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Assessing the Optimal Location of Near Side Bus Stop to Enhance Advantages of Bus Signal Priority (BSP)

Pradeep Kumar SHRESTHA
Research Associate
Graduate School of Engineering
Yokohama National University
79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, JAPAN
Tel/Fax : +81-45-339-4031
E-mail: erpradeep78@yahoo.com

Fumihiko NAKAMURA
Professor
Graduate School of Engineering
Yokohama National University
79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, JAPAN
Tel/Fax: +81-45-339-4032,
E-mail: f-naka@ynu.ac.jp

Toshiyuki OKAMURA
Associate Professor
Graduate School of Engineering
Yokohama National University
79-5 Tokiwadai, Hodogaya-ku, Yokohama 240-8501, JAPAN
Tel/Fax:+81-45-339-4031,
E-mail: tokamura@ynu.ac.jp

Abstract: In this paper, bus signal priority (BSP) with different near side bus stop position in reference to the average queue during red time of the selected intersection and bus detection after bus departure from stop was modeled. Three alternative positions such as bus stop within normal queue, at the end of normal queue and beyond the distance of normal queue were evaluated for traffic flow ratios of 0.7, 0.9 and 1.1 by simulation method. Two objective functions i.e. decrease in delay for priority movement and increase in delay for non-priority movements were considered. Since there are two objective functions, Pareto-optimal situation arises. The optimal case was selected based on the shortest normalized distance to Pareto optimal sets. Bus stop at the end of normal queue outperforms reducing total person delay in priority direction with least increase in total person delay on non-priority direction.

Key Words: *Near side bus stop, Bus signal priority, Simulation, Optimal bus stop location*

1. INTRODUCTION

Road intersection is an important facility of urban development. Most of urban activities and developments are found to be concentrated around road intersection. The increased activities make it an ideal bus stop location for passenger boarding and alighting. At the same time, intersection is signalized for proper channelization of conflicting vehicular and pedestrian traffic flows in desired directions through the intersection. Thus, bus stops and intersections are two types of nodes along the bus route which affects bus operational efficiency primarily.

Bus Signal Priority (here after BSP) is broadly considered approach of improving bus service performance by reducing stopped delay of buses at signalized intersection. Hence, BSP has been implemented in several cities of the developed countries (ITS America, 2002). It is to be noted that decreasing cost of information and communication technologies and a recent increased attempt of many developing countries to implement advanced form of bus system such as Bus Rapid Transit (BRT) has shown potential of extending BSP application in developing world as well. At the same time, there are many aspects such as BSP and bus operation control, infrastructure management, possibilities of transfer technologies to developing countries etc have not been yet covered (Shrestha *et al.* 2008).

One of the influential factors for the productive BSP is the proper location of bus stops. Near side bus stop has potential of utilizing red time of signal while serving passenger but buses conflicts with the left turning vehicles and bus may still serving the stop even after traffic signal turns green or extended green time in BSP mode resulting wastage of green time. Similarly, far side bus stop avoids those disadvantages but the accumulation of buses at a far side stop may spill over into the intersection affecting traffic flow through intersection approach (Levinson *et al.*, 2003). Most researches have concluded the presence of the near side bus stop escalates variance in bus arrival at the intersection, there by diminishing BSP effectiveness. Several studies have recommended moving bus stop into far side (Rakha and Zhang, 2004). However, movement of bus stop is not always possible due to site constraints, passenger activities etc. Sakamoto *et al.* (1997) proposed bus signal priority in which bus can overtake queue by using adjacent opposite lane. Satiennam *et al.* (2005) tried to reduce lost green time at near side bus stop. One of the options is to move bus detector to the downstream of the near-side bus stop. However, the shortened distance from the bus detector to the stop line reduces time for traffic controller to adjust signal timings for suitable BSP treatments (Zheng *et al*., 2007). One possible way is to select bus stop position keeping view on the time required to communicate the bus information and to adjust the signal timing. Furthermore, in mixed mode operation, buses have to join a vehicle queue, wait in the queue, and depart from the queue in a manner similar to other vehicles in the traffic stream (Lin, 2007). Vehicle queue at intersection even block the bus to reach at the near side bus stop thereby further intensifying delay to bus. Therefore, vehicle queue at the intersection should also be taken into account while deciding stop position for BSP.

