Optimum Bus Headway for Preemption
A Simulation Approach

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Preemption techniques are designed to provide preferential treatment for buses at signalized intersections. A preemption strategy, if properly designed, can provide continuous green phases for buses at successive intersections, thereby reducing travel times and delays along the bus route. However, the length of delay incurred by all the vehicles in the system may be affected by the different bus headways under preemption operation. Unfortunately, no formal technique is available to assess the cumulative delay consequences of bus headways. The application of a simulation model, NETSIM, to test the effect of different headways is presented. NETSIM was selected because it can microscopically simulate vehicular movements on a street network and because an animation feature within NETSIM is available that allows the user to track an individual vehicle from the source to the sink. A major bus route in Ann Arbor, Michigan, was used as the experiment site. The major conclusions are that NETSIM can generate delay data at various levels of aggregation (e.g., link, node, and route) that can be used to assess the operational consequences of bus headways under preemption conditions. For the volume levels studied in the project, the savings in delay along the bus route resulting from preemption appears to be a good measure for determining the optimum headway.

Preemption techniques are designed to provide preferential treatment for buses at signalized intersections. Uncertainties resulting from variations in passenger boardings and deboardings at bus stops make the prediction of the exact arrival times of buses at intersections extremely difficult. The location of bus stops also affects the ability of buses to travel through intersections uninterrupted. A preemption strategy, if properly designed, may provide continuous green phases for buses at successive intersections.

A preemption system includes instrumented buses, detectors, sensing devices, and a real-time traffic-control device. The system should be able to detect an approaching bus, predict its exact arrival time at the intersection, and communicate the information to the signal control for necessary action. Preemption can be granted only if the amount of preemption needed by the bus to clear the intersection does not exceed a specified maximum value. With the emergence of intelligent transportation systems (ITS), preemption appears to be a viable tool for providing priority for buses even though a system with all the listed features does not currently exist (*1,2*).

Three broad categories of preemption strategies are possible: green extension (GE), red truncation (RT), and red interruption (RI). In GE, the green phase on the bus route can be extended by a specified amount. RT allows a premature termination of the red phase on the bus route. In RI, a short green phase, not contiguous with the adjacent green, is injected within the red phase along the bus route; the lack of contiguity in this case calls for an additional amber phase. In all three cases, the result is an increase of green time along the main street, allowing the bus to cross the intersection.

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PROBLEM STATEMENT

Limited experience with signal preemption in the United States and Europe suggests that preemption is a workable solution and, if implemented properly, may result in significant operational improvements along the bus route. It is likely to contribute to reduced delays and queue lengths and to increased throughput along the bus route. It also may adversely affect the traffic operation along the cross street by increasing delays and queue lengths and by reducing throughput. As discussed in a following section, several studies have used simulation techniques to try to assess the possible consequences of preemption of an intersection or of a series of intersections. Khasnabis et al. (*3*) demonstrated the use of the microscopic simulation model NETSIM to evaluate different bus preemption strategies.

In most transit operations, determination of bus headways is a policy decision and a specified set of peak and off-peak headways is followed for bus routes, on the basis of a general understanding of the route-level demand. But the complex interaction between vehicles of different classes and traffic control devices may have varying effects on system operation for different bus headways. Particularly if the transit operator is considering preemption to improve bus operation, an objective decision on bus headways is desirable. Very little work is reported in the literature to address the question of the optimum bus headway for preemption operation. Research reported in this paper attempts to address this gap.

In this paper, the authors present a simulation approach in which the microscopic model NETSIM was used to examine the possible consequences of different headways for bus preemption operation. A series of intersections on a major bus route in Ann Arbor, Michigan, was selected for this demonstration.

BACKGROUND

TRAF-NETSIM is a microscopic simulation model designed to depict the dynamics of traffic operation on an urban network (*4*). It uses a fixed-time, discrete-event approach to model the movement of each vehicle in the network as it travels along the links, crossing the intersections controlled by various devices. The model computes a wide range of measures of effectiveness (MOEs) as the vehicles interact with one another and respond to the control devices. The user has the option to vary roadway features including volume, network geometry, turning movements, signal timing, and offsets. The MOEs generated by the model are expected to reflect the effect of the changes in these input variables.

