A REAL-TIME SIGNAL CONTROL STRATEGY FOR MITIGATING THE IMPACT OF BUS STOPS ON URBAN ARTERIALS

Celeste Chavis[1], and Eleni Christofa[2]

[1] Department of Transportation and Urban Infrastructure Studies, Morgan State University
1700 East Cold Spring Ln., Baltimore, MD 21251, USA
+1 (443) 885-5061

[2] Department of Civil and Environmental Engineering, University of Massachusetts
216 Marston Hall, 130 Natural Resources Road, Amherst, MA 01003, USA
+1(413) 577-3016

emails: celeste.chavis@morgan.edu, christofa@ecs.umass.edu

ABSTRACT

Buses stopping at transit stops reduce the capacity of signalized intersections, which can lead to excessive delays for all users. In order to avoid such phenomena signal control strategies can be utilized. This paper presents a signal control strategy to mitigate the impact of bus stop operations on traffic operations along an undersaturated approach. The objective of the proposed strategy is to increase the green time for the bus stop approach during the cycle after the bus has left the stop in order to ensure that the residual queue that was created by the presence of the bus at the bus stop can fully dissipate within the following cycle. In addition, this strategy ensures that the cross-street approaches can clear any residuals queues caused by this strategy within a cycle after its implementation. Kinematic wave theory is utilized to track the formation and

dissipation of queues and determine the red truncation (or equivalently green extension). The benefits achieved from the proposed strategy are illustrated through simulation tests at a single intersection for a variety of bus stop and bus operation characteristics. Average delay, and average queue length for the bus stop and cross-street approaches re used to assess the performance of the system. The tests performed indicate that the signal control strategy can achieve substantial reductions in delay for the bus stop approaches without adversely affecting the cross street operations and the overall intersection delay, when the demand at those cross streets is low.

INTRODUCTION

Efficient multimodal transportation systems are essential components for maintaining and improving the livability of our cities. However, the presence of multiple modes that differ in their dimensions and performance often complicates traffic operations and leads to underutilization of available capacity. Such an example is the existence of bus stops that are common in urban areas. If no bus bays exist, bus stops block lanes causing disruptions to the traffic stream, reducing the capacity of signalized intersections, and leading to excessive delays and potentially gridlock. Therefore, a comprehensive evaluation of the impact of bus stops on the capacity of signalized intersections and the development of signal control strategies to reduce this impact are critical for achieving efficient multimodal traffic operations and improving mobility for all users in urban networks.

The impact of bus stops on traffic and transit operations, and in particular on the capacity of signalized intersections has been extensively studied (Coeymans & Herrera, 2003; Tang et al., 2003; Teply et al., 2008; Yang et al., 2009; Zhao et al., 2007; 2008; 2009; TRB, 2010). However, several of the studies have not provided explicit formulas for estimating the impact (Tang et al., 2003; Zhao et al., 2007; 2008), or have investigated the impact in developing countries where bus stops are commonly located on the non-motorized traffic lane and the behavior of drivers is substantially different than in the U.S. (Coeymans & Herrera, 2003; Yang et al., 2009; Zhao et al., 2009). Other studies have developed analytical formulas to estimate the impact as a function of the bus frequency and dwell time, the number of lanes, as well as the location of the subject bus stop with respect to the stop line (i.e., near side vs far side). However, some of these studies have not explicitly considered the impact of the bus stop's location (i.e., distance from the stop line) on the capacity of the signalized approach (Teply et al., 2008; TRB, 2010). Only a recent analytical method has accounted for the location of the bus stop, the bus dwell time, and the bus frequency when determining the impact of bus stops on capacity (Li et al., 2012).

While the impact of bus stops on the capacity of signalized intersections has been studied extensively, the literature on strategies that mitigate the impacts of bus stops on the capacity or delay of signalized intersections is very limited. A recent study by Gu et al. (2013) investigated the impact of near-side bus stop location on the residual queue length and proposed a real-time bus holding strategy that ensures clearance of the queue within a signal cycle. However, the study used predicted arrival times instead of actual arrivals. The study was later extended (Gu et al., 2014) to estimate car and bus delays when the existence of bus stops affects their delays assuming stochastic bus arrivals and both nearside and far side bus stops. However, the proposed formulas assumed that the car arrival flow is always less than the restricted capacity due to the presence of a bus at a bus stop and developed their formulas for certain distances of bus stops downstream and upstream of a signalized intersection.

Given the limitations of the literature, the objective of this study is to investigate the impact of bus stops on the capacity of signalized approaches as a function of the bus stop's location, bus arrival, and dwell times. The study investigates the impacts of those factors for cases that the car arrival flow is higher or lower than the restricted capacity when a bus is present at the bus stop during the green time interval, therefore, covering a variety of cases that can occur in reality. In addition, it suggests using information on the bus stop's impact on capacity to implement a real-time signal control strategy that ensures clearance of the residual queue within the cycle(s) following the detection of a bus's presence at a bus stop. The focus is on a well-timed signalized intersection for which all four approaches are undersaturated.

The rest of the paper is organized as follows: First, we describe the research approach that includes the methodology used to estimate the impact of an incident on traffic operations, in particular queue formation and dissipation as well as the proposed red truncation signal control strategy. Next, we present all different cases that can arise with regards to queue formation and dissipation patterns for a variety of incident locations, start times, and durations, as well as demand and signal timing characteristics. The required red truncation amounts are also calculated for a sample of cases. Next, results on the impact of the signal control strategy on the performance of the bus stop and cross-street approaches under a variety of demands, bus stop locations, and dwell times are presented. Finally, we comment on the applicability of the proposed strategy and suggest steps for extending the study.

RESEARCH APPROACH

The proposed research is based on tracking traffic conditions in the time-space domain while bus stops are both occupied and unoccupied by a bus. In order to do so kinematic wave theory (Lighthill & Whitham, 1955, Richards, 1956) is utilized. In particular it is assumed that traffic operations for an approach that contains a bus stop can be described by a triangular fundamental diagram. By illustrating traffic conditions as states on a time-space diagram, it is possible to identify the formation and dissipation of queues and determine the impact of a bus stop on traffic conditions (e.g., queue length, delays).

