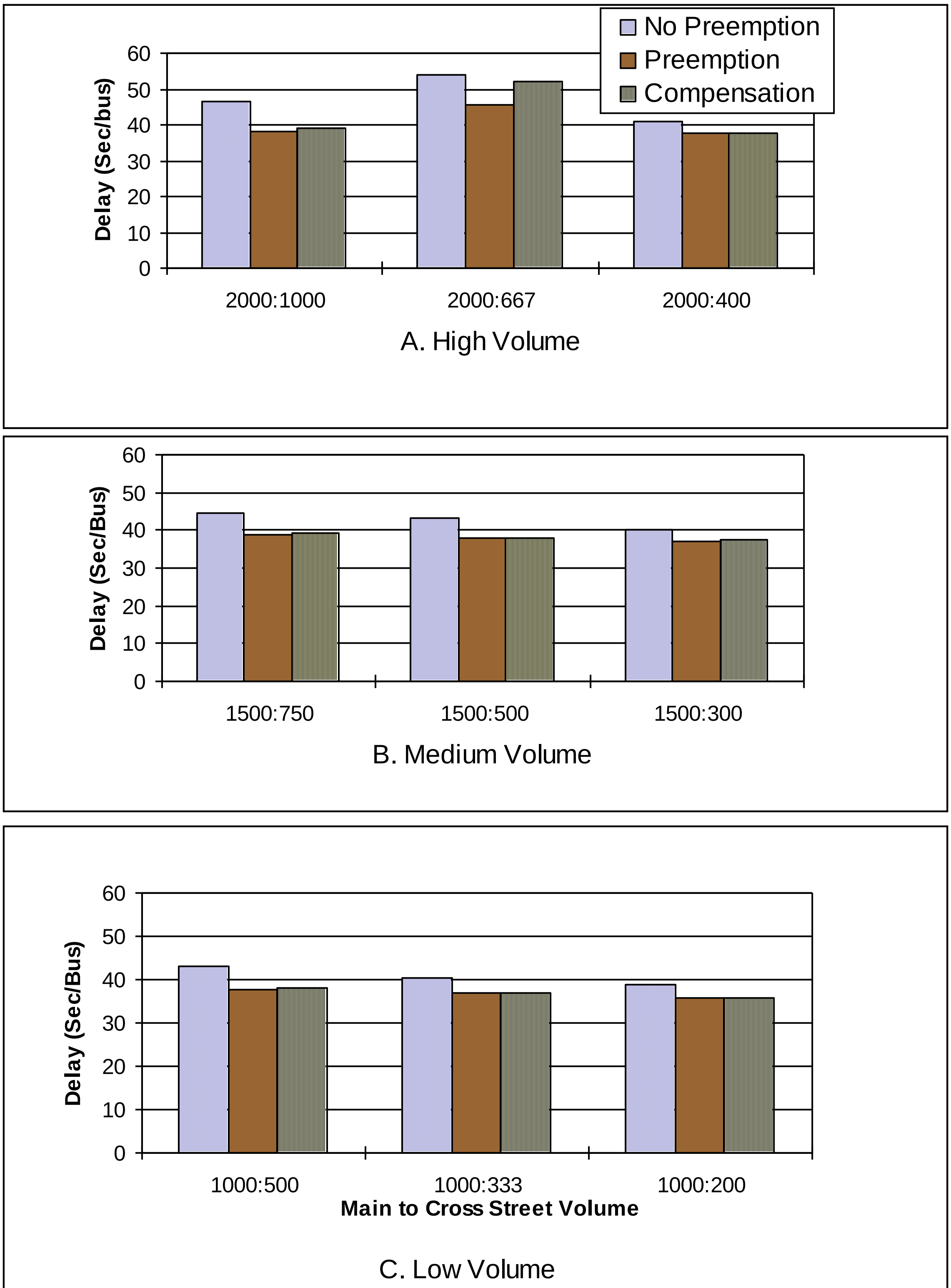


Figure 2: Average Total Bus Link-Trip Delay

for granting successive preemptions for buses was; therefore, four cycles to separate the effect of each preemption on another. Bus statistics also showed the same trend.

