TRAFFIC SIGNAL STRATEGIES FOR TRANSIT PRIORITY – A RECENT CASE STUDY

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1. INTRODUCTION

For the transportation system to be more efficient in terms of moving people rather than vehicles, the emphasis has moved in recent years from the private vehicle as the predominant mode of transport to more effective high occupancy vehicles, in effect, endeavouring to benefit the passenger of the high occupancy vehicle, to the detriment of drivers and passengers in private vehicles. However, for most metropolitan areas, a careful balance is required to maintain mobility for both private vehicles and high occupancy vehicles.

One of the available measures that could be implemented to assist high occupancy vehicles is to provide priority to such vehicles at traffic signals. However, in an area already experiencing high traffic volumes, and substantial increases in traffic projected for the future, the possible impact of bus signal priority on arterial operations could be significant.

In a recent case study in Orlando, (Florida, USA), the impact of bus priority measures at traffic signals on the transportation system were analysed and evaluated. The analysis had the following objectives:

- To identify locations where bus signal priority might have a noticeable impact on bus operations.
- To identify an appropriate signal priority strategy in light of the signal system in place in the study area.
- To identify the impact of signal priority on reducing bus delay at intersections and overall travel time.
- To identify the impact of bus signal priority on average and total vehicle and person delay at intersections.

The analyses concentrated on the weekday p.m. peak hour conditions for which detailed intersection traffic counts and signal timing plans were available. Furthermore, the analyses focused on specific busy intersections where the bus routes were to join or cross a major arterial. These were locations where priority for the bus would have the greatest benefit to the bus and its occupants and at the same time resulting in possible disruption of the major traffic flows on the main street.

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2. STUDY AREA

The bus priority evaluation was conducted at seven intersections, five of which were located on State Route 436 (SR 436, See Figure 1) and two of them located on Maitland Boulevard. Both of these are major arterials running east-west, approximately 3 kilometres apart and intersecting with Interstate 5 running north-south through Orlando. For most of the route, the two bus routes run north-south just west of Interstate 5, crossing Maitland Boulevard in the south at Keller Road (Bus Route 1) and at Maitland Summit (Bus Route 2). Bus Route 1 crosses SR 436 at Westmonte Drive and then loops to the east over Interstate 5 and back again to cross SR 436 at Essex Drive and loops back again to cross SR 436 for the third time at Boston Drive. From the south Bus Route 2 turns right onto SR 436 at Douglas Avenue and continues along SR 436 to turn left again at Westmonte drive and then loops back again on the same route as Bus Route 1. The two major arterials (SR 436 and Maitland Boulevard) are currently carrying between 4 000 and 5 000 vehicles in the p.m. peak hour, in both directions. The side road volumes vary from 400 vehicles per hour to nearly 2 000 vehicles per hour. Some of the study intersections are currently operating at high degrees of saturation.