Thus, this paper has considered three alternative positions of near side bus stop such as bus stop within normal queue, at the end of normal queue and beyond the distance of normal queue and evaluation was carried out for three traffic flow ratios 0.7, 0.9 and 1.1 in CORSIM micro simulation package. BSP activate only after bus being ready to depart bus stop and two cases of BSP namely, red truncation and green extension was considered. At first, the impacts of modeled signal priority with various position of near side bus stop on measures of performances of buses along measures of performance to the vehicles on priority road and non-priority road were aggregated. Comparing the measures of performances for buses, vehicles on priority and non-priority directions for different bus stop position, an optimal position could be recommended for deployment. Since there were more than one performance measures, an analysis led to a set of Pareto-optimal cases, which is optimal in the sense that it is not possible to improve measures of performance for priority direction without worsening measures of performance in non-priority direction. The optimal case was selected based on the shortest normalized distance to Pareto optimal sets, which is optimal for both measures of performances in priority and non-priority direction. Further investigation was carried out for more measures of performance and sensitivity effect of traffic congestion to confirm the result.

2. PURPOSE AND OBJECTIVES OF RESEARCH

The interaction of bus with other traffic in mixed flow, delay at bus stop and delay at signalized intersection increase bus delay and its variation. BSP is one of the important measures to reduce bus delay at signalized intersection. The layout of bus stop is a critical factor for bus operation to reduce bus delay variations. In addition, bus stop location has been critical factor for signal priority effectiveness as well. Researchers only recommended the far side bus stop for maximum benefit of BSP but there are the cases where near side bus stops can not be avoided. In such cases, the approach to combine bus stop location, point of bus detection and bus signal priority to get optimum benefits from signal priority with least harm to non-priority vehicles is to be investigated. Thus, the purpose of this paper is to study the combined approach of bus operation and BSP for finding optimal bus stop location at near side for BSP benefits considering bus detection control and varied traffic saturation levels. The specific objectives of the study are:

- Quantifying impacts of Signal priority with various position of near side bus stop
- Comparison of the impacts to bus under different traffic demand with reference to performance indicators of bus itself, traffic on priority and non-priority direction.
- Suggest optimal location of bus stop for near side approach while considering BSP

3. RESEARCH METHODOLOGY

The purpose of this study was to assess the relative effects of bus stop location at near side approach of signalized intersection in BSP on the priority and non-priority road for different performance factors. Micro-simulation model, which can track individual vehicles and buses through the network, was considered for studying the operation of BSP. The main components of the methodology are as follows:

a. Setting up cases of combination of bus stop position, detection and BSP
b. Development of proposed Bus Signal Priority method
c. Simulation evaluation of BSP schemes developed
d. Analysis for different cases of traffic demand
e. Recommend Optimal near side bus stop for bus signal priority

3.1 Setting up Cases for BSP

The different combination of elements such as bus stop location and point of bus detection along with bus signal priority (BSP) offer different level of service and impacts on vehicular traffic and bus (Shrestha *et al.*, 2008). As explained earlier, the increased penalty such as increased delay, reduced speed etc to vehicles on the non-priority direction due to BSP with near side bus stop can be reduced if bus detector is moved downstream to bus stop or BSP is activated after communication of door closing time i.e. when bus is ready to depart from bus stop after serving last passenger. In such case, there would be least time available to adjust the signal parameters. In recent advancement of telecommunication and information technologies, time to adjust the signal parameters would not be of a big deal than the possible benefits and disbenefits to vehicles and buses. Hence, this study has attempted to test three different locations, considering the average queue observed in the selected intersection over red period, of near side bus stop and their effects on measures of performances.

<u>**Section 1:**</u> Bus stop at near side and bus has to wait at queue to enter bus stop if arrive at red time (30-45m). (**Alternative I**)
<u>**Section 2:**</u> Near side Bus stop at the end of normal queue (90m) (**Alternative II**)
<u>**Section 3:**</u> Near side stop, beyond the distance of normal queue (150m) (**Alternative III**)