Once traffic conditions are depicted on a time-space diagram, a signal control strategy is introduced. This strategy aims at increasing the green time for the bus stop approach over the next signal cycle in order to clear the additional queues created by the presence of the bus and avoid oversaturation of the subject approach. If the impact of the bus stop is small and the green time interval of the next cycle is sufficient to clear the residual queue, then no additional green time is provided for that approach over the next cycle. The proposed strategy can be implemented as an early green or green extension depending on the phase sequence within the cycle. Note that this strategy is based on the assumption that the cycle length remains constant for the cycle under consideration and the ones immediately following it. For illustrative purposes throughout this paper it is assumed that the green time interval follows the red in a cycle and therefore, the signal control strategy implemented corresponds to an early green (i.e., red truncation). In addition this study calculates the maximum red truncation that is allowed so that the cross-street returns to undersaturated conditions within a cycle after the red truncation.

The proposed methodology assumes knowledge of the triangular fundamental diagram, a constant demand level for the subject approach, q_A, for the cycle under consideration and the ones immediately following it as well as the reduced capacity, q_I, caused by a bus dwelling at a bus stop; see Figure 1. It has also been assumed that the reduced capacity q_I is equivalent to the capacity of a traffic lane, which indicates that a bus dwelling at a stop would block one lane. In addition, the exact bus stop location as measured from the stop line, X, is known. Note that X is negative. It is also assumed that detection technologies such as Automated Vehicle Location systems exist and can provide information on the bus arrival at the bus stop, T_o, and its departure from the stop, T_e, in real time. Note that no prediction of arrival of departure time is necessary since the signal control strategy is always implemented in the cycle following the bus departure from the stop. It is further assumed that the bus dwell time does not exceed a cycle length, which is a reasonable assumption for most bus stops. Finally, it has been assumed that vehicle demand is available through sensing technologies such as loop detectors placed upstream of potential queue spillbacks and the uncontrolled signal timing parameters of the pre-timed signal are known.

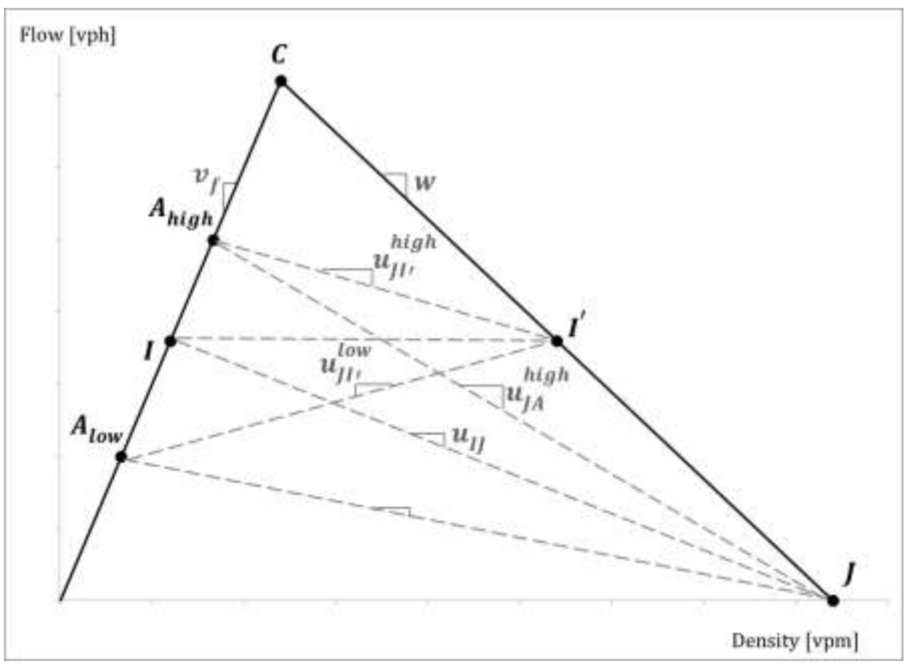


Figure 1: Fundamental Diagram

Red Truncation Estimation

In the absence of a bus at the stop the number of vehicles arrived and therefore, served in one cycle length, N, is equal to $q_A C/3600$ where C is the cycle length in seconds and is the sum of the red time, R, and green time, G. However when a bus is present and oversaturation occurs, the number of vehicles, N_i, served can be determined by examining the flow rates at the stop line using the equation:

$$N_i = (\tau_C q_C + \tau_I q_I + \tau_A q_A)/3600 \qquad (1)$$

where τ_C, τ_I and τ_A is the total time that the flow rate is q_C, q_I and q_A respectively during the cycle(s) that the bus is stopped at a bus stop. Given that the number of vehicles which were served by the intersection, N_i, is less than the number of vehicles that arrived, N_o, during the cycle(s) the incident is present, the amount that the red time interval is shortened is such that the number of vehicles that were unable to go through the intersection due to the bus stop-induced reduced capacity ($N_o - N_i$) plus the number of vehicles arriving in the next cycle (N) is equal to the number of vehicles which can be served during the initial green time for the bus approach, G, plus the additional green provided, -D_R. This can be expressed as follows:

$$D_R = min\left\{G - 3600\frac{N_o - N_i + N}{q_C}, 0\right\} \qquad (2)$$

where D_R is given in seconds and N_o and τ_C are based on whether or not the incident spans one or two cycles yielding:

$$N_o = \begin{cases} N & \text{if } T_e \leq C \\ 2N & \text{otherwise} \end{cases} \qquad (3)$$

$$\tau_C = \begin{cases} G - \tau_I - \tau_A & \text{if } T_e \leq C \\ 2G - \tau_I - \tau_A & \text{otherwise} \end{cases} \qquad (4)$$

The equations for τ_I and τ_A are dependent on the cases defined by the position of the bus stop, the arrival and departure time of the bus from the stop as well as the demand levels and signal timings and they will be determined in the following section. Note that D_R is negative because it corresponds to the change in the red time for the bus approach. If it becomes positive, then no truncation is needed because the initial green time for the approach *G* is sufficient to serve all vehicles despite the reduced capacity due to the presence of a bus at the stop.