NETSIM has been applied as an evaluation tool for many situations ranging from complex, multimodal networks to simple, isolated intersections (*5*). The focus of these studies has ranged from the evaluation of traffic control and geometric alternatives to the assessment of NETSIM itself as an analytic tool. Among the studies to test alternative geometric and control strategies are the works of Maki and Branch; Schafer; and Bruce and Hummer (*6–8*). Other researchers have tested NETSIM on drawbridges (*9*), light rail transit (*10*), approaches to congested urban networks (*11*), and real estate development (*12*). More recently, studies to address the issue of variability of NETSIM output have been conducted by Kim and Messer (*13*), Rathi and Santiago (*14*), Chang and Kanaan (*15*) and Rathi (*16*).

Despite the comprehensive application of NETSIM to assess various traffic and geometric situations, very little effort is reported in the literature on its use in transit operations. Among the few studies reported are those of Yedlin and Lieberman (*17*) and Smith (*18*). Yedlin and Lieberman in 1981 attempted to assess the benefits to transit operations of implementing bus signal priority strategies through the use of NETSIM. Smith developed an algorithm for NETSIM to allow signal preemption by buses in 1985. This algorithm later was programmed into the model by FHWA and tested by comparing NETSIM output with the results obtained from manual implementation of bus preemption at an intersection. However, little is reported in the literature on the application of this model.

METHODOLOGY

The primary purpose of the research project that serves as the basis of this paper was to develop a procedure for assessing operational consequences of signal preemption (*3*). A review of the literature on traffic simulation models led to the selection of NETSIM because of its versatile features, its ability to microscopically simulate vehicular movements on a street network, its long record as a powerful traffic simulation tool, and the availability of animation features. This decision was made although there are only limited applications of NETSIM with a bus as the primary vehicle.

Experiment Site

A major transit corridor [Routes 4 and 9, Ann Arbor Transportation Authority (AATA)], Washtenaw Avenue, located in southeast Michigan 40 mi west of Detroit, was selected as the experiment site. It connects the central business district (CBD) of a small town, Ypsilanti, with the western end of the city of Ann Arbor, utilizing a transfer point at the Ann Arbor CBD. The transit ridership along this corridor is approximately 2,000 per day, with the entire AATA system carrying approximately 14,000 passengers daily.

Following an examination of the geometric and traffic features, a decision was made to concentrate on a portion of the eastern section of the transit corridor (Route 4) consisting of 11 signalized intersections as the experiment site. The sections near the CBDs at the two ends of the bus route were excluded because of high pedestrian volume and close intersection spacing. Buses are operated on this route at 15- and 30-min headways during peak and off-peak periods, respectively.

After further examination, the experimental site was limited to seven successive intersections for an approximate corridor length of 3 km (1.84 mi) (Figure 1). Several intersections at either end of this segment were eliminated because the signals were either actuated or semiactuated. Preemption of actuated signals was beyond the scope of the project. Table 1 lists the seven intersections along with relevant traffic and roadway data.

NETSIM Calibration

Initial validation efforts were directed toward testing the sensitivity of the model output to changes in input variables and parameters. On completion of a series of sensitivity analyses, calibration efforts concentrated on comparing the model output with observed traffic data. As a part of this effort, roadway data on traffic volume, roadway geometrics, and traffic operational features were collected from the site. The model calibration process consisted of using these data as input and running NETSIM by selectively changing model parameters until the model output compared favorably with the observed data. Queue and delay data were used as MOEs for comparison purposes. Detailed results of the calibration were presented by the authors elsewhere (*3*).