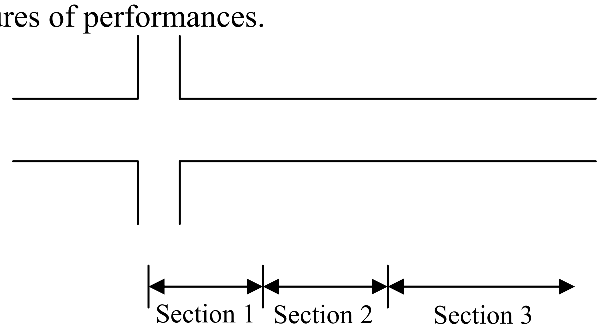

Figure 1 Section considered for simulation

This analysis tries to encompass the effect of under saturated and saturated traffic condition on measures of performances by considering three traffic flow capacity levels 0.7, 0.9, and 1.1. The traffic flow capacity 0.9 is observed condition in the field where as flow capacity level of 0.7 and 1.1 attempted to incorporate reduced traffic flow and saturated condition respectively. Thus, there will be 9 cases in total as shown in Table 1.

Table 1 Setting up of cases

Bus stop Position	Distance of detector from stop line or distance of near side bus stop	Traffic Demand (V/C Ratios)
Near	i) 30 m (100ft) **(Alternative I)** ii) 90 m (300ft) **(Alternative II)** iii) 150m (500ft) **(Alternative III)**	0.7, 0.9 and 1.1

3.2 Development of Proposed Bus Signal Priority Model

3.2.1 Signal Priority Logic

Signal priority logic was developed to change traffic signal parameter in order to give priority to buses. The priority logic includes bus detection at user specified distance, prediction of time at which bus will arrive at intersection stop line or join intersection queue, decide bus priority scheme according to bus arrival time and granting priority. The priority logic can be explained as follows:

1. The detector detects bus at bus stop.
2. The system will check whether bus is ready to depart from bus stop.
3. If bus door has been closed i.e. ready to depart, information will convey to control centre.
4. Bus arrival time at intersection is estimated by the bus prediction model considering traffic signal state and demand as explained below.
5. The control system will determine signal priority strategy based on time at which bus arrives at intersection i.e. (green extension if bus arrives within green extension interval, early green if buses arrive within early green interval).

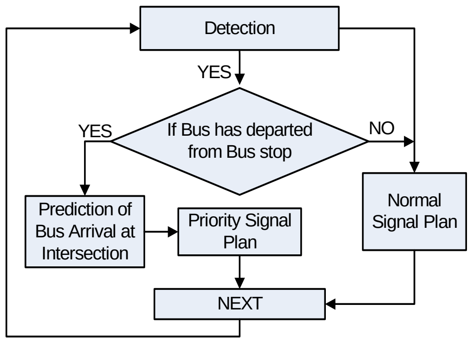

Figure 2 Flow diagram of BSP activation

3.2.2 Bus Detection

Since the purpose of this study is to make effective signal priority with near side bus stop at suitable location, the detection of buses has been considered downstream of the bus stop. Appropriate way is to communicate the door closing information with control centre. In this simulation model, bus is detected when bus is about to depart from bus stop. Thus, the uncertainty of bus departure from bus stop due to variation in dwell time is expected to reduce.

3.2.3 Bus Arrival Time Estimation

It is necessary to know when bus will arrive at intersection since its first detection so that appropriate signal priority scheme could be selected for all case of priority. The time of detection of approaching bus, its speed, and other traffic data such as queue at intersection, queue discharge headway, signal status etc. are important factors which affects bus arrival time at intersection. Since bus is assumed to be detected when bus is ready to depart, the bus arrival time at intersection stop line is independent of bus dwell time.

An attempt was made to model bus arrival time for bus signal priority considering signal state. The estimation will be modified for signal state and accumulated queue at intersection by the similar concept used by Li, *et al.* (2005). It has considered under saturated intersection and queue would not back up over the advance loops. The travel time 'T' of a bus is the sum of travel time since departure from bus stop to travel time to intersection.

$$T_{ai} = \alpha_1 L_{ai} + \beta_1 \quad (1)$$

Where, Travel time, T_{ai} was expressed as linear relationship with distance. The coefficient 'α' can be considered as reciprocal of average speed of bus, and the coefficient 'β' accounted for variation in travel time.

In most cases, buses have to join a queue, wait in the queue, and then discharge with the queue. In order to initiate priority, the time when bus reaches at intersection stop line or time when it joins at the end of queue is necessary. The number of queuing vehicles can be estimated based on the arrival and departure counts from loop detectors.