Impact on the Cross-Street Traffic

The red truncation implemented for the bus stop approach, D_R, will result to a reduced green for the cross-street approaches. Assuming undersaturated traffic conditions for the cross streets, the maximum cross-street degree of saturation that will allow it to return to undersaturated conditions within a cycle after the implementation of the red truncation for the bus stop approach is determined. This maximum red truncation time, $D_{R_{max}}$, can be calculated as:

$$D_{R_{max}} \geq \frac{2q_{Ax}C}{q_{Cx}} - 2G_x. \tag{11}$$

where q_{Ax} is the arrival rate at the cross street and q_{Cx} is the saturation flow for the cross-street approach *x*, and G_x is the green time interval for cross-street approach *x* when no red truncation is implemented for the bus stop approach.

Identifying the Cases

Depending on the location of the bus stop, starting time and dwell time of the bus the capacity reduction can be categorized as falling into one of five cases. All other instances that do not fall into one of the five cases do not require red truncation, i.e. $D_R = 0$. In order to determine which case each bus stop induced capacity reduction incident is under and estimate its associated red truncation time, the following critical times have been identified as:

$$T_1 = \frac{3600}{5280} \cdot \frac{X}{U_{JA}} \tag{5}$$

$$T_2 = R + \frac{3600}{5280} \cdot \frac{X}{w} \tag{6}$$

$$T_3 = \frac{q_C}{q_C - q_A} \cdot R + \frac{3600}{5280} \cdot \frac{X}{v_f} \tag{7}$$

$$T_4 = C + \frac{3600}{5280} \cdot \frac{X}{v_f} \tag{8}$$

$$T_5 = \frac{v_f T_o (q_A - q_I) + 3600/5280\, X (q_C - q_A) + v_f q_C R}{(q_C - q_I) v_f} \tag{9}$$

$$T_6 = \frac{T_e (q_I - q_C) + T_o (q_A - q_I)}{q_A - q_C} \tag{10}$$

where $T_1, T_2, T_3, T_4, T_5, T_6$ are given in seconds. These times are measured at the location of the dwelling bus, X.

Table 1 provides the constraints that are used to identify each of the cases. All constraints in each case must be satisfied and each case is mutually exclusive. Figure 2 shows the constraints for Cases 1 to 3 on a time-space diagram for undersaturated conditions as well as the locations of T_1 through T_4. Note that for illustration purposes the yellow time intervals are not shown in the time-space diagrams of Figures 2-8 but are considered to be present at the end of each phase. The area with the horizontal lines represents the possible locations that T_o may be located and the vertical lines the locations where T_e may be located (subject to constraint $T_e - T_o \leq C$). It is not feasible for an incident to begin at a location in the jam state since a bus cannot proceed to the bus stop if it is within the zero speed jam state. Cases 4 and 5 are not shown as they represent special cases when the queue following the start of the incident is starved due to the presence of that incident when demand exceeds the capacity during the incident, i.e. $q_A > q_I$.

Table 1: Constraints for each Case

Case	***Constraints***
1	$T_o \leq T_3,\ T_2 \leq T_e \leq T_2 + C,\ \ T_5 > T_2$
2	$T_o \leq C,\ T_e \geq T_2 + C\ ,\ T_5' > T_2$ if $q_A > q_I$ $T_o \leq T_3, T_e \geq T_2 + C,$ otherwise
3	$T_3 < T_o \leq C,\ T_2 + C \leq T_e \leq 2C,\ \ T_1 \leq T_2,\ q_A \leq q_I$
4	$T_5 \leq T_2,\ T_6 \geq T_4,\ \ T_o < T_3,\ \ q_A > q_I$
5	$T_5' \leq T_2,\ T_6 \geq T_4 + C,\ \ T_o \geq T_3,\ \ q_A > q_I$

Once the case has been determined the red truncation time, D_R, can be calculated using the values in Table 2 which shows how long the intersection is discharging at rates as defined by States *A* and *I*. Figures 3 - 8 show example time-space diagrams for each case and depict the critical times defined above. Each figure shows in solid black lines the propagation and dissipation of queues if no signal control strategy is implemented and in dashed lines how the queue dissipates when the red truncation strategy is in place. The gray dotted lines represent the formation and dissipation of queues in the absence of a bus at the bus stop; see Figure 4. The bold line in yellow represents the presence of a stopped bus. For all cases shown it is assumed that traffic operations can be described by a fundamental diagram with the following characteristics: $q_c = 3600$ vph, $q_i = 1800$ vph, $w = -12$ mph, and $v_f = 30$ mph. As can be seen by the time-space diagrams in Figures 6 and 7, Case 5 is nearly a translation of Case 4. In order to determine the red truncation time in Case 5, three new variables must be defined: $T_e' = T_e - C$, $T_o' = T_o - C$, and T_5' can be found by substituting T_o' for T_o in equation (9).

The characteristics of bus stop operations for each sample case and the required red truncation as well as the resulting average vehicles delays for the bus stop approach and the cross street with and without control are shown in Table 3. When demand is low (Case 3 - Figures 5 and Case 6 – Figure 8) no truncation is needed. In fact, if the bus is not present at the bus stop while the signal is discharging, there is no increased delay due to the bus dwelling. In Cases 1 and 4, the presence of a bus at the bus stop increases delays; however, queues dissipate within a cycle without control. Cases 2 and 5 demonstrate scenarios which require red truncation. As expected the strategy improves the average and total delays along the bus stop approach and slightly increases delays along the cross street. Additional results are given in the following section.

Table 2: Time Spent in States *A*, τ_A, and *I*, τ_I.