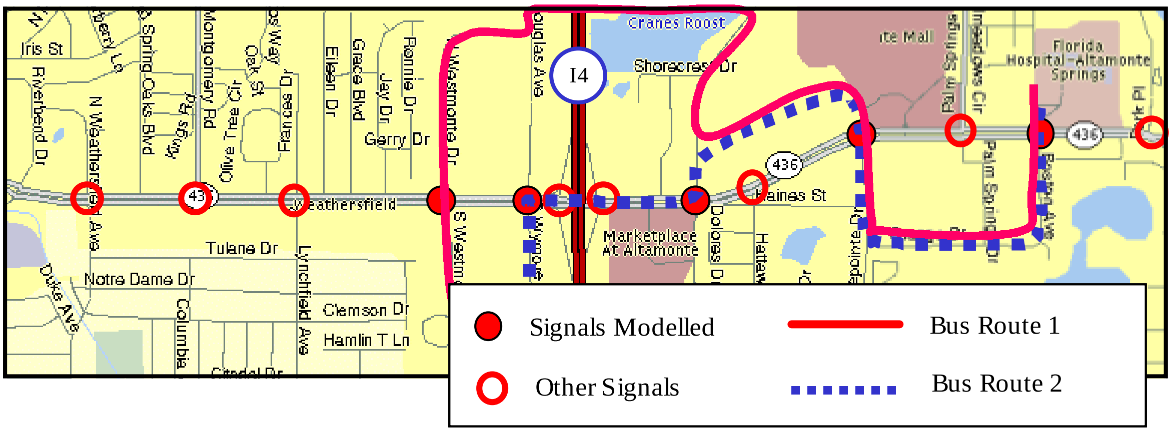

Figure 1: Study Intersections along SR 436

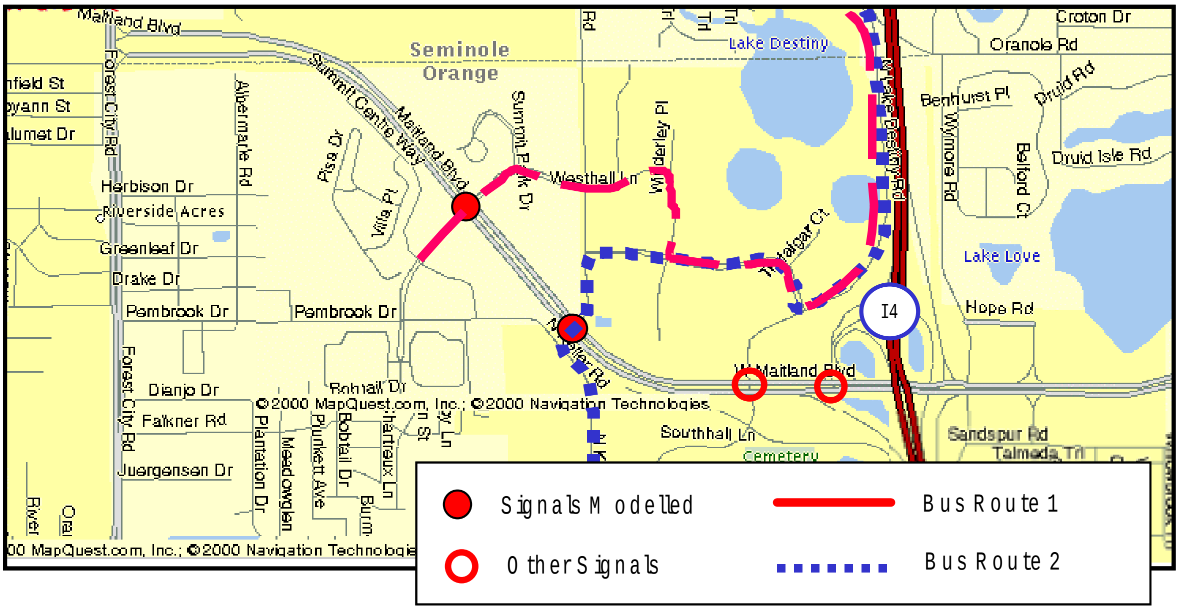

Figure 2: Study Intersections along Maitland Boulevard

3. METHODOLOGY AND STUDY APPROACH

The most effective method of evaluating the impact of bus-priority measures is the use of micro-simulation. For the purposes of this evaluation it was decided to use micro-simulation and specifically the PARAMICS software. PARAMICS is a suite of software programs applied for the microscopic simulation of road and rail- based transportation systems and was developed by SIAS Ltd and Quadstone Ltd of Scotland. It is a microscopic simulation tool designed for a wide range of applications where traffic congestion is a predominant feature. It has extensive visual capabilities, and high performance in terms of speed of simulation. The scalability of the PARAMICS model allows for application across a whole spectrum of network sizes, from single intersections up to national networks, with the computer hardware on which the model is run typically being the only constraint in terms of network size and speed of simulation. PARAMICS is able to run on Windows or Unix-based operating systems.

3.1 Simulation Approach

The two bus routes cover a relatively large area (see Section 2) and to simulate the bus routes as a whole would have required a calibrated simulation model of the total study area. This would have been an extensive and costly exercise. Therefore, to limit expenses it was decided to do an isolated analysis of the significant intersections along the routes. However, to include the effect of upstream intersections (platooning) and to evaluate the impact on green band progression along the major arterials, the analysis was extended to include the major neighbouring signalised intersections (See Figure 3 for the study intersection of SR 436/Essex Driver). Since the two study intersections on Maitland Boulevard are neighbouring signalised intersections, they were evaluated together.