NETSIM Application

After calibration, the model was used to test the consequences of three sets of headways under various preemption strategies. NETSIM, in its current form, cannot be applied directly for such purposes. However, the vehicle-generation process within NETSIM ensures that a bus is generated in the stream so that the specified headway is maintained. The animation feature of the model was used for this research. The effect of the bus preemption of a series of intersections as it travels from the source to the sink along the target direction was assessed over a 2-hr simulation period.

The animated graphic version was used to track the subject bus from the source to the sink for the base case and for the preemption case. For the preemption case, the arrival time of the bus at each intersection was noted. If it arrived during the green phase, nothing was done. If it arrived during the red phase, the signal-timing data were changed so that the bus would cross the intersection provided that the additional green time needed did not exceed a specified maximum of 10 sec. Either a GE or an RT was used depending on the arrival time of the bus relative to the signal phase. The RI strategy was not explored because the cycle length of 70 sec was considered too short and would warrant additional amber phases of 5 sec. A total of 2 hr of simulation was conducted for each headway group for the base condition and preemption condition by using the calibrated model. The simulation results were used to test the sensitivity of delays to bus headways.

RESULTS

The MOE used in the evaluation of bus headways is person-minutes of delay. However, a direct comparison of the person-minutes of delay in the base and preemption cases would not constitute a valid analysis because of the unequal number of vehicles likely to be processed during the two cases. Hence the MOE in the preemption case was corrected through a normalization procedure using the following relationship:

$$\text{corrected delay (person-minutes) for preempted case} = (VT1/VT2) * D_p$$

where

$VT1$ = total vehicle trips in base case,
$VT2$ = total vehicle trips in preempted case, and
D_p = total delay (person-minutes) in preempted case.