(i) Signal state is green when bus is detected: The remaining green time can be calculated as;

$$G_{remain} = G(p) - G'(p) \quad (2)$$

Where G(p) and G'(p) are green time and elapsed green time of phase 'p', the difference of the counted arrival and the estimated departure counts gives the queue length, and the corresponding queue discharging time can be calculated as:

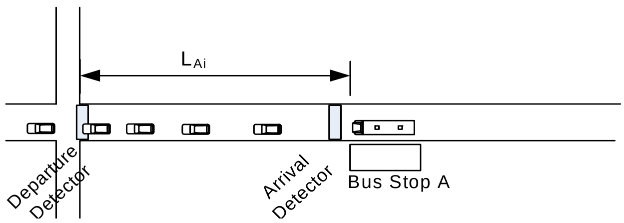

Figure 3 Queue situations when signal state is green

$$q_{discharge} = [D(t) - A(t)] \big/ Saturation\ flow \quad (3)$$

If $q_{discharge} \le G_{remain}$, Bus arrival time will be equal to Equation (1).
If $q_{discharge} > G_{remain}$, Bus arrival time can be obtained by subtracting ($q_{discharge} - G_{remain}$) time from Equation (1).

(ii) Signal state is red when bus is detected: If signal stage is red at the time bus was detected, the end of queue is to be determined. Then, time when the bus will join intersection queue is calculated by,

$$T_{ai} = \alpha_2 X_{ai} + \beta_2 \quad (4)$$

Where, $X_{ai} = L_{ai} - Queue\ Length$

If $T_{ai} > R_{remain}$, $T_{ai} = \alpha_2 L_{ai} + \beta_2$ for calculating bus arrival time as per Equation (1) above.

If $T_{ai} \le R_{remain}$, then bus arrival time is $T_{ai} = \alpha_2 X_{ai} + \beta_2$

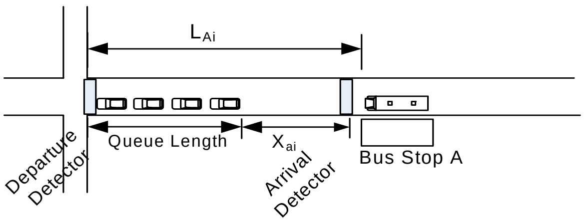

Figure 4 Queue situations when signal state is red

3.2.4 Bus Priority Scheme

Green extension and early green are two major priority logics considered for this study. The green extension is used when the upper level of priority can be accommodated by extending green. To extend the green phase until the priority window ends, the force-off point (the point where end of phase begin) of the main street phase with the green extension strategy, T_1^{ext}, is set at the upper value as shown in Figure 5(b). The green extension can be used for the bus that arrives at the intersection between upper and lower value shown in Table 2. As shown in

Equation (5), the maximum green time extension 'G_{max}', is the difference between cycle time, and the minimum green time '$G_{min,i}$', the change interval (I_i) of all non-priority phases which is sum of Amber time (Y_i) and all Red time (A_i) , and green time (G_i) of main road. Where, *i*, Φ_i, C, G, Y, A and I denote phase number, phase, cycle time, green, amber, all red and change interval, respectively.

$$G_{\max} = C - G_1 - \left\{ \sum_{i=2}^{n} G_{\min,\,i} + \sum_{i=1}^{n} (Y_i + A_i) \right\} \tag{5}$$

As phase 2 and phase 4 are very short and minimum green time for phase 3 is 30 sec, additional green time for providing priority at Main Street was deduced only from phase 3. The maximum green time from Equation (5) will be G_{max}= (130-33-[{7+30+7} + {3+(3+2)+3+(3+2)}] = 37. The upper and lower values of green extension can be calculated as per Table 2.Thus, if bus arrives at intersection between 33 and 70 sec, green extension is activated.

Similarly, if a bus is expected to arrive during the red signal and upper level of priority cannot be accommodated by green extension, then the non-priority phases is shortened to allow the main street to receive a green earlier than normal. The early green depends on the number of non-priority phases between the current phase at which bus arrives and the main street phase. The current phase is stopped or provided the minimum green, and its change interval initiated. The maximum early green time is the difference between the cycle time, and phases that has already been served, the maximum of elapsed green of the current phase (t_k) and its minimum green($G_{min,k}$), and minimum requirements of phases (G_{min}, I_i) as shown in Equation (6).Similar types of mathematical relation has been used by Kim *et al.* (2005)

$$G_{early} = C - \left\{ (G_1 + I_1) + \sum_{i=2}^{k-1} (G_i + I_i) + \left\{ \max(G_{\min,k}, t_k) + I_k \right\} + \sum_{i=k+1}^{n} (G_{\min,i} + I_i) \right\} \tag{6}$$

$$G_{early} = C - \left\{ (G_1 + I_1) + (G_2 + I_2) + \left\{ \max(G_{\min,3}, t_3) + I_3 \right\} + (G_4 + I_4) \right\} \tag{7}$$