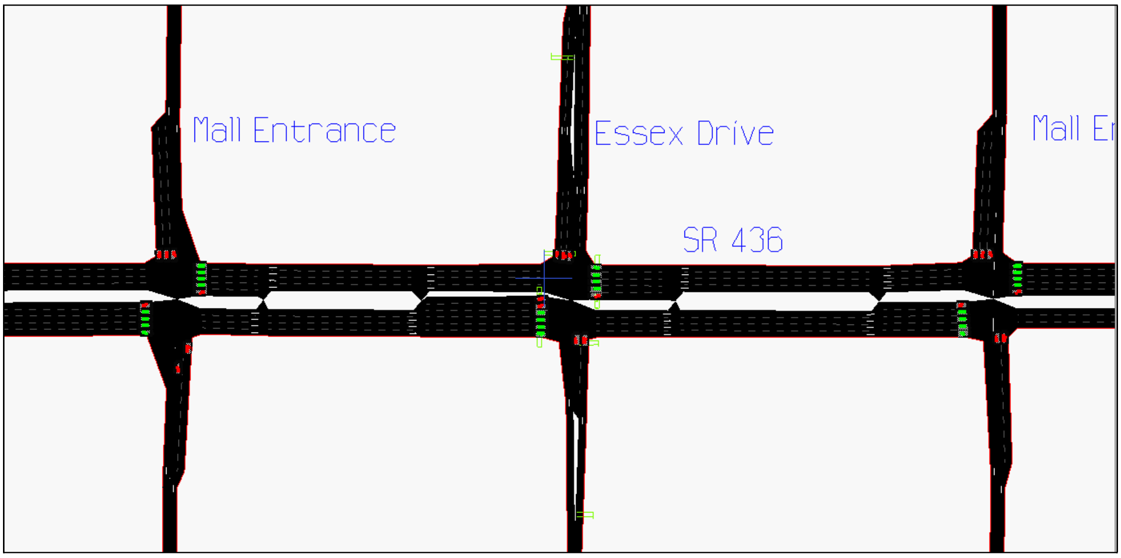

Figure 3: Study area for the intersection of SR 436/Essex Drive

3.2 Definition of Average Conditions

As in most simulation models, the simulation process in PARAMICS is based on a sequence of random numbers initiated by a single seed number. Initiating the simulation with a different seed number typically results in a different simulation process and different results. This represents the random nature of traffic and the variation that can be observed between different peak hour operations. Therefore, the simulation model has to be run with different seed numbers to identify an average condition that can be compared with other averages, or the simulation has to be run for a long period to average out all the variations.

The “average” condition can be identified by the numerical average of a number of simulation runs, or by identifying a single simulation run that is representative of the “average”. In this study the latter approach was adopted. For every study intersection and for every alternative, the simulation model was run with ten different seed numbers for the peak period. The simulation results obtained from the ten simulation runs were plotted on a graph from which the ‘average’ or ‘typical’ run could be identified. An example of such a graph is included in Figure 4, which shows the average travel time for all vehicles during the simulation period. Each line on the graph in Figure 4 represents the results of a simulation process with a specific seed number. From the set of lines a single seed number or process can be identified that is typical of the average condition. The results of the “typical run” were then used for evaluation and comparison with other results. Note that the reported travel times are between the zones (origins and destinations) as used in the simulation model and do not refer to travel times between actual origins and destinations.

As can be seen from Figure 4, the analysis period was based on the weekday p.m. peak hour conditions. The simulation was started at 4:15 p.m. and run for 90 minutes until 5:45 p.m. The first 15 minutes were typically used as a “warm-up” period with the actual peak hour of analysis starting at 4:30 p.m. The period that was used for the comparison of the results was the 15-minute period between 5:00 and 5:15 p.m.

