An Evaluation of Signalized Intersection System Analysis Techniques

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A system of signalized intersections is a critical element in the smooth operation of both arterial and urban street facilities. The amount of vehicular and pedestrian traffic which can be processed by a system of intersections depend on a) characteristics of the traffic and pedestrian stream, b) traffic control measures, c) various physical and operating characteristics of the roadway and d) the environmental conditions which have a bearing on the experience and actions of the driver. Because many such factors influence interrupted flow through a system of intersections, it is important that the best technique be utilized for analyzing a system of intersections. A system of signalized intersections is defined as two or more signalized intersections that are closely spaced (under 1500') together. Intersection systems not only control, to a large extent, the capability of major and secondary arterial streets to accommodate the flow of traffic and pedestrians in an urban area, but they also may seriously affect or limit the ability of nearby freeways to perform at maximum efficiency. The system of signalized intersections selected for this study provide an ideal representation of this operational scenario.

Today there is a variety of engineering analysis tools/software's available to analyze and model an existing or proposed signalized intersection system. While the majority of the analysis tools provide the engineer with valuable information pertaining to intersection system delays, queue length, saturation flow, levels of service, etc, there is not a single analysis software that could accurately predict all this valuable information for an actual or proposed field condition. For example, when signalized intersections are closely spaced, some software analysis techniques are good at predicting delays only and weak at predicting other valuable information such as queue length or queue spill back.

The purpose of this report is to evaluate techniques for the design and analysis of a system of signalized intersections. As a case study, a grid system of eight signalized intersections located in downtown Boston was chosen for this report. These eight closely spaced intersections, provide an ideal condition for testing analysis tool's ability to predict all the available information related to delays, queue length, saturation flow rates and other measures of effectiveness.

This report compares several analysis techniques and their predicted and observed results for the eight observed network intersections. Evaluation includes testing how well these techniques predict delays, queue lengths, queue spillback and levels of service. In addition, sensitivity analyses are performed to evaluate the limitations of these techniques.

Finally, the report will determine how efficiently each analysis technique performed on the signalized intersection system. In addition, the report shall spell out the requirements for an "acceptable technique" to aid in the design and evaluation of signalized intersection systems.

LITERATURE REVIEW

The history of signalized intersection system analysis techniques is addressed in this review. A detailed literature search revealed that signalized intersections capacity have been subjected to a great deal of study since the mid 1950's. The procedures/techniques for the design and analysis of signalized intersections are tabulated as follows:

Software	Software's Function	Types of Facility
1. HCS – Highway Capacity Software Release 3.0	Computes intersection capacity, delays and level of service (LOS) based on the Highway Capacity Manual.	Developed for analyzing isolated intersections. The intersections may be signalized or controlled by two-way or all way stop signs. Applying arrival adjustment factors to interconnected lane groups may approximate progression.
2. PASSER II	Analyzes arterial progression only. Optimize and simulate only the mainline arterial and ignores the side streets. Optimize cycle length, splits and offsets. Provide bandwidths, time-space diagram, efficiency attainability, fuel consumption and speed progression.	Developed for analyzing arterial progression.
3. PASSER III	Analyzes signalized diamond interchanges only. Computes signal timing coordination for the signalized interchange. Optimizes offset and splits.	Developed for analyzing signalized diamond interchanges.
4. PASSER IV	Analyzes a network of signalized intersections and based on progression bandwidth optimization also based on MAXBAND.	Developed for a network of more than one arterial where bandwidth optimization is the main goal . It also computes the cycle length and green split but not phasing .
Software	Software's Function	Types of Facility