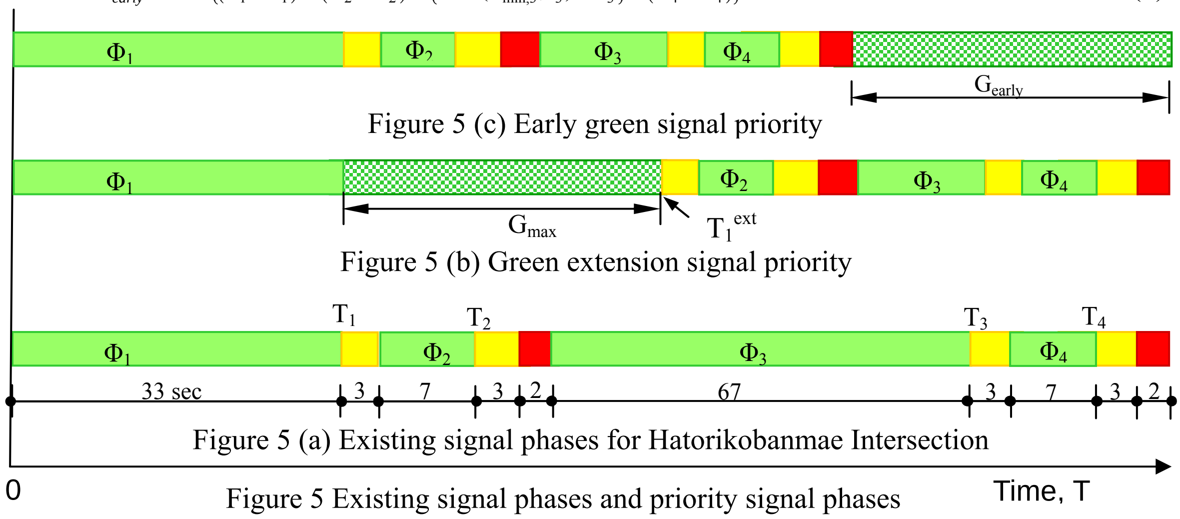

Figure 5 Existing signal phases and priority signal phases

Where, 'i' and 'k' are numbers of phases and the phase during which bus will arrive, respectively. It is to be noted that the phase 2 and 4 are very small and only phase 3 can contribute to the early green time. Thus, early green is calculated as in Equation (7).If bus arrived in phase 3 and the elapsed green time of phase 3 is 40 sec, then, early green can be calculated as G_{early}=(130-{(33+3)+(7+5)+{max(30,40)+3} + (7 + 5)}) = 27. The upper and lower values of early green are 130 and 103 sec as per Table 2. Thus, if bus arrives at intersection beyond 70 sec, early green was activated.

Table 2 Upper and lower values of signal priorities

	Upper value		Lower value	
Green extension	$T_1 + G_{max}$	= (33+37) = 70	T_1	= 33
Early Green	C	= 130	C - G_{early}	= 130 -27 =103

3.3 Study Area and Data Collection

The study area is the Fujisawa City of Japan, situated 50 km west of Tokyo. The target corridor for the bus signal priority is the bus route carrying commuters to the Tsujido railway station. The bus route has to pass through the major intersection with National Highway 1, which brings travelers to Yokohama downtown. Field surveys were conducted during 7.00-10.00 of randomly selected 3 weekdays in May 2008. Physical characteristics of the study site such as road geometry, intersection layout, lane configuration etc. has been shown in Figure 6. The 15 min traffic volume in main and cross road, and traffic signal parameters (cycle time, offsets, phase length etc) for entire data collection period were obtained through video recording and further processing at laboratory. Arrival and departure of the buses were recorded using video cameras, which were positioned at the bus stop and the convenient places of intersection. The intersection has near side bus stop. The collected bus related data include average bus speed, headway, bus dwell time, bus departure time, and time of joining traffic queue.