Case	$\boldsymbol{\tau_A}$	$\boldsymbol{\tau_I}$
1	0	$\min\{T_e, T_4\} - \max\{T_o, T_2\}$
2	$\min\{T_o, T_4\} - \min\{T_3, T_o\}$	$\max\{T_o, T_4\} - T_o + T_e - (T_2 + C)$
3	$T_4 - T_3$	$\min\{T_e, T_4 + C\} - (T_2 + C)$
4	0	$\min\{T_e, T_4\} - T_5$
5	$T_4 - T_3$	$\min\{T_e', T_4\} - T_5'$

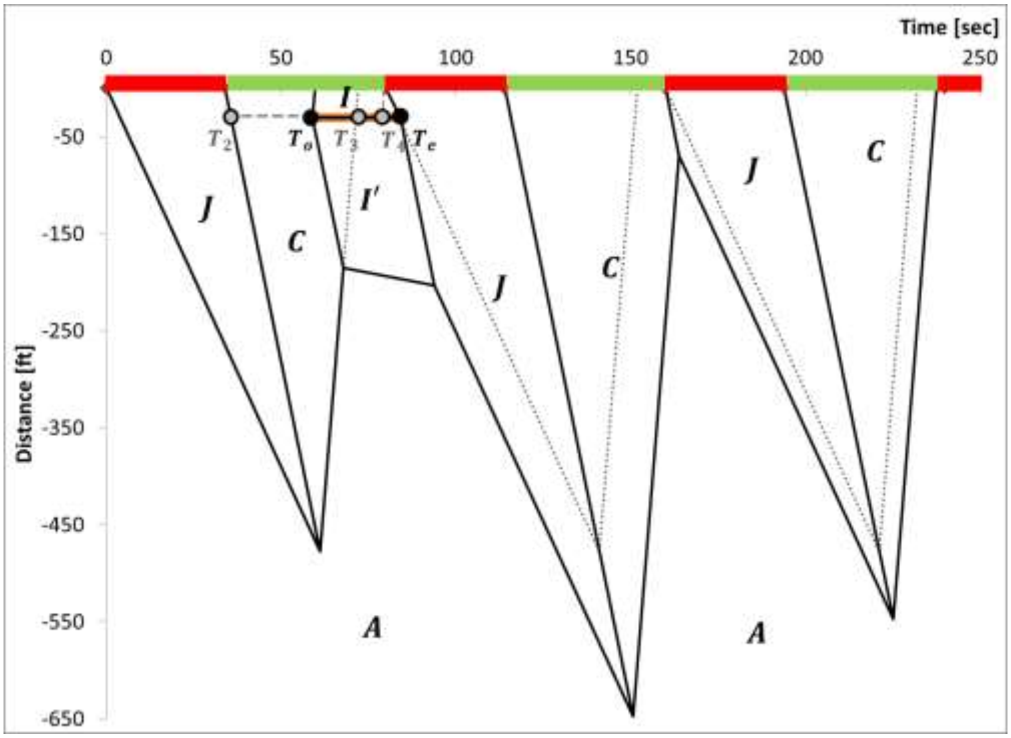


Figure 3: Case 1 Time-Space Diagram (No Control)

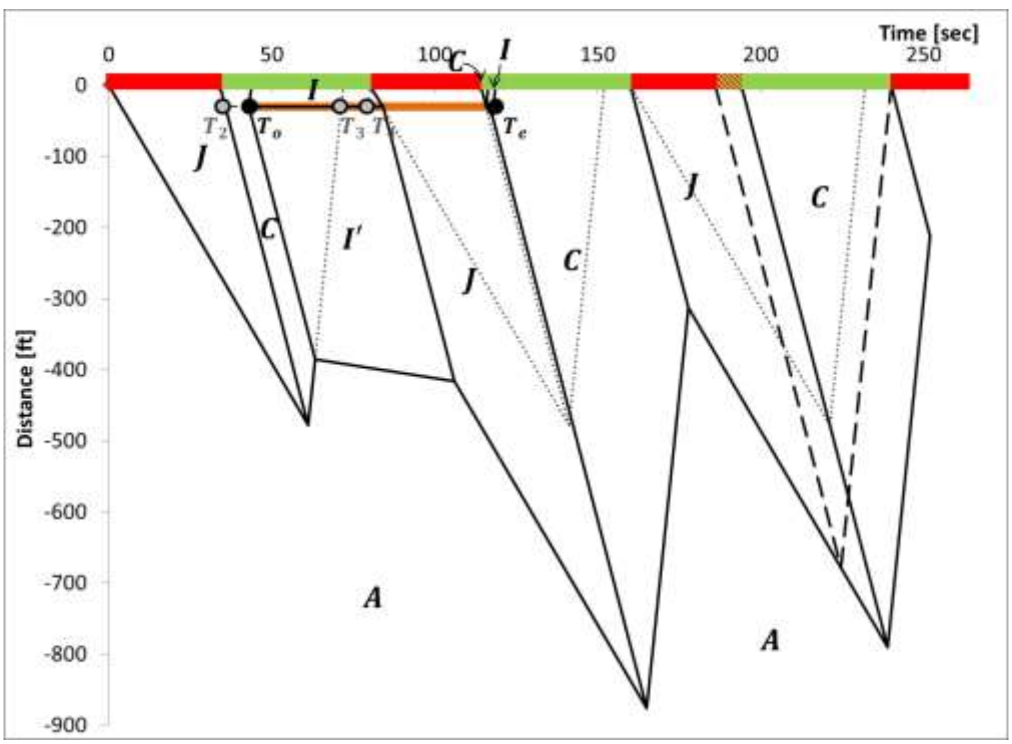


Figure 4: Case 2 Time-Space Diagram (Truncation needed)