5. SYNCHRO	Analyzes and optimizes a network of signalized intersections. It provides a detailed summary report on capacity, level of service, lanes, volumes, timing, queue lengths, blocking problems, delay, stop and fuel consumption.	Developed for analyzing and simulating a network / grid of signalized intersections.
6. SimTraffic	Analyzes and simulates a network/ grid of signalized and unsignalized intersections. It provides result on the amount of MOEs such as delay, stops, queues, average speed, fuel consumption, and throughput. Sim Traffic models intersection traffic throughput based on car following formulas, acceleration rates, deceleration rates, reaction to yellow light, reaction times, gap acceptance, cruise speed, turning speed and vehicle driver performance characteristics.	Developed for analyzing and simulating a network / grid of signalized and unsignalized intersection.
7. SIDRA	Analyzes signalized and unsignalized intersections and roundabouts. It computes delay, level of saturation , and level of service. Its output consists of queue length, stop rate, fuel consumption, and reserve capacity. Calculates queues for various probabilities of occurance based on empirical data.	Developed for isolated signalized intersections and roundabouts
8. SIG/CINEMA	Analyzes and optimizes cycle length, timing and phasing sequence. Equalizes v/c ratios for critical lane group analysis, delay/vehicle for critical lane group and all approaches. Minimizes total delay of intersection.	Developed for isolated signalized intersections.
Software	Software's Function	Types of Facility

9. HCM/CINEMA	Computes level of service and lane capacity for all approaches. Similar to the HCM (1985) procedure for analyzing isolated signalized intersection.	Developed for isolated signalized intersection.
10. TRANSYT – 7F	Evaluate existing timings and optimize proposed condition to minimize stops, delay, fuel consumption and cost. Provides delays, average queues, stop, fuel consumption. & Time space diagrams .	Developed for analyzing a network and grid system of signalized intersections.
11. NOSTOP	Analyze arterial progression program that optimizes offsets and cycle lengths to provide maximum two-way progression. Provide a plot of the cycle optimization results and a time-space diagram.	Developed for analyzing signalized intersection on arterial street.
12. TRAF-NETSIM	Simulate a network / grid system of signalized intersections. Provide an animation of the system that display effect of progression, bus stop , gaps, delays , signal phasing and timing plan, queue for all approach intersections. It also provides part of the system in real time.	Developed for simulating a network / grid system of signalized intersections.
13. CORSIM	Current update for the TRAF-NETSIM and TRAF-FRESIM products. Corsim is similar to Sim Traffic with some limitations and enhancements. Relative limitations include longer running time and capacity to analyze fewer iintersections. Relative enhancements include ability to model parking, bus stops and random interruptions.	Developed for simulating a network / grid system of signalized intersections.

Among all the analysis techniques identified, six techniques were selected for consideration in this study. The five techniques were selected based on each of the techniques ease of use and its ability to compute important traffic characteristics of a network of signalized intersections. For comparison purposes, the HCS techniques was also selected for this study. The techniques considered are:

1. TRANSYT – 7F
2. CORSIM
3. SimTraffic
4. Passer
5. Synchro
6. HCS

A detailed description of each of the techniques is described below. Out of these six techniques, the four techniques that specifically analyze a network / grid system of signalized intersections were further reviewed and categorized based on technique's input requirements and output options as shown in Table 1.

Table 1. A Comparison of Signal System Analysis Input Requirements and Output Options.

Signal System Input Requirements and Output Options		**Synchro 3.2**	**HCS**	**Sim-Traffic**	**Corsim**	**Transyt**
Input Requirements						
Map	Links and Nodes	X		X	X	X
	Coordinates	X		X	X	X
Lanes	Number and movements permitted	X	X	X	X	X
	Ideal Saturation Flow	X	X			
	Lane Width	X	X			
	Grade	X	X			
	Detector Locations	X	X			
	Turning Speed	X	X	X	X	X
	Right Turn on Red	X	X	X	X	X
Volumes	Traffic	X	X	X	X	X
	Conflicting Pedestrians	X	X	X	X	X
	Peak Hour Factors	X	X	X	X	X
	Growth Factors	X	X	X	X	X
	Heavy Vehicles	X	X	Limited (L)	L	L
	Adjacent Parking Lane	X	X		X	
	Parking Maneuvers	X	X		X	
	Bus Stops per Period	X	X		X	
Control Type	Sign	L	X	X	X	L
	Signal	X	X	X	X	X
	Signal Settings	X	X	X	X	X
	Lost Time	X	X	X	X	X
	Phase Sequence	X	X	X	X	X
	Left Turn Type	X	X			X