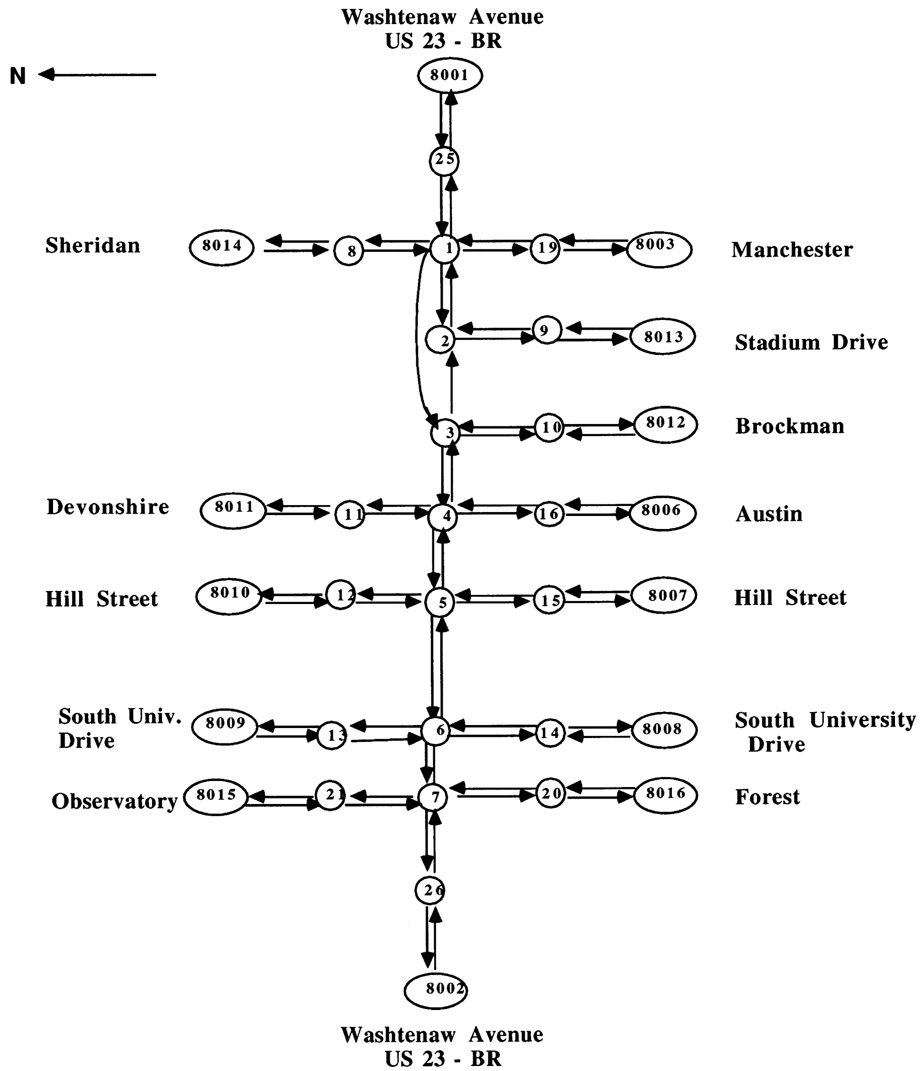


FIGURE 1 Link node diagram.

The following assumptions were made in the model application process:

1. Average bus occupancy, 40 persons per bus;
2. Average car occupancy, 1.4 persons per car;
3. Cycle length, 70 sec;
4. Preemption, 10 sec;
5. Bus headway, 15 min; and
6. Target direction, eastbound (from Forest to Manchester).

Three pairs of headways (15-min, 10-min, and 7.5-min), each consisting of base case and preemption case and each case consisting of two batches, were simulated using the animation version of NETSIM. Ideally, the average bus occupancy should have been adjusted upward or downward, depending on an increase or decrease in headways, to reflect actual transit demand. For each base case, buses on the main street in the eastbound direction (the target direction) were tracked from the source to the sink, with input data that reflect the current traffic, roadway, and operational characteristics for a 2-hr simulation period. The present version of NETSIM has a maximum of 19 time periods for each run, which makes it impossible for the user to complete a 2-hr simulation in one batch. Because of this limitation, the 2-hr simulation was conducted in two batches.

Next, for the same set of conditions and random number seed, the preemption case was simulated. As the bus approached an intersection, a check was made to determine if it needed and qualified for preemption. If the answers to both were positive, preemption was granted and the procedure was continued to the following intersections until the bus crossed the last intersection. Not all buses in need of preemption may qualify for it because preemption can be granted only if the amount of preemption needed to clear the intersection does not exceed a maximum value.

Figure 2 presents the means for granting preemption by the method described for a 15-min headway operation for the first batch. Note that the target for the subject bus is from Intersection 7 to Intersection 1. Figure 2 provides the arrival time of each bus at the intersections for the base case and the preemption case. In the preemption case, the first bus arrives at Intersection 5 at the 66th sec, toward the end of the red phase. The red phase is 28 sec long, with a

TABLE 1 Seven Intersections with Traffic and Roadway Data

Intersection (#)	Volume (no. of vehicles during the evening peak hour)												Speed on the Approaches (mph)	
	Eastbound (Target Direction)			Northbound			Westbound			Southbound			Main Street	Cross Street
	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right	Left	Thru	Right		
Forest Observatory (7)	22	305	123	81	97	8	13	349	81	257	223	19	30	25
South University Drive (6)	12	537	21	26	66	76	130	406	11	22	53	11	30	25
Hill Street (5)	0	1250	70	107	137	136	0	660	27	28	94	27	30	25
Austin/ Devonshire (4)	42	1102	37	18	25	12	16	651	23	14	41	11	30	25
Brockman (3)	-	1031	97	44	-	28	19	646	-	-	-	-	35	25
Stadium Drive (2)	-	1025	34	0	-	810	774	665	-	-	-	-	35	45
Manchester/ Sheridan (1)	38	1709	102	42	32	65	104	1370	24	40	23	33	40	25

Note: 1 mph = 1.6 km/hr.

cycle length of 70 sec. An RT of 10 sec allows the bus to travel through the intersection without stopping and to arrive at Intersection 4 on the 62nd sec. An RT of 10 sec allows the bus to cross Intersection 4 and arrive at Intersection 3 at the 45th sec, toward the end of the green phase. At Intersection 3, a 10-sec GE allows the bus to travel through without stopping. The bus arrives at the last two intersections during green phases so that it can travel through the corridor without stopping at any intersection. For the remaining buses, which are released every 15 min, a similar procedure was followed to provide these buses continuous green phases at all the intersections.