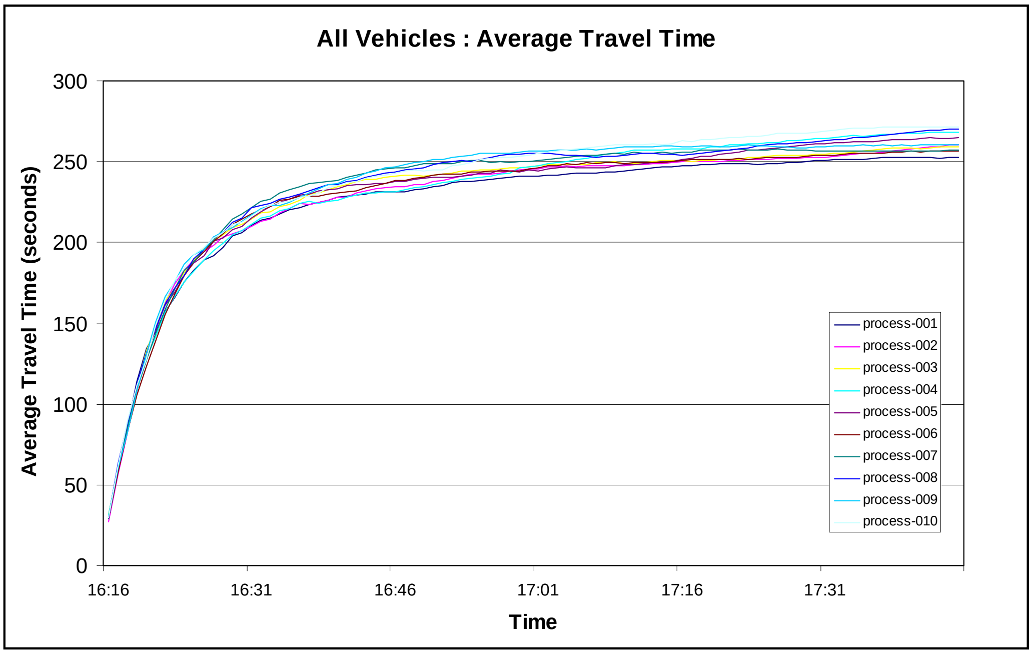

Figure 4: Random Variation of Simulation Results for 10 Different Seed Numbers

3.3 Bus Signal Priority Algorithm

Signal priority to buses can be provided in various ways as well as in different degrees of aggressiveness and complexity. For the purposes of this analysis it was decided to provide priority to buses in a way that has relatively little impact on the main road vehicles, but with sufficient aggression to still benefit the bus.

In principal the proposed methodology is based on extensions of the bus green phase (the green phase during which the bus arrives) as well as truncations of opposing green phases, once the minimum green on those phases has expired. The proposed methodology does not allow for the skipping of any phases and all phases would be displayed in the normal sequence, albeit for only a minimum duration if a bus call was received on a conflicting approach. The existing offsets (synchronisation) between the neighbouring intersections were maintained. However, if a green phase on the major road was forced to 'gap out' after the extension of the minimum green time to return to a side road green phase for a bus call, the green phase on the major road is over-saturated, resulting in longer queues negating the benefit of the synchronisation. This impact could take several cycles to return to 'normal', at which time the next bus could be approaching again.

This low aggression approach was adopted because of the high traffic volumes on the major arterials and the possible significant disruption an aggressive priority approach could have. Typically buses arrive on the side roads with the bus priority measures intended to assist the buses by either extending the green on which they arrive, or if the bus arrives on a red phase, by returning the green to the side road as quickly as possible. This of course reduces the available green time for the traffic movements on the major approaches. At two of the study intersections on SR 436, where Bus Route 2 on either the inbound or outbound run arrives on the major approach to the intersection, the bus priority measures would benefit the traffic on the major approach.

3.4 Evaluation Measures

As a microscopic simulation program simulating individual vehicles travelling through a network, the PARAMICS model can be used to extract detailed information of each vehicle as well as for the network as a whole. For the purposes of this study and for comparing one alternative with another, it was decided to use *vehicle and person delay* as the evaluation measures. These measures provide an adequate description of how the system performs and how vehicles and eventually people are affected by the transportation system. Since PARAMICS does not directly model person trips, the vehicular delay provided by the simulation model had to be converted to person delay by assuming certain average occupancies for private vehicles and buses. It was assumed that the vehicle occupancy would be on average 1.13 persons per auto (average occupancy rate for Orlando) and 30 passengers per bus.

3.5 Validation of PARAMICS Model

The seven study intersections were coded in the PARAMICS model, similar to the examples shown in Figure 3. The coding of the intersection geometry was based actual geometry obtained from aerial photographs. Once the intersections were coded in PARAMICS and the demand O-D matrices were developed from the existing traffic count volumes, the next step was to validate the operation of the simulation model and to compare the results of the simulation with field observations.

For this, the modelled queue lengths were compared with the observed queue lengths. The validation of the operation of the simulation model and the observed modelled queue lengths were compared with the observed actual queue lengths in a qualitative manner. This analysis was completed for all the study intersections and the intersection geometry and phasing corrected until the modelled queue lengths agreed with the observed queue lengths.