	Right Turn Type	X	X			
		Synchro 3.2	**HCS**	**Sim-Traffic**	**Corsim**	**Transyt**
Output Options						
	Total Delay	X		X	X	X
	Stop Delay	X	X	X	X	
	Total Stops	X		X	X	
	Stops/Vehicle	X		X	X	
	Travel Distance	X		X	X	
	Travel Time	X		X	X	
	Fuel Used	X		X	X	X
	Emissions	X		X	X	
	Vehicles Entered & Exited	X	X	X	X	
	Vehicles Denied Entry			X		
	Maximum Queue			X	X	
	95th Percentile Queue	X				
	50th Percentile Queue	X				X
	Queuing Penalty	X		X		

1. TRANSYT – 7F

Transyt – 7F is a traffic signal simulation and optimization program that can evaluate an existing traffic signal timing condition and evaluate and optimize a proposed signal timing conditions. The optimization involves the minimization of delay, stops, fuel consumption and fuel cost. The procedure provides output that includes average queues, delays, stops, fuel consumption, time-space diagrams, flow profile diagrams and platoon progression diagrams. The main function of this procedure does not provide bandwidths but it does minimize stops, delay and fuel consumption, which may or may not provide arterial progression. The disadvantage of this procedure is it provides a poor model for analyzing or simulating arterial progression if the primary goal is wide bandwidth along the arterial. However, this is an excellent tool for minimizing stops and delays in a network / grid system of signalized intersection. This procedure is mainly used for traffic signal network and arterial where signalized intersections are closely spaced (less than 1500') together. The Transyt – 7F procedure provides a detailed methodology for optimizing signal system, also called MOST. The methodology for optimizing signal system includes the following: conduct and management of signal timing projects; traffic signal timing elements as applied to the traffic signal timing and analysis program; timing performance measures; model calibration; and timing implementation.

2. SimTraffic

SimTraffic is a simulation program developed for analyzing and simulating traffic behavior in a network / grid of signalized and unsignalized intersections. Its primary function is to check and fine tune traffic signal operations that are normally difficult to model such as closely spaced intersections with blocking and lane change problems, operations near unsignalized intersections and driveways, and operations of heavily congested intersections. SimTraffic is run directly from Synchro data input and requires data related to mapping, links, geometry, lanes, volume, timing and actuation. When compared to its predecessor ,CORSIM, SimTraffic generally uses the same driver vehicle performance characteristics, and gives comparable amounts of MOEs (measures of effectiveness) such as delay, stops, queues, average speeds, fuel consumption and throughput. Although SimTraffic has fewer features than CORSIM, it can model larger networks and is much easier to use.

3. CORSIM

SimTraffic and Corsim are virtually identical in describing existing traffic operations. The traffic behavior algorithms are the same. This program will simulate bus stops and parking maneuvers, which SimTraffic will not. However, since virtually no parking activity occurred during the study, we elected to use the more user friendly SimTraffic for our study.

4. PASSER II

Passer II performs signalized intersection arterial progression analysis. This technique simulates and optimizes arterial progression. This technique is only used to evaluate arterial progression and it is not a good tool to use for analyzing a network or grid system of signalized intersections. It is an excellent model for bandwidth optimization. It calculates level of service, queue, bandwidth, efficiency, fuel consumption, number of stops, speed of progression, a time-space diagram and offsets. Furthermore, it optimizes cycle length, splits and offsets.

Since the network studied is a grid rather than an arterial, we did not evaluate this software.

5. Synchro

Synchro uses 1994 Highway Capacity Manual Techniques and considers the same factors as HCS described below. In addition, traffic signal offsets and random traffic variations are factored into the computational procedure.

Like Transyt – 7F, Synchro uses traffic signal optimization procedures that can evaluate existing traffic signal timing conditions and evaluates and optimize a proposed signal timing conditions. .

The procedure provides output that includes average and 95 percentile queues, delays, stops, fuel consumption, and percent of time that queues exceed available storage.

6. HCS

HCS (Highway Capacity Software) is a program based on the Highway Capacity Manual. Its primary function is to analyze capacity and provide level of service for isolated intersections.