After the preemption is granted, the arrival times of the bus at the following intersections change from those in the base case. Also, in both the base case and the preemption case, the bus is allowed to pick up and drop off the same number of passengers at the bus stops. Necessary boarding and deboarding times are accounted for in the computation of the bus arrival time. Results of the simulation are presented at three levels of aggregation.

Link-Level Results

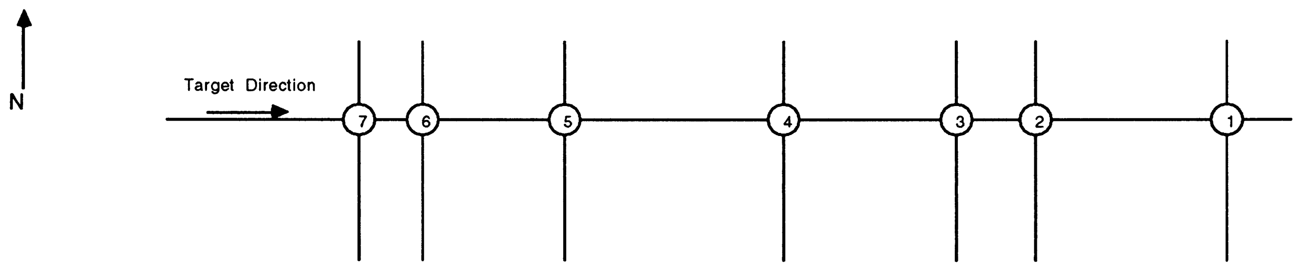
In Table 2, results of Batch 1 of the 10-min headway operation are presented at the link (approach) level for all seven intersections. Similar information for Batch 2 is presented in Table 3, to show a complete 2-peak-hr simulation. A comparison in the delay data (in person-minutes) between the base case and preemption case is presented in the last column. As a general rule, a reduction in delay in the eastbound Main Street direction (target direction) is expected. A smaller reduction in the westbound Main Street direction also is expected. Along the cross street, increases in delay are expected for obvious reasons. The last column in Tables 2 and 3 illustrates that the trends in the percent change in person-minutes of delay are in the expected direction. Similar information at the link level for the other two headway groups, 7.5 min and 15 min, was compiled but is not presented here.

Node-Level Results

Results of the simulation are presented at the node (intersection) level for each of the seven intersections in Table 4, which illustrates that in most cases a reduction in delay at the intersection level ranges from a low of 0.2 percent to a high of 15.5 percent. In a few cases unwarranted increases in delay at the intersection level are observed. Also, the significant delay and the batch-to-batch variation in delay at the Stadium Drive intersection are directly attributable to the large peak-hour volume on Stadium Drive. Traffic data presented in Table 1 show that the volume on Stadium Drive is significantly higher than that on other cross streets.

Route-Level Results

Information at the route level is presented in Table 5, disaggregated by the following four categories: main street target direction, main street both directions, cross street both directions, and main street and cross street combined. Table 5 indicates that there was a decrease in delay for the main street not only in the target direction, but also when both directions are combined. In the latter case, the amount of reduction is somewhat smaller for obvious reasons. Further, a decrease in delay along the cross direction is observed, although this was not expected. Last, when all the directions are combined, a decrease in delay is observed, indicating that decreases on the main street clearly outweigh increases along the cross street.