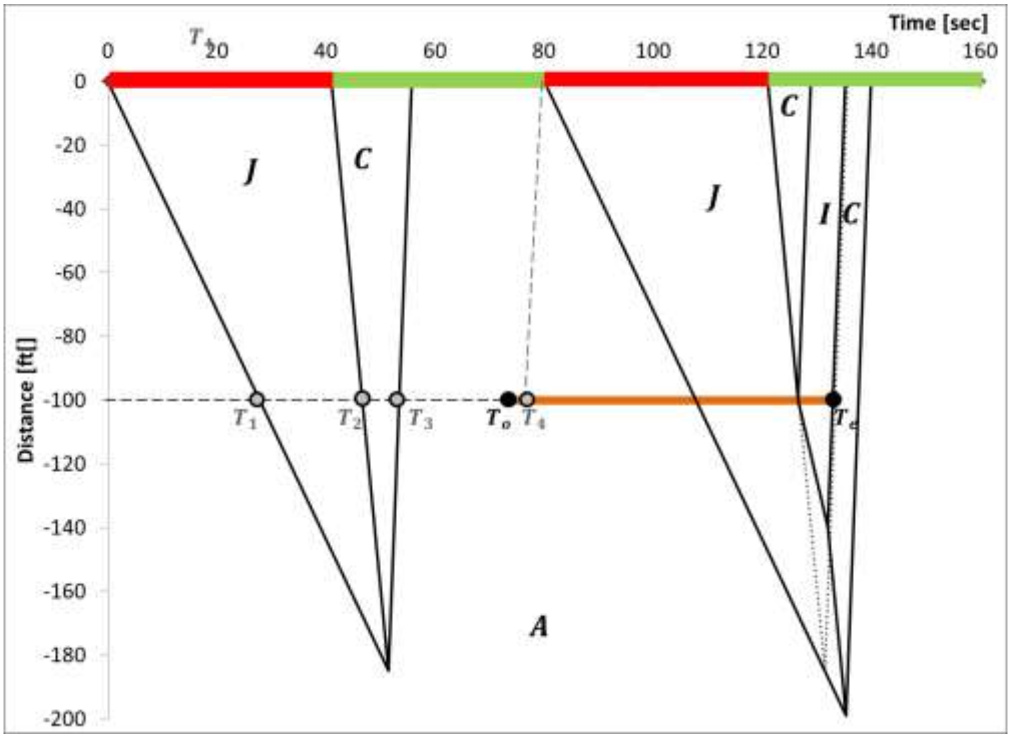


Figure 5: Case 3 Time-Space Diagram (No Control)

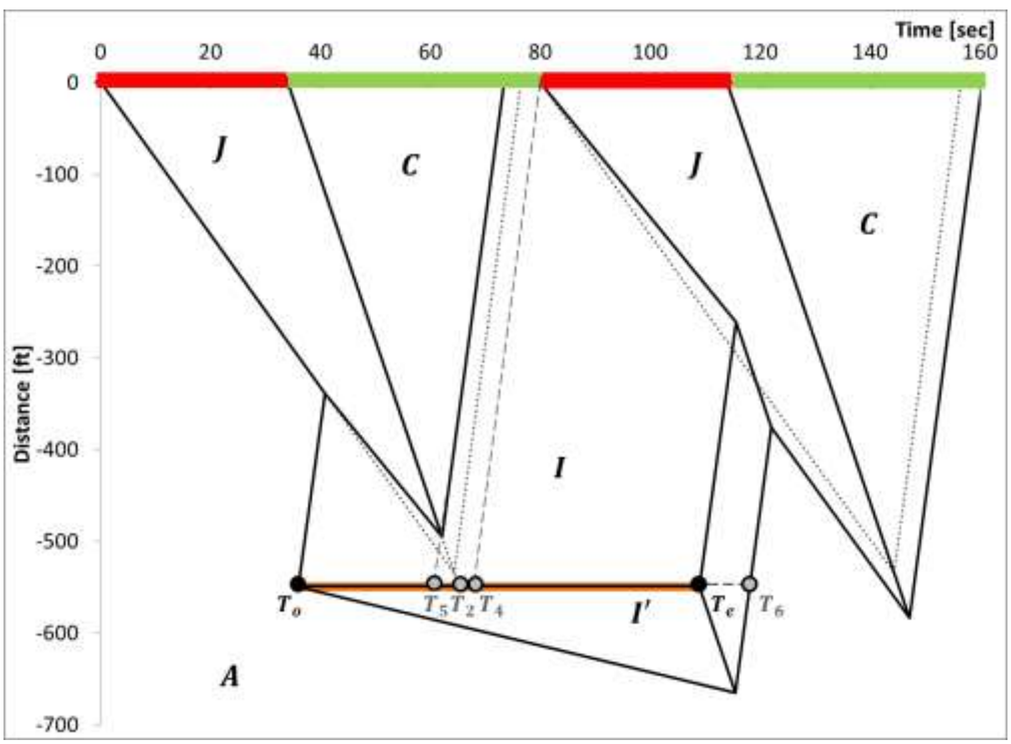


Figure 6: Case 4 Time-Space Diagram (No Control)

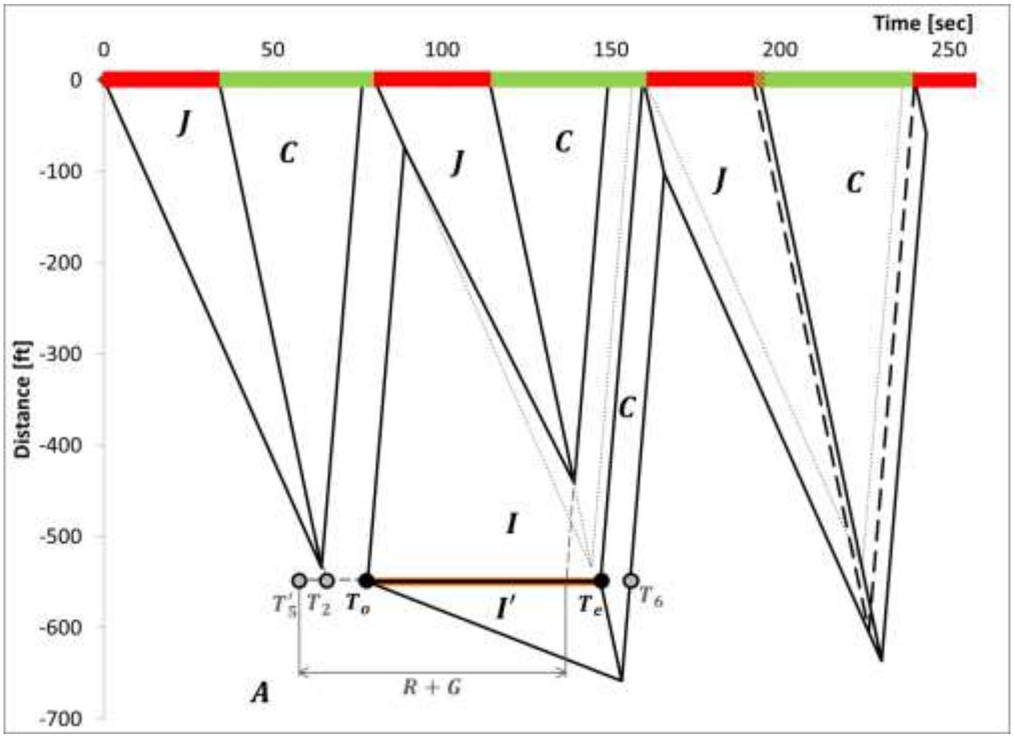


Figure 7: Case 5 Time-Space Diagram (No Control)