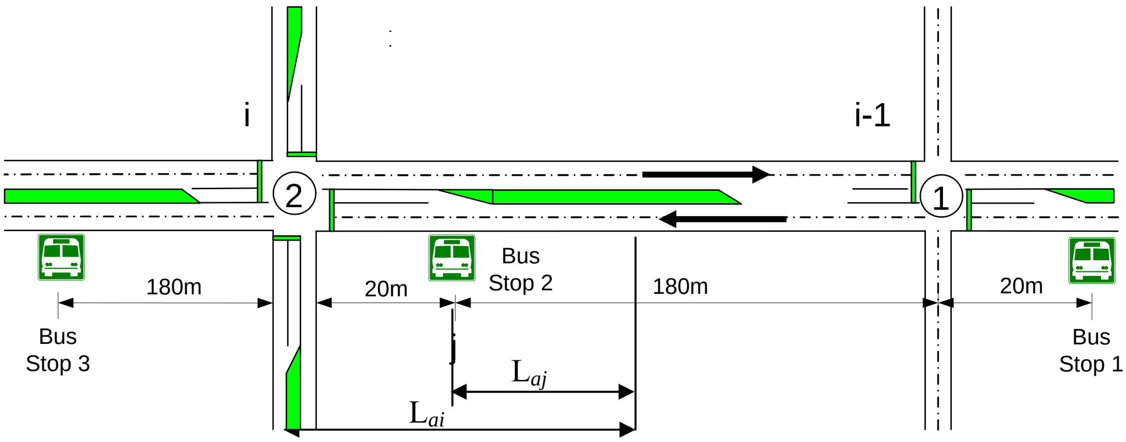

Figure 6 Schematic layout of the road section considered for study

The basic data used for modeling are road geometry data, main and cross street traffic volume of 879 veh/hr (SB) and 754 veh/hr (EB), 844 (NB), 576 veh/hr (WB); queue discharge headway = 2.4 sec; mean dwell time = 26 sec with bus headway = 240 sec. Some important assumptions made particularly for this study were minimum green time of 30 sec for through flow, and activation of only one signal priority per cycle.

3.4 Simulation Model

CORSIM (2006) simulation based evaluation method was adopted for evaluating the proposed signal priorities. CORSIM (2006) is a microscopic traffic simulation program that combines two separate programs one for modeling arterial streets, called NETSIM, and other one for modeling freeways, called FRESIM. Before proceeding with simulation, the CORSIM should be calibrated and validated for its measures of performances (MOEs) so that they can match those in the field. The parameter considered for alterations were mean discharge headway, mean startup delay, reaction time and mean free flow speed etc. The calibration process is the iterative process as altering a parameter could bring one factor to calibration target where as other factor move away from target value. The model was calibrated against traffic count, and measures of performances such as travel time and queue length collected in the field manually and by video-camera recording. The simulation output and field data were compared and the iterations were repeated until the calibration MOEs were within 15% of field value (CORSIM, 2006; Holm *et al.*, 2007). The CORSIM Run Time Extension (RTE) capability was used to model and simulate the signal priority logic considered. The simulation was carried out to find measures of effectiveness (MOE) with regard to various cases of BSP systems such as delay, average travel time, speeds of bus and other vehicles along priority and non-priority direction.

4. EVALUATION ANALYSIS

The bus signal priority have benefits and disbenefits associated with it. In the case of the major intersection, non-priority movements can be severely affected for providing signal priority. This study attempted to test different location of near side bus stop for BSP and their effects on priority and non-priority movements. The bus was detected right after door closing i.e. when about to departure from bus stop. Comparing different measures of performances resulting from different position of bus stop and BSP, it would be possible enough to draw out the extent of impact on priority and non-priority approach due bus signal priority in the micro scale.

The important measures of performances such as bus and other vehicle delay, travel time, queue and speed etc were summarized from the simulation for evaluating the priority measures. The average speed, delay and average travel time of vehicles on priority and non-priority road, and bus were obtained for each cases considered separately from CORSIM simulaion analysis.