HCS requires the input of factors related to ideal conditions (12 ft lanes, level grade, no parking, all passenger vehicles, no pedestrians, etc.) which affect capacity and level of service. Each intersection required the following traffic inputs: number of lanes per approach, volumes per lane, lane width, % grade, % heavy vehicles, parking, # bus stops per hour, conflicting pedestrian crossings per hour, pedestrian button and minimum pedestrian green time, arrival type, right turns on red and lost time. The required timing inputs for each intersection include phasing diagrams, whether the signal is actuated, and the green, yellow and red times for each phase. HCS output the following information: adjusted saturation flows for each approach, volume adjustments, capacity analysis, delays and levels of service.

For the purpose of this study, HCS was run for each of the eight urban signalized intersections.

DATA COLLECTION AND REDUCTION

Traffic data utilized in this report were obtained in the Boston downtown central business district. Eight signalized intersections described below were selected for this study. These intersections are located in the vicinity of Boston City Hall, Haymarket Bus Station, Freedom Trail and major on and off ramp connection to Interstate 93. Video cameras were set up at each of the eight locations during the PM peak hour period. Data were collected for the heaviest traveled weekday peak hour conditions, which were from 5:00 to 6:00 PM. Each of this locations was videotaped for a minimum of 45 minutes between 5:00pm and 6:00 PM. On certain intersection approaches where the traffic volumes were heavy and back of queues long, an additional dedicated camera was assigned to tape the approach.

The traffic volume, delays, vehicle classifications, and maximum back of queue were obtained for most approach lane groups at each of the eight intersection locations. These data were collected by cycle for 20 cycles. Twenty cycles were selected since SimTraffic calculates only the longest back of queues and the longest queues in twenty cycles represent the 95 percentile. Signal timing did not vary over the study period since all signals analyzed are pretimed. Cycle lengths, signal phases and offsets were measured before and after each analysis period and they were unchanged.

STUDY LOCATIONS

Geometry and Lane Use

Sudbury Street at Congress Street

Congress Street is a divided; two-way roadways crossed by Sudbury Street a northbound one way street. Between intersections, Congress Street has a fence in the median to discourage midblock pedestrian crossings and no parking except for buses.

A thousand feet upstream of its intersection with Congress Street, Sudbury Street begins with two travel lanes with parallel parking on the right side and angle parking on the left. Four hundred and eighty feet from the intersection, general parking is prohibited on the right side and parking is restricted to bus passenger pickup and discharge. Eighty feet from Congress Street the left side angle parking is eliminated to permit entry to the Haymarket parking garage. From this point to the north, the approach is marked for five lanes, with the right curb lane marked for right turn only and used for bus pickup and discharge. Within 60 feet of the Congress Street intersection, an illegally parked car occupied the left lane, which is marked as left turn only.

During our PM peak analysis period, the right curb lane is usually occupied with buses lying over or engaged in picking up or discharging passengers and other buses occasionally use the second lane from the curb to pickup passengers. Typically, more than 60 feet from the intersection there are three lanes for moving traffic: a right turns lane, a right/through lane, and a left/through lane. Additionally, when there is blockage of the right lane, vehicles will turn right from the second and third lane from the curb. In our study period, 148 vehicles (25% of the total lane traffic) turned right from the second from curb lane and 9 vehicles turned right from the third from curb lane.

On the eastbound Congress Street approach there are three through lanes and an exclusive left turn lane about 140 feet long. Buses stop to pickup or discharge passengers on the right curb lane. Beyond Sudbury Street, the median lane is signed for left turn only.

On the westbound Congress Street approach there are three through lanes with the curb lane being used mostly for right turns.

There are crosswalks on all approaches with heavy pedestrian traffic during peak periods, with J walking prevalent on the northern crosswalk during the PM peak.

Congress Street and Merrimac Street at New Chardon Street
Congress/Merrimac Street is a divided road in the vicinity of the intersection. New Chardon Street is a four lane, one way southbound street.

Westbound, Congress Street has three lanes of which one is exclusively for left turns. During our study period, a bus was parked on the westbound curb lane 25 percent of the time. Eastbound, Merrimac Street has two lanes, with no parking and the curb lane used for through and right turning traffic.