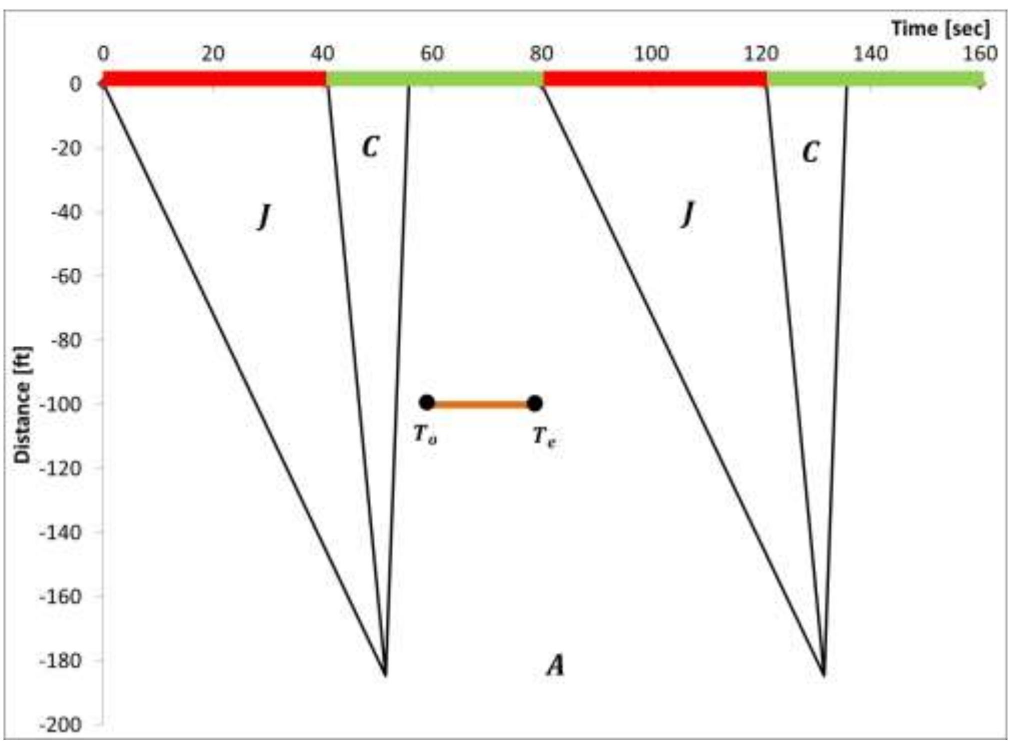


Figure 8: Case 6 - No Impact (No Control)

Table 3: Parameters and Average Vehicle Delays for Each Sample Case

	X (ft)	T_o (sec)	T_e (sec)	Demand Case	DR	Bus Stop Approach Average Delay (sec/veh)		Cross Street Average Delay (sec/veh)	
						No Control	Control	No Control	Control
Case 1	-30	1819	1843	$q_A>q_I$	0.00	16.49	--	31.46	--
Case 2	-30	43	118	$q_A>q_I$	-7.97	38.63	35.11	27.11	28.73
Case 3	-100	314	373	$q_A<q_I$	0.00	15.86	--	25.82	--
Case 4	-550	605	684	$q_A>q_I$	0.00	20.91	--	26.29	--
Case 5	-550	78	147	$q_A>q_I$	-2.06	18.15	17.44	27.11	27.11
Case 6	-100	619	639	$q_A<q_I$	0.00	11.10	--	16.47	--

APPLICATION

The evaluation of the proposed methodology and real-time signal control strategy has been performed with the use of simulation, in particular with the software AIMSUN through its Application Programming Interface (API). API allows for implementing the proposed signal control strategy in real-time and evaluating its performance through a variety of performance measures such as delay for the subject bus stop approach, delay for the cross-streets, and average queue length for all approaches.

Test Site

The test site used for the application of the proposed signal control strategy is the intersection of San Pablo and University Avenues in Berkeley, CA; see Figure 9. The intersection operates with a four-phase signal with a cycle length of 80 seconds. Six bus routes with headways that vary between 10 and 30 minutes on each route, travel through the intersection and stop at six bus stops located at different distances from their corresponding stop lines.

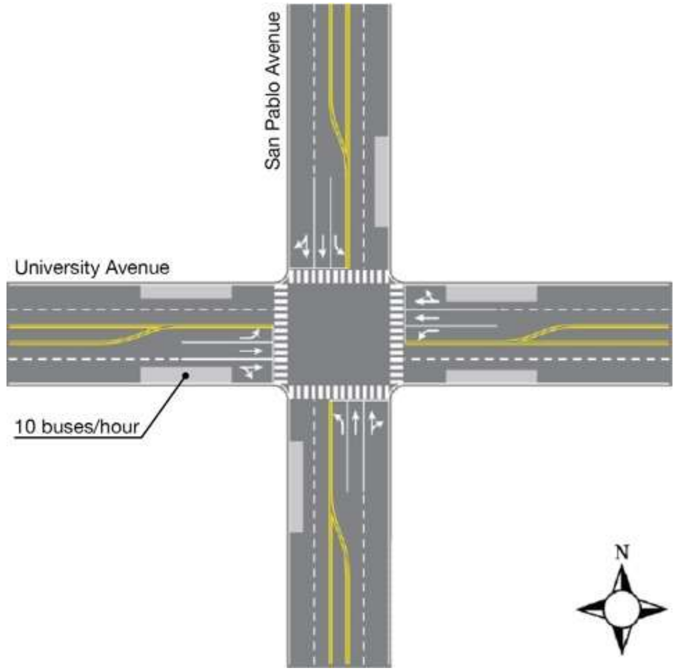


Figure 9: Test Site: San Pablo and University Avenue, Berkeley, CA

The focus of this study is on the eastbound approach of University Avenue which has a nearside bus stop where buses of three different bus lines stop with an overall frequency of 10 buses per hour. The demand levels of both approaches were set in such a way so that the test site represents traffic conditions at the intersection of a major with a minor roadway. This was essential since the proposed signal control strategy has been designed under the assumption of undersaturated conditions and performs best when the cross street approach is not operating close to saturation. The car demand for the cross-streets was set to 250 vph. Two scenarios of high and low demand were created for the bus stop approach (eastbound approach of University Avenue) and the opposite direction of University Avenue. The high demand was set to 2000 vph and the low to 1000 vph with turning ratios of 85% for through, 10% for right, and 5% for left for both demand scenarios. The same turning ratios were used for the cross-street demands.