		7	6	5	4	3	2	1
Cycle G/R splits (Main Street)		33/24**	45/25	42/28	44/26	44/26	***	44/26
Bus reaching* intersection (Base case)	1st Bus	48	37	66	55	68	62	40
	2nd Bus	48	48	38	46	60	28	30
	3rd Bus	49	43	19	7	69	32	32
	4th Bus	29	51	34	18	32	42	11
	5th Bus	27	40	36	31	19	22	22
Bus reaching* intersection (Preemption case)	1st Bus	48	37	66 (RT)	62 (RT)	45 (GE)	13	65
	2nd Bus	48	48 (GE)	24	32	65 (RT)	26	25
	3rd Bus	49	43	19	7	69 (RT)	16	27
	4th Bus	29	51 (GE)	26	9	21	28	22
	5th Bus	27	40	36	31	19	29	22

* This is the time elapsed from the start of main street green in the corresponding cycle, in seconds.

RT - Red Truncation

GE - Green Extension

** There is a separate left turn phase of 13 sec G+A time after the main street green.

*** Has a complex two–phase signal. In this the E/B approach of the main street has (G+A) time of 42 sec and W/B (G+A) time at 27 sec whereas the cross street (Stadium Drive) (G+A) time is 22 sec.

FIGURE 2 Five preempted buses (15-min headway).

Comparative Headway Analysis

Tables 2 through 5 present the consequences of preemption for a 10-min headway operation for different levels of aggregation. Similar data were generated for 15 min and 7.5 min of headway with all other input variables and parameters unchanged but are not included here. A comparative analysis of the delay data at different headways is presented in Tables 6 and 7.

Table 6 presents an intersection-level analysis and can be used to trace changes in delay at each intersection resulting from changes in headways. Similar changes in delay at the route level can be observed from the data presented in Table 7, which

TABLE 2 Comparison of MOEs for Preemption and Base Cases, Batch 1 (10-min Headway)

Intersection/ Approach	Vehicle Trips (number)		Delay (person-minutes)		Corrected Delay (person-minutes)	
	Base	Preempted	Base	Preempted	Base	Preempted
Forest/Observatory						
E/B (Main St.) (7a)	473	475	442.8	358.7	442.8	357.1
N/B(Cross St.) (7b)	196	196	68.5	74.8	68.5	74.8
W/B (Main St.) (7c)	363	363	323.0	327.7	323.0	327.7
S/B (Cross St.) (7d)	523	523	196.9	202.4	196.9	202.4
S. Univ. Drive						
E/B (6a)	580	581	141.6	122.0	141.6	121.7
N/B (6b)	176	176	151.5	131.5	151.5	131.3
W/B (6c)	576	570	186.3	177.1	186.3	178.9
S/B (6d)	91	91	36.6	38.8	36.6	38.8
Hill Street						
E/B (5a)	989	987	700.7	678.2	700.7	679.5
N/B (5b)	400	400	225.5	226.1	225.5	226.1
W/B (5c)	710	710	388.8	381.2	388.8	381.2
S/B (5d)	156	156	46.5	46.4	46.5	46.4
Austin Devonshire						
E/B (4a)	1276	1277	630.4	628.5	630.4	628.0
N/B (4b)	58	58	23.5	23.7	23.5	23.7
W/B (4c)	698	698	295.5	298.0	295.5	298.0
S/B (4d)	69	69	23.3	23.1	23.3	23.1
Brockman						
E/B (3a)	1019	1017	499.9	491.9	499.9	492.8
N/B (3b)	75	75	23.2	23.9	23.2	23.9
W/B (3c)	670	670	457.3	451.0	457.3	451.0
Stadium Drive						
E/B (2a)	939	933	706.4	672.1	706.4	676.4
N/B (2b)	708	708	3416.7	3416.7	3416.4	3416.7
W/B (2c)	758	758	1808.4	1823.8	1808.4	1823.8
Manchester/Sher.						
E/B (1a)	1645	1633	665.2	659.7	665/.2	664.5
N/B (1b)	176	176	74.9	73.8	74.9	73.8
W/B (1c)	1492	1492	1311.6	1320.7	1311.6	1320.7
S/B (1d)	100	100	50.2	50.6	50.2	50.6

Assumptions:

Bus Capacity - 40 persons/bus
Car Capacity - 1.4 persons/car
Cycle length - 70 sec
Preemption - 10 sec
Bus Headway - 10 min
Target Direction - E/B(from Forest to Manchester)

Note: E/B = eastbound; N/B = northbound; W/B = westbound; S/B = southbound.

illustrates that if reducing delay along the target direction is the objective, a 10-min headway produces the best results. Since the entire preemption operation was conducted with the main street eastbound direction as the target direction, such an objective should be logical. Note that a 10-min headway also produces the best results when reduction in delay along the main street for both directions is the objective. If reduction in delay for the main street and all cross streets is the objective, a 7.5-min headway should be considered the best alternative. However, these observations must be tempered by the limited simulation data base used. A decision to arrive at an optimal headway can be made only after repeated simulation runs for these different headway groups.

TABLE 3 Comparison of MOEs for Preemption and Base Cases, Batch 2 (10-min Headway)

Intersection/ Approach	Vehicle Trips (number)		Delay (person-minutes)		Corrected Delay (person-minutes)	
	Base	Preempted	Base	Preempted	Base	Preempted
Forest/Observatory						
E/B (Main St.) (7a)	456	456	488.4	336.0	488.4	336.0
N/B(Cross St.) (7b)	185	185	66.5	66.7	66.5	66.7
W/B (Main St.) (7c)	323	330	261.3	274.8	261.3	268.9
S/B (Cross St.) (7d)	495	494	196.9	183.7	196.9	184.0
S. Univ. Drive						
E/B (6a)	577	577	127.5	134.2	127.5	134.2
N/B (6b)	170	169	115.4	153.1	115.4	154.0
W/B (6c)	564	560	221.8	211.1	221.8	212.6
S/B (6d)	186	186	38.0	38.9	38.0	38.9
Hill Street						
E/B (5a)	982	982	689.2	695.2	689.2	695.2
N/B (5b)	377	380	240.8	215.2	240.8	213.5
W/B (5c)	685	685	385.1	369.4	385.1	369.4
S/B (5d)	147	147	54.2	51.0	54.2	51.0
Austin Devonshire						
E/B (4a)	1255	1261	643.1	677.1	643.1	673.8
N/B (4b)	55	55	19.0	18.6	19.0	18.6
W/B (4c)	683	682	304.1	294.5	304.1	294.9
S/B (4d)	65	65	24.8	23.5	24.8	23.5
Brockman						
E/B (3a)	1010	1026	510.5	522.9	510.5	514.7
N/B (3b)	71	71	20.4	21.2	20.4	21.2
W/B (3c)	662	662	502.6	489.7	502.6	489.7
Stadium Drive						
E/B (2a)	981	981	759.2	785.8	759.2	785.8
N/B (2b)	801	801	739.4	728.1	739.4	728.1
W/B (2c)	809	809	381.3	380.3	381.3	380.3
Manchester/Sher.						
E/B (1a)	1784	1783	1008.8	845.9	1008.8	846.3
N/B (1b)	167	167	67.9	66.7	67.9	66.7
W/B (1c)	1493	1493	495.4	525.5	495.4	525.5
S/B (1d)	95	95	32.8	32.6	32.8	32.6

Assumptions:

Bus Capacity - 40 persons/bus
Car Capacity - 1.4 persons/car
Cycle length - 70 sec
Preemption - 10 sec
Bus Headway - 10 min
Target Direction - E/B(from Forest to Manchester)

Note: E/B = eastbound; N/B = northbound; W/B = westbound; S/B = southbound.