Southbound approaching Congress Street, New Chardon Street has four lanes: one for lefts, one for left and through traffic, with the others unmarked. Occasionally, the third lane is used for left turns. New Chardon Street south of the intersection is one way with three travel lanes and one parking lane. There is a major parking garage entrance on the left side of the street, immediately followed by the parking garage exit.

There are crosswalks on all approaches.

New Chardon Street and Ramp RC
Ramp RC intersects New Chardon Street between Blackstone Street and Congress Street. Ramp RC has one lane that is stop sign controlled. All ramp traffic must turn right at New Chardon Street. Immediately downstream of Ramp RC New Chardon Street is four-lane wide. The ramp essentially adds a lane to New Chardon Street, but most ramp traffic turns left at Congress Street. About 150 feet downstream of the Ramp RC intersection is a very heavily traveled, uncontrolled crosswalk.

New Chardon Street at Blackstone Street, Relocated Cross Street and North Washington Street

Blackstone Street is a one way street with two lanes carrying through and left turning traffic. Many buses use this approach to make U-turns into the Haymarket bus station.

Relocated Cross Street is also a one way street with two lanes at the intersection, carrying through and right turning traffic.

Blackstone Street is a divided, four lane, two way street with no parking in the vicinity of the intersection. Some buses from North Washington Street turn into the Haymarket bus station immediately downstream of the intersection.

New Chardon Street is a one way, three-lane street with no parking south of the intersection.

There are crosswalks on Cross Street Extension and Blackstone Street.

Sudbury Street at Blackstone Street

Sudbury Street is a five lane, one way street. A Jersey Barrier that limits traffic movements to right turns into and out of a new parking garage separates the right curb lane from the other lanes. This barrier continues around the northeast corner onto Blackstone Street. Few vehicles except those entering and leaving the garage use this lane.

Lanes on Sudbury Street to the left of the barrier consist of two for left turns only, one for through movements, and one for through and right turning traffic.

Blackstone Street is a two lane, one way street leaving the intersection in both directions. It is one way eastbound east of Sudbury and one way westbound west of Sudbury. East of Sudbury, Blackstone Street has two travel lanes with parking on the right side. West of Sudbury, Blackstone Street has two travel lanes with no parking.

The continuation of Sudbury Street north of Blackstone Street is a one way, two lane road segment joining a U-turn from Cross Street to form a weaving section leading to Ramp RG and Blackstone Street.

The traffic actuated, signalized exit from the MBTA bus station joins Sudbury Street immediately south of Blackstone Street. Many buses from this exit make a U-turn onto Blackstone Street. Frequently the phase is skipped since many buses turn left on red.

There are crosswalks on the Sudbury Street and the western Blackstone Street legs of the intersection.

Traffic Signal Operations

Five of the Congress Street signalized intersections are interconnected and part of the system including the Blackstone Street intersections with Sudbury Street and New Chardon Street. During our period of analysis, all system locations were pretimed, operating with a 100-second cycle. This system included:

- Congress Street at Merrimac and New Chardon Street

- Congress Street at Sudbury Street
- Congress Street at Hanover Street
- Congress Street at North Street and City Hall garage
- Congress Street at City Hall Crosswalk
- Blackstone Street at Sudbury Street and MBTA Station
- Blackstone Street at New Chardon Street and Cross Street

Two other signalized intersections are adjacent to the system, but are not part of the system and operate on different cycle lengths. They are Blackstone Street at Hanover Street and Congress Street at State Street. These locations were included in the study due to their proximity and the impact their signal operations have on traffic arrivals at the system.

Intersection phasing for the system locations is described below.

Congress Street at New Chardon Street is controlled by a three phase, pretimed traffic signal. The westbound left turns move only on the leading protected phase. Pedestrians walk with green.

Sudbury Street at Congress Street is controlled by a three-phase traffic signal. The eastbound left turns have a lagging protected phase during which these left turns and non-conflicting crosswalks have right-of-way.

Congress Street at Hanover Street has a two-phase signal with right turns from Hanover Street sharing a phase with the pedestrian crossing of Congress Street.