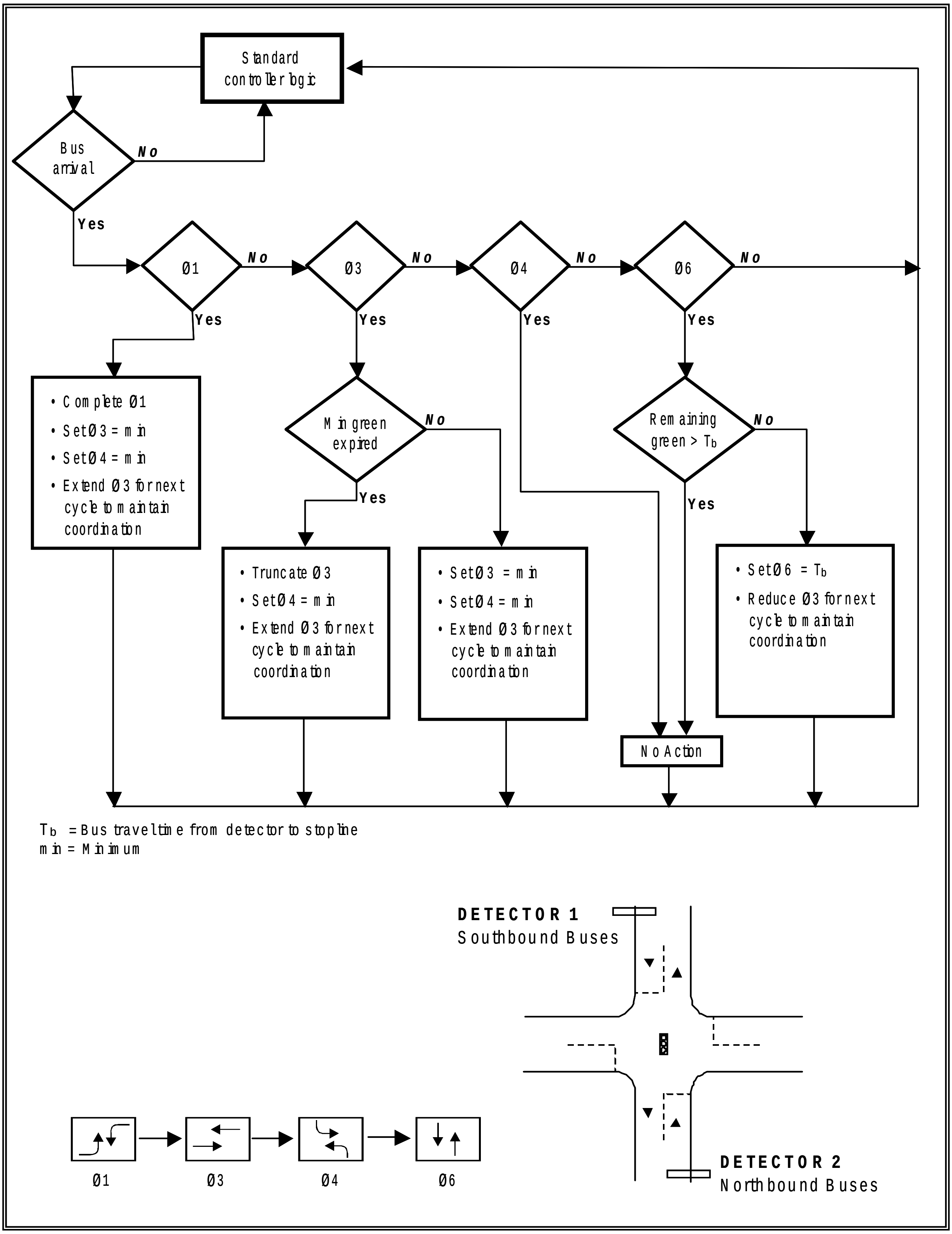

Figure 5: Signal Logic Flow Diagram for Bus Priority (For North-South bus routes through the intersections)

4. SIMULATION RESULTS

4.1 Definition of Alternatives

For the purposes of this study three alternatives were identified:

- Alternative 1: Existing traffic with no buses.
- Alternative 2: Existing traffic with buses but with no priority to the buses.
- Alternative 3: Existing traffic with buses and with priority to the buses.

4.2 Impact of Arrival Time of Buses

One aspect that was identified during the study and which required more detailed attention was the issue of the arrival times of a bus and its relationship to the cycle and phasing strategy at the intersection. Furthermore, the scheduling and headway between buses could also have an impact on the bus priority measures. For instance, if the bus arrives at the beginning of the green phase, it would be a best-case scenario and no bus priority measure would be required since the bus should clear the intersection during the standard green time. On the other hand the bus could arrive just after the green phase has ended, which would either result in long wait time for the bus or a significant impact on the phasing, and operation of the intersection if an aggressive bus priority measure is activated.

It was hypothesised that since the headway between the buses (assumption of ten to 15 minutes) and the typical cycle lengths (approximately 160 seconds) of the controllers are not equal or equal multiples, the buses would always arrive at different times during the cycle. Therefore, the bus arrival times in relation to the signal cycle, and hence the green time display for the approach on which they arrive, should be random. Furthermore, buses do not run exactly on schedule, which would further increase the randomness of the arrivals. To test this hypothesis a number of simulation runs were conducted with the buses arriving at different times.