For the low demand scenario the green time for the phase that serves the University through movements was set to 37 seconds, and the one for the cross-street through movements to 19 seconds. For the high demand scenario, these green times were set equal to 44 seconds and 12 seconds respectively. The other two phases that serve the left-turning vehicles had a constant green time of 5 seconds allocated to them for both scenarios. Therefore, red truncation was implemented only on the phase that serves the through cross-street movements. In addition, the lost time, which is assumed to be equal to the total yellow time was kept constant and equal to 14 seconds, 4 seconds after each of the through phases and 3 seconds after each of the left-turning phases. It is assumed that cars will continue through the intersection for 2 seconds of the yellow interval thus an extra two seconds was added the green time with remaining time in the cycle denoted as red time.

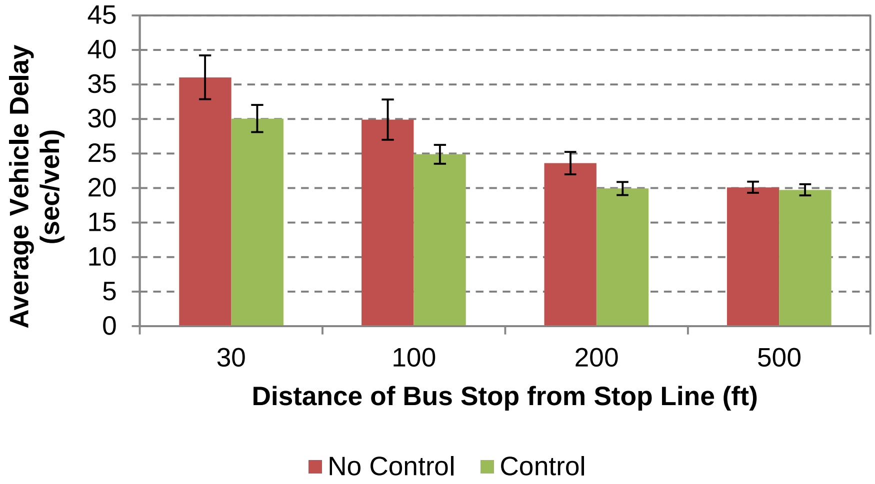
Based on this information, the degrees of saturation for the University through movements were 0.57 and 0.96 for the low and high demand scenarios and for the San Pablo approaches equal to 0.28 and 0.44 for the low and high demand scenarios. Bus stop locations of 30, 100, 200, and 500 ft from the stop line were tested. The average bus dwell time was set to 40 seconds with a standard deviation of 30 seconds. These ensured that several different cases of bus stop obstruction were captured.

Results

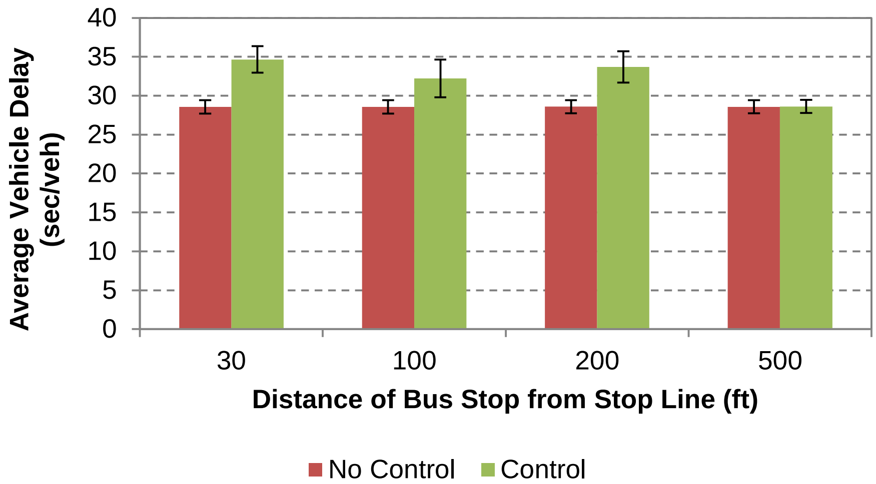
Several tests were performed with the help of the microsimulation software AIMSUN as described above and the results were evaluated primarily through two performance measures: average vehicle delay and average queue length for both the bus stop approach and the cross streets (an average of the performance of the two cross street directions is presented here). Ten replications were run for each scenario to account for the stochasticity in bus and vehicle arrivals as well as bus dwell times and the average as well as the 95% confidence intervals of those replications are presented here.

Tests were performed both for a high bus stop approach demand which exceeds the reduced capacity due to the bus dwelling and for a low demand. The results for the low arrival rate along the bus stop approach show there is no need for red truncation at the cross street since even with reduced capacity the intersection approach is still capable of serving all vehicles within one cycle thus maintaining undersaturated conditions. It is possible that truncation is needed when the arrival rate is lower than the reduced capacity of intersection as the presence of the bus may impede the discharge rate when a signal turns green. However, if the incident is sufficiently upstream and/or the degree of saturation low, the blockage caused by the bus dwelling at the stop does not greatly restrict the flow of arriving vehicles.

Figures 10 and 11 show the changes in average vehicle delay and average queue length for both the bus stop approach and the cross streets (presented as a weighted average of the two cross-street through approaches) as well as the 95% confidence intervals. The results indicate that the proposed signal control strategy can significantly reduce average vehicle delay for the bus stop approach for all bus stop location scenarios other than the one of 500 ft. As the distance of the bus stop from the stop line increases its impact on traffic operations close to the signalized intersection diminishes. As a result, even when no control is in place, the delays of vehicles on the bus stop approach are on average lower than the ones when the bus stop is located close to the intersection stop line. This verifies the findings of previous research efforts on the higher impact of nearside bus stops on the capacity and delays of vehicles at the signalized intersection. While the average vehicle delay for the cross streets increases, the amount by which is increases is very low, on the order of 3-5 seconds per vehicle. Taking into account that the cross street is less heavily traveled than the main street, the strategy results to an overall reduction of delay of about 6% for the case that the bus stop is located directly upstream of the intersection stop line.