Congress Street at North Street has a four-phase signal with the following phase sequence:
- Congress Street eastbound
- 2-way Congress Street (during which left turns are permitted)
- exclusive pedestrian walk
- North Street and the City Hall garage exit

Congress Street at City Hall crosswalk has the following phase sequence:
- exclusive pedestrian walk
- Congress Street eastbound
- 2-way Congress Street

Blackstone Street at Sudbury Street has three phases:
- Sudbury Street northbound
- exclusive pedestrian walk, when actuated
- MBTA parking station, when actuated

Blackstone Street at New Chardon and Cross Street has two phases, with Blackstone Street left turns permitted.

EXISTING AND COMPUTED OPERATIONAL CONDITIONS

Table 2. shows a comparison of measured and computed delays and queues for each of the lane groups in the study area. Following Table 2 we have described traffic operations at each study area intersection as observed or measured and as predicted by the various analysis methods employed.

Table 2. Analysis Result Comparison

			Stopped Delay/Veh				50 %-Tile Back of Queue (ft.)		95%-Tile Back of Queue (ft)		
			HCS	Synchro	SimTraffic	Actual	Synchro	Actual	Synchro	SimTraffic	Actual
New Char. at Congress			21.4	20.4	21.4	23.1					
		EB	24.7	24.6	28	24	115		161	141	
	WBL		27	30.8		30	157	150	208	210	225
	WBT		23.4	11.3		17	276	100	348	175	
		WB	25.1	20.6	22	23	276	150	348	210	225
	SBL		17	17.7			203	238	288	280	400
	SBTR		19.9	20.4			79	290	115	260	525
		SB	18.8	19.2	16.5	23	203	290	288	280	525
Congress at Sudbury			15.1	15.5	54	20.3					
	EBL		29	31.3		38	119		188	135	
	EBT		17.8	8.3		19	68		93	425	
		EB	19.8	12.9	15.5	22.8	119	175	188	425	250
		WB	9.5	2.9	5.8	6	15		34	384	
	NBTL		15	15.2			94		152	51	
	NBTR		10.9	21.5			349		438	1028	500
	NBR		24.4	25.5			288		480	1028	
		NB	15.1	22	100	25	349	300	480	1028	500
Congress at Hanover			3.3	3.7	3.2						
		EB	3.1	3.5			95		87	198	
		WB	2.7	3			22		31	50	
		SB	19.3	19.7			23		52	30	
Congress at North St.			14.4	14.2	12.6						
	SBL		16.4	38.6			182		352	350	
	SBTR		18.2	16.8			184		225	384	
		SB	17.7	22.4	18.5		184		352	384	
	NBTL		7.1	0			0		1	14	
	NBR		2.6	1.5			40		98	14	
		NB	5.4	1	0.1		40		98	14	
	WBL		36	29.9			95		162	140	
	WBLTR		29.4	29.9			89		154	105	
		WB	33.7	29.9	35.9		95		162	140	

Congress at Crosswalk		11	11.1	18.8				
	SB	0	0.7	2.9		18	85	
	NB	24.2	22	33.4		256	406	304
Blackstone at Hanover		3.9	3.9	3.1				
	SB	3.9	3.9	3.1		71	80	
Blackstone at Sudbury		1.1	2.1	3.1				
NBL		0	0.5			50	85	
NBTR		0	0.5			20	70	
NBR		0	0.5			30	37	
	NB	0	0.5	0.75		50	85	
T-Station	EB	23.2	34.2	36.9		91	58	80
Blackstone at New Chardon		5.3	5.9	8				
	NB	0	1.1	2.3		0	112	112
	SB	3.6	3.7	3.6		90	100	
	WB	26.2	26.2	31.8		123	122	

NEW CHARDON AT CONGRESS STREET operates at a C level of service, with all arrivals being serviced during the cycle. There are, however, queuing problems during the course of the cycle caused by downstream blockages. New Chardon Street left turns have to wait nearly every cycle for the eastbound queue on Congress Street to move forward. Many of these left turners enter the intersection but are unable to clear the intersection; thereby blocking westbound left turns on the following phase.