In PARAMICS, the simulation of scheduled vehicles, such as buses, takes place on a fixed schedule with no variation in the actual start time of the bus. The bus would always leave the first bus stop at the predetermined headway. The start time of the first bus in relation to the top of the hour is set in PARAMICS and from this point forward the buses would be generated at the specified headway. Buses could be delayed through the network and at bus stops, but because the study area for each intersection is relatively small, the buses would arrive very close to the 10-minute or 15-minute headways. Therefore, a number of alternatives were identified for the simulation with different start times for the first bus. This was done for both Alternative 2 (buses with no priority) and Alternative 3 (buses with priority) and for a 10-minute headway. This resulted in the following alternatives:

- Alternative 2.1: No bus priority – start of first bus at one minute past hour.
- Alternative 2.2: No bus priority – start of first bus at two minutes past hour.
- Alternative 2.3: No bus priority – start of first bus at three minutes past hour.
- Alternative 2.4: No bus priority – start of first bus at four minutes past hour.
- Alternative 3.1: With bus priority – start of first bus at one minute past hour.
- Alternative 3.2: With bus priority – start of first bus at two minutes past hour.
- Alternative 3.3: With bus priority – start of first bus at three minutes past hour.
- Alternative 3.4: With bus priority – start of first bus at four minutes past hour.

The result of the analysis of the bus arrival times is summarized in Figure 6 for each of the above alternatives. The evaluation of the different bus arrival time scenarios supported the hypothesis that the start of the bus schedule does not significantly affect the outcome of the simulation and that the arrivals are actually random when compared to the actual point in the signal cycle at which the buses arrive. Therefore, it was concluded that the actual start time of the first scheduled bus is immaterial and that it could be set randomly for all the other study intersections.

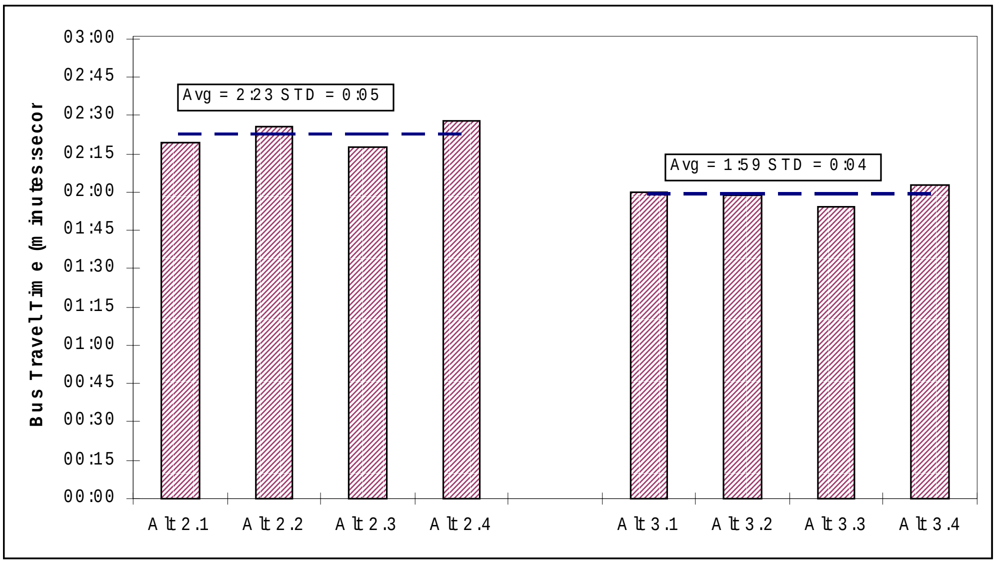

Figure 6: Testing of impact of bus arrival times (See above list of Alternatives).

4.3 Detailed Results for Maitland Boulevard Intersections

Since the total result of all the simulations is extensive, it was decided to discuss and present in detail the results for the two study intersections that were simulated as a system and only summarize the results for the other five study intersections. The results for the other study intersections are similar and are summarized in the next section.

The average travel times for all vehicles through the two Maitland Boulevard intersections are summarized in Figure 13 for Alternative 2.3 (No Priority) and Alternative 3.2 (With Priority). These two alternatives were selected as typical results for the “no priority” and “with priority” scenarios on Maitland Boulevard. The comparison of the simulation results for the intersections on Maitland Boulevard in Figure 7 shows a small change in travel time for all the vehicles on the network. Adding the bus priority measures would result in a relatively small increase in the average travel time of all vehicles travelling through the intersection. Note that the bus priority measures not only benefit the buses but also the side road vehicles, and the results in Figure 7 represent the net impact on the system.

The change in travel time for the buses only, at both Maitland Summit Boulevard and Keller Road, is shown in Figure 8. Note that the buses are travelling on the side streets and across Maitland Boulevard (the major street) at the intersections with Maitland Summit and Keller Roads. From the summary of the simulation results in Figure 8 it is clear that the introduction of limited bus signal priority would have a significant impact on the average bus delay. For the two bus routes crossing Maitland Boulevard this would typically result in a reduction in travel time of approximately 20 seconds at the intersection only. This result is typical and similar changes in bus travel times would be experienced at the other study intersections.