CONCLUSIONS

The purpose of this paper is to explore the feasibility of using simulation as a tool for determining the optimum headway under bus preemption operation. The animation version of NETSIM was used to track buses between a series of intersections on a simulated network. A major bus route in Ann Arbor, Michigan, was used as the experiment site. Actual traffic and roadway data from this site were used as model input. Before its application NETSIM was validated with field data. The conclusions of this paper are the following:

1. By using the animation process within TRAF-NETSIM, buses may be tracked from the source to the sink along the target direction and the buses may be used as subject vehicles as they interact with

TABLE 4 Comparison of Person-Minutes of Delay at Intersection Level (10-min Headway)

Batch	INTERSECTION											
	Forest/Observatory			South Univ. Drive			Hill Street			Austin/Devonshire		
	Base Case	Pre-empted Case	% Change	Base Case	Pre-empted Case	% Change	Base Case	Pre-empted Case	% Change	Base Case	Pre-empted Case	% Change
1	1031.2	962.0	-6.7	516.0	470.7	-8.7	1361.5	1333.2	-2.0	972.7	972.8	+0.01
2	1013.1	855.6	-15.5	502.7	539.7	+7.3	1369.3	1329.1	-2.9	991.0	1010.8	+1.9

Batch	**INTERSECTION**								
	Brockman			Stadium Drive			Manchester/Sheridan		
	Base Case	Preempted Case	% Change	Base Case	Preempted Case	% Change	Base Case	Preempted Case	% Change
1	980.4	967.7	-1.2	5931.2	5916.9	-0.2	2101.9	2109.6	+0.3
2	1033.5	1025.6	-0.7	1879.9	1894.2	+0.7	1604.9	1471.1	-8.3

TABLE 5 Comparison of Person-Minutes of Delay at Route Level (10-min Headway)

Batch	Main St. Delays in E.B. direction (Target Direction)			Main St. Delays in both directions			Cross St. Delays in both direction			Delays in Both Main St. & Cross St.		
	Base Case	Pre-empted Case	% Change	Base Case	Pre-empted Case	% Change	Base Case	Pre-empted Case	% Change	Base Case	Pre-empted Case	% Change
1.	3787	3620	- 4.4	8558	8401	- 1.8	4337	4331	- 0.1	12895	12732	- 1.2
2.	4227	3986	- 5.6	6778	6527	-3.7	1617	1599	- 1.1	8395	8126	- 3.2

TABLE 6 Change in Person-Minutes of Delay Between Base and Preemption Cases, Intersection Level

Headways	Forest/Obser.	S. Univ. Drive	Hill Street	Austin/Devon	Brockman	Stadium Drive	Manch./Sheridan
15 min	-0.9	+18.2	-2.5	-3.7	-3.2	-0.5	-2.1
10 min	-11.0	-0.8	-2.5	+1.0	-1.0	+0.3	-3.4
7.5 min	-1.9	+1.1	-0.7	-2.7	-3.2	-1.5	-0.4

TABLE 7 Change in Person-Minutes of Delay Between Base and Preemption Cases, Route Level

Headways	Main Street (E/B)	Main Street (Both)	Cross Street (Both)	Main & Cross Streets
15 min	-4.0	-2.3	+3.2	-0.7
10 min	-5.0	-2.6	-0.3	-2.0
7.5 min	-1.5	-2.0	-4.1	-2.7

all other vehicles on the simulated roadway. This method appears to be a valid way to assess consequences of signal preemption.

2. By using the tracking mechanism, the batch process may be used to compile operational statistics over a 2-hr simulation period for the base condition and the preemption condition.

3. The batch process can be used to assess the operational consequences of varying bus headways under preemption conditions. However, a larger number of simulation results are desirable before optimum headways can be statistically validated.

4. For the volume levels studied, the limited number of simulations, and the three sets of bus headways simulated, the 10-min headway appears to produce the largest reduction in delay (compared with the base condition and the preemption condition) for all vehicles along the target direction, as well as for all vehicles along the bus route (both directions combined). Whether these reductions justify the implementation of preemption cannot be determined without a comprehensive benefit-cost analysis. It is possible, however, to conclude from the limited simulation data that signal preemption does not have any adverse effect on delay.

5. The procedure proposed for testing the operational consequences of varying bus headways under preemption conditions appears workable. However, further testing is recommended before such a process is formalized.

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