All of these blockage problems are resolved within a few seconds, as the blocking vehicles move forward, so gridlock does not occur.

None of the software programs correctly indicated blockage problems. Synchro predicted longer maximum (95 percentile) queue lengths than SimTraffic, but not as long as those observed on two of the three approaches. On the third approach, Synchro over-predicted maximum delays by 50%, while SimTraffic predicted maximum queues within 10 percent of that observed.

Overall, stopped delay predictions agreed well with those measured – mostly within 10 percent.

CONGRESS STREET AT SUDBURY STREET operates at a C level of service, with all arrivals being serviced within a cycle. During a few cycles per hour, eastbound through traffic and northbound right turn traffic is blocked by downstream queues on Congress Street. Frequently, J-walking pedestrian’s block eastbound left turns for a few seconds, but the vehicles easily clear the intersection within their phase. Eastbound back of queues extends into the upstream New Chardon Street intersection almost every cycle, but the last vehicle always clears during the green.

The Sudbury Street approach has the longest delays and queues of all intersection lane groups. The back of queue during the cycle on this approach extends 8 to 20 vehicle lengths from the stop line. When there are buses occupying the right lane, the queue is longer, with no buses the queue is shorter. Vehicles in the longest queue are often delayed half a minute.

HCS and Synchro predicted average delays for the intersection that were about two thirds of those measured. SimTraffic predicted double the measured delays.

None of the models predicted the eastbound blockage or high delays that were observed. Synchro and HCS under-predicted northboound delays by 24 and 17 seconds per vehicle, respectively, while SimTraffic over-predicted delays observed by more than a minute.

SimTraffic accurately predicted maximum eastbound queues, but significantly over estimated northbound maximum queues. Synchro, on the other hand, accurately predicted northbound maximum queues, but significantly underestimated eastbound queues.

CONGRESS STREET AT HANOVER STREET operates at an A level of service. When long queues occur they are due to backups from North Street.

Predicted average delays were within one second of each other here.

CONGRESS STREET AT NORTH STREET AND THE CROSSWALK should be considered as one intersection since they are about 100 feet apart. Considered as such, the level of service is D, with westbound right turning queues to North Street extending back to State Street almost every cycle and eastbound left turn queues occasionally extending upstream through Hanover Street to Sudbury Street. Pedestrians crossing North Street often interfere with Congress Street left and right turning traffic.

The three software packages predicted delays within 10 percent of one another at this location.

The westbound queue that often extends to State Street was predicted by SimTraffic but underestimated by Synchro.

BLACKSTONE STREET AT SUDBURY STREET operates at an A level of service. The pedestrian phase is seldom called and the buses from the T-station often turn left on red without waiting for a signal.

All software also predicted very short delays at this location.

BLACKSTONE STREET AT NEW CHARDON STREET operates at a B level of service. All vehicles arriving on red were served on the following green and delays are minimal except on the southbound approach, where they average about half a minute per vehicle.

The software programs all predicted delays within 2 or 3 seconds of each other.

CONCLUSIONS

For most lane groups, Synchro, HCS, and SimTraffic computed stopped delays with the same level of service. Computations by approach with these methods also yield delays that are within 20 percent of measured delays. One exception was the northbound approach of Sudbury Street to Congress Street which has various types of parking and curb activity along its length.

SimTraffic underassigns traffic to the right lane on this Sudbury Street approach, resulting in computations of longer queues and delays than actually occur. HCS ignores the short available storage and predicts delays that are too short by nearly ten seconds.

Synchro generally predicts slightly shorter queues than observed and less than computed by SimTraffic.

SimTraffic would be more accurate and useful in urban environments if bus stops and other user-specified interruptions could be specified.

Using proper arrival type factors HCS yields results comparable to those computed by network models in predicting delays. Research by the New England ITE Technical Committee indicated that this close agreement would not occur. We are surprised that this close agreement occurred. One reason for this may be that there is only one lane in the system that does not have a protected left turn phase.

Overall, SimTraffic was best at identifying traffic problems when they exist. It did, hovever, exaggerate these problems.

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