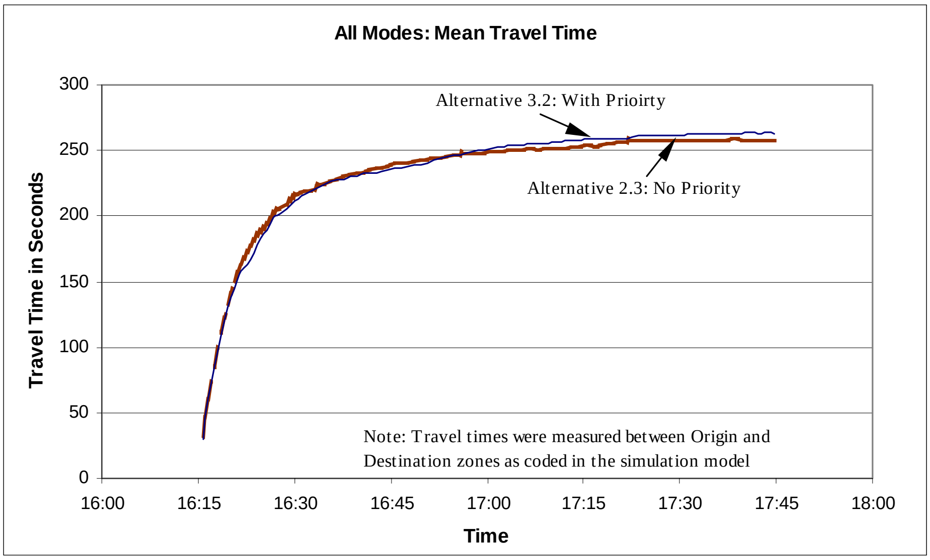

Figure 7: Comparison of Total Travel Time for all Modes and all Approaches

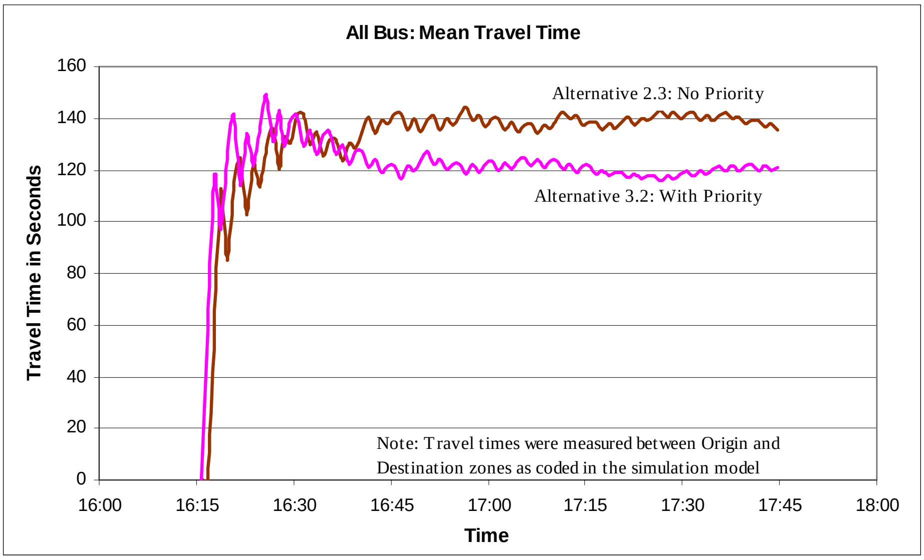

Figure 8: Comparison of Bus Travel time “Without” and “With” Bus Signal Priority

4.4 Overall Results

Table 1 summarises the average change in vehicle and person delay for each of the intersections assuming bus signal priority. From these results the following is evident:

- In general where buses typically arrive on the side road, the main road vehicles would experience an increase in delay due to the bus priority measures. The average vehicle delay for general traffic along the main roads increases by 13.8 seconds assuming 10-minute bus headways and 11.1 seconds assuming 15-minute bus headway. During the p.m. peak hour, there would be a disbenefit to the vehicles on the main road that could be as high as nearly 100 person hours of delay or a 31 percent increase over the “no priority” (Alternative 2) option for the 15-minute headway scenario and over 120 person hour increase in delay or a 38 percent increase in delay for the 10-minute headway scenario.