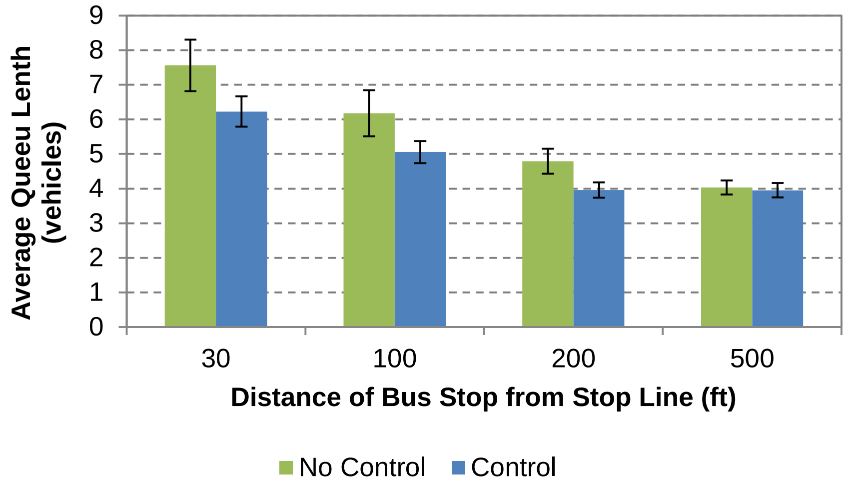
(a) Bus stop approach (eastbound University Avenue)



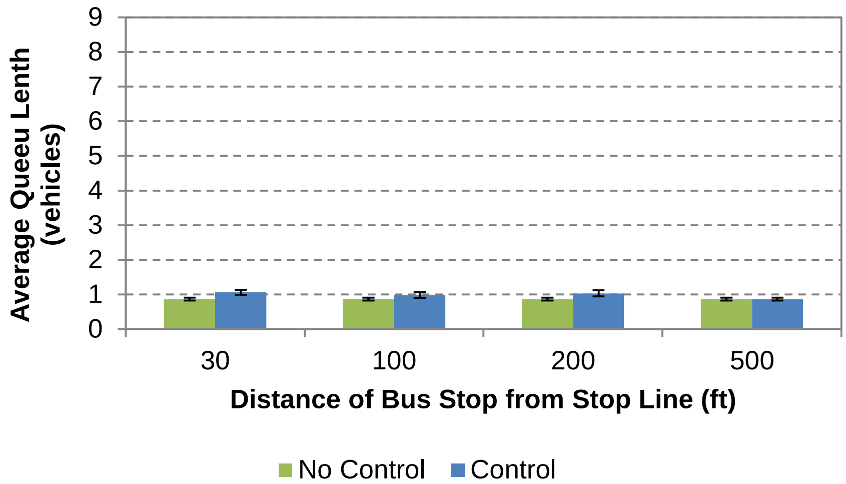
(b) Cross-street approaches (average of northbound and southbound San Pablo Avenue)

Figure 10: Average Vehicle Delay for Various Bus Stop Locations with and without Control

Similar trends are observed for the average queue length at the bus stop and the cross-street approaches. The reduction of average queue length at the bus stop approach diminishes as the distance of the bus stop from the intersection stop line increases. At the same time the increase in average queue length observed at the cross-street approaches is minimal on the order of 0.2 vehicles. This happens because for the tests performed the cross streets were far from reaching saturation.



(a) Bus stop approach (eastbound University Avenue)



(b) Cross-street approaches (average of northbound and southbound San Pablo Avenue)

Figure 11: Average Queue for Various Bus Stop Locations with and without Control

CONCLUSIONS

This study presents the development of a real-time signal control strategy that utilizes information on the location of a bus stop, as well as the bus dwell time, traffic demand levels and, signal timings. The proposed bus stop mitigation strategy utilizes kinematic wave theory to track the formation and dissipation of queues and estimate the amount of green that needs to be added to the subject approach so that residual queues are cleared within one cycle.

Several tests were performed for a variety of bus stop locations, dwell times, and for two levels of bus stop approach demands through microsimulation. The outcomes of the tests indicate that rarely if ever there is a need for implementing the real-time signal control strategy when the capacity of the approach when a bus is present is higher than the demand of the incoming traffic to the subject approach. On the other hand, when the arrival demand at the bus stop approach exceeds the lower capacity caused by a bus dwelling at the bus stop, the proposed mitigation strategy can achieve average delay and average queue length reductions of up to 17% for the bus stop approach. The 17% reduction in average delay corresponds to about 6 seconds per vehicle average delay savings. At the same time, the mitigation strategy only slightly increases average delay for cross street on the order of 3-5 seconds per vehicle. When the cross street is less heavily traveled than the bus stop approach, net benefits from such a control strategy are achieved and the overall delay at the intersection decreases. The mitigation strategy is most beneficial when the bus stop is located very close to the stop line of the signalized approach. Note that the proposed strategy is applicable for cases where all intersection approaches are undersaturated and is most beneficial when implemented at intersections that the bus stop approach has a much higher demand than the cross street.

The benefit of the proposed real-time signal control strategy is that it can be implemented for any bus stop location, dwell time, and can be used both when the vehicle demand is higher than the reduction in capacity induced by a bus stopping at bus stop and when it is lower. Therefore, in addition to investigating and mitigating the impact of bus stops on capacity and delay, the equations presented here and the mitigation strategy is applicable to any type of incident that can occur in signalized arterial networks, such as freight deliveries, accidents, etc. So, under the assumption that the characteristics of the incident are known in real-time (after the incident had been removed), the proposed strategy can be implemented to mitigate the impact of that incident on traffic of that approach. Overall the proposed strategy can be used for real-time mitigation of bus stop or incident-induced reductions of capacity to improve traffic and transit operations in urban signalized arterials.

Future steps include improving the mitigation strategy so it can handle bus stop events that occur within the same cycle or consecutive cycles and cases when a bus is stopping for longer than one cycle length. In addition, extending the focus of the strategy to include cases where vehicle demand varies from cycle to cycle.

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