The preemption strategies of green extension/red truncation, skip phase, and with compensation were applied. For the cases with volume ratio of 5:1, the only possible plan was skip phase because the cross street green interval was already at the minimum.

Statistics for four cycles before preemption and four cycles after preemption for two preemptions were obtained. The results are shown in Figures 3 and 4 for various types of preemption plans tested.

Some of results between preemption #1 and #2 were conflicting. Low main street volumes would have a high chance of clearing the intersection at the original signal timing. Therefore, extending the green time to allow the bus to pass may not benefit vehicles other than the bus. Cross street right turning traffic may have enough gaps to turn on red and thus reduce excessive cross street delays. Therefore, preemption for these cases was generally beneficial.

It was observed in many instances that vehicle generation at the entry nodes, vehicle arrivals, driver’s behavior (cautious, normal, or reckless), and turning movements, which were randomly assigned by TRAF-NETSIM, played a major role in the network MOE. A different random number seed was used to test the effect of random variation. Results showed that the effect of randomness for some of the network statistics was sometimes as high as the effect of preemption. Although randomness influenced these results, not all the changes described were the result of randomness.

INSERT FIGURE 2

INSERT FIGURE 3

CONCLUSIONS

The study investigated several bus preemption signal strategies under various conditions. For each case of preemption run the following measures of effectiveness were evaluated: the network overall vehicular delay, the average trip lengths, number of vehicular trips, the number of persons-trips, average person delay, average number of bus-trips, bus trip length, and average bus delay. However, some of these MOE are not presented because the amount of information that can be displayed in this paper is limited.

The general conclusion for the study corridor was that BPS provided limited benefits. The costs of providing the BPS could outweigh its benefit. Therefore, it was not recommended to provide BPS for this corridor under the existing conditions of geometry, signal phasing, traffic volume, and bus operations.

Transportation planners are faced with question of when (under what conditions) the bus preemption signal is beneficial. Based on the previous results the following planning guidelineswere established.

- The optimum signal progression of a corridor provides the coordinated signal settings and the least network delay. Therefore, it is the most favorite strategy for the overall vehicular traffic in a corridor.
- BPS is disruptive to signal coordination of a corridor and; therefore, must be carefully investigated and used.
- No single BPS strategy is appropriate for a corridor. The most appropriate strategy (or strategies) at every intersection should be investigated first, and then applied at the particular intersection. The success or failure of a specific preemption plan is a function of signal phasing and intersection volume.
- BPS provides little benefit to a corridor with low bus frequency. The bus frequency for the study corridor was 15 minutes, and BPS benefits were limited. The impact of adopting any particular strategy or a set of strategies at any

intersection to the surrounding area or other intersections as well as the level of service for the entire corridor should be studied.

- The Green Extension/Red Truncation preemption plan was the least disruptive among the other preemption plans to the coordinated signal system.
- The skip phase preemption should be used for intersections with high cross street traffic volume or low main street to cross street volume ratio.
- Compensation for the green time cut from the cross street should not be used when main street traffic volume is high.
- The impact of (delay caused by) BPS on the general vehicular traffic was limited for very low and very high network volumes.
- In general, the 3:1 main to cross street ratio is a borderline. Providing BPS for intersections above this ratio is beneficial.
- For main to cross street ratios below 3:1, BPS is not be favorable, and if preemption is provided, compensation is warranted.
- BPS is also beneficial when cross street volume is less than 500 VPH (on two lanes).
- Skip phase preemption plan is beneficial for high main to cross street ratios (above 3:1).
- BPS for carpools is more attractive to users than buses. Providing limited number (or percentage) of carpools with BPS is beneficial. For the study corridor, this percent was between 5 and 10 percent of the main street traffic.

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