- With the buses arriving on the side road, the general side road vehicles typically also benefit from the bus priority measures. The average vehicle delay for general traffic along the side roads decreases by 0.2 seconds for 10-minute bus headways and 0.7 seconds for 15-minute bus headways.
- The introduction of the bus signal priority would result in significant reductions of the bus delay compared to the “no priority” alternative. The reduction in delay for the buses would vary depending on the intersection and the traffic demand and would vary from “no change” to as much as a 55 percent reduction. The average delay per bus at the study intersections along the circulator routes decreases by 24.1 seconds for 10-minute bus headways and 32.8 seconds for 15-minute headways. The reduction in overall person delay at all of the study intersections is 34 percent for 10-minute headways and 44 percent for 15-minute headways. The average decrease in intersection delay per vehicle on the bus is between 24.1 and 32.8 seconds. Note that this reduction only refers to the delay incurred at the study intersections. During the weekday p.m. peak hour the bus passengers would benefit by savings in person delay of around 20 person hours per hour.

5. CONCLUSIONS

From the results of this study the following is concluded:

- Micro-simulation can be used as an effective tool to evaluate bus priority measures at traffic signals.
- The introduction of bus priority measures could have significant benefits to the buses and the bus passengers in terms of travel time savings, on-time arrivals and less delay.
- Introducing bus priority measures along high volume arterials where the buses arrive on the side road would result in disbenefits to the arterial traffic, which could far outweigh the benefits to the buses and their passengers.
- Assisting buses with bus priority measures, where the bus routes follows a major arterial, could be a benefit to both the buses and the general traffic on the arterial. This benefit should be compared to the concomitant disbenefit that the side road traffic would incur.

Table 1: Summary of Results

Intersection/ Section	Roadway/ vehicles	Number of Vehicles per p.m. peak hour		Change in Delay (p.m. peak hour) due to introduction of Bus Priority Measures (Negative indicates delay decreasing while positive indicates delay increasing)						Percentage Increase in Person Hours of Delay (Alternative 2 to Alternative 3)	
				Average Delay per vehicle (seconds/vehicle)		Total Delay (vehicle hours)		Total Delay (person hours)			
		10 min	15 min	10 min	15 min	10 min	15 min	10 min	15 min	10 min	15 min
SR436/Boston	SR 436	4799		32.3	29.6	43.1	39.5	48.7	44.6	119%	97%
	Boston	770		-4.5	-4.7	-1.0	-1.0	-1.1	-1.1	-6%	-7%
	Buses	24	16	-37.0	-49.0	-0.25	-0.22	-7.4	-6.5	-49%	-58%
SR436/Essex	SR 436	4283		13.4	22.0	15.9	26.2	18.0	29.6	50%	85%
	Essex	424		-3.0	-0.8	-0.4	-0.1	-0.4	-0.1	-5%	-1%
	Buses	24	16	-30.0	-33.0	-0.20	-0.15	-6.0	-4.4	-49%	-56%
SR436/North Lake	SR 436	4968		0.5	0.8	0.7	1.1	0.8	1.2	1%	2%
	North Lake	1139		-1.8	-2.2	-0.6	-0.7	-0.6	-0.8	-3%	-4%
	Buses	12	8	-8.0	-13.0	-0.03	-0.03	-0.8	-0.9	-10%	-16%
SR436/ Westmonte	SR 436	3404		10.8	12.6	10.2	11.9	11.6	13.5	50%	65%
	Westmonte	617		1.2	1.6	0.2	0.3	0.2	0.3	2%	3%
	Buses	12	8	-13.0	-18.0	-0.04	-0.04	-1.3	-1.2	-29%	-40%
CentralParkway/ Douglas	Central Parkway	2033		9.3	3.7	5.2	2.1	5.9	2.4	19%	7%
	Douglas	1294		3.1	2.0	1.1	0.7	1.3	0.8	6%	3%
	Buses	12	8	-10.0	-15.0	-0.03	-0.03	-1.0	-1.0	-9%	-13%
Maitland/Keller	Maitland	4827		14.0	3.8	18.8	5.1	21.2	5.8	34%	10%
	Keller	1266		7.8	6.7	2.7	2.4	3.1	2.7	23%	18%
	Buses	12	8	-31.0	-37.0	-0.10	-0.08	-3.1	-2.5	-52%	-61%
Maitland/ Maitland Summit	Maitland	4356		12.9	1.8	15.6	2.2	17.6	2.5	27%	4%
	Maitland Summit	1847		-5.0	-5.8	-2.6	-3.0	-2.9	-3.4	-10%	-11%
	Buses	12	8	-21.0	-48.0	-0.07	-0.11	-2.1	-3.2	-32%	-55%
OVERALL TOTAL	Main Road	28670		13.8	11.1	109.6	88.1	123.8	99.5	38%	31%
	Side Road	7357		-0.2	-0.7	-0.4	-1.4	-0.5	-1.6	0%	-1%
	Buses	108	72	-24.1	-32.8	-0.72	-0.66	-21.7	-19.7	-34%	-44%