4.1 Impacts of BSP with various position of near side bus stop

This section compares and explains the major performance measures for evaluating the bus signal priority. Four measures of performances travel delay per vehicle, control delay per vehicle, total stop time, and maximum vehicles in queue have been considered. Increase or decrease in priority benefits for three alternative cases mentioned in sub chapter 3.1 compared with base model without BSP were presented in Figure 7 and 8 for the vehicles on priority and non-priority direction. From Figures 7 and 8, it can be deduced that alternative case I with bus stop within distance of 30m shows highest reduction in all four kinds of MoEs for vehicles in priority direction. Where as it is to be noted that alternative case I has highest increases in disbenefit to vehicles in non priority direction. While comparison among three alternative cases, alternative case I, has reduction of travel delay/veh by 35%, control delay/veh by 37%, total stop time by 44% and maximum vehicle in queue by 14%. Though Alternative I seems to be better, it is to be

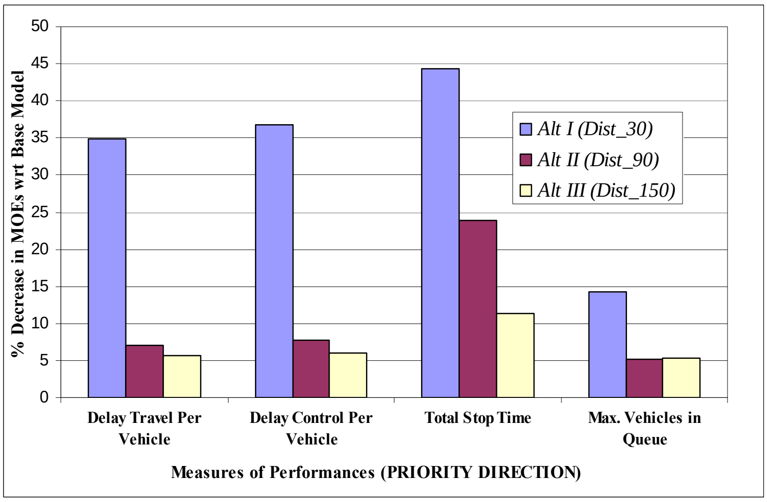

Figure 7 Percentage decrease in MOEs (priority)

noted that it has highest disbenefit for the vehicles on non-priroity direction. Alternative case I has more than 25% increase in travel delay/veh, 31% increase in control delay/veh, 35% increase in total stop time and 38% increase in maximum vehicle queue in non-priority direction. Alternative II has least disbenefit to the vehicles in non-priority direction. Compared to base model, Alternative II has reduced travel delay by 7%, control delay by 8%, total stop time by 24% and maximum queued vehicles by 5% in priority direction at the expense of increase in control delay of 5%, control delay of 7%, total stop by 17%, and maximum queue by 10% in non-priority direction.

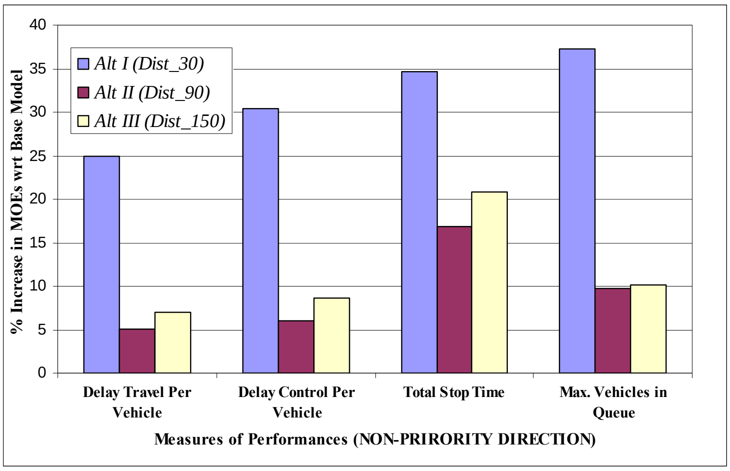

Figure 8 Percentage increase in MOEs (non-priority)

4.2 Effect on Bus Delay and Bus Speed

To evaluate the benefits of bus priority, bus performance measures, including bus delay time and bus speed were compared for all three alternative cases. Figures 9 and 10 illustrate that significant reductions in bus delays and increase in average speed of buses depend on chosen bus stop location and the traffic congestion. It can be deduced that compared to base case, Alternative II with traffic flow ratio of 0.7 has least intersection bus delay for given signal cycle and phases. Traffic flow ratio of 0.7 means less interruption to bus movement resulting more effective BSP. When distance of bus stop location is increased further from 90m i.e. Alternative III, delay of bus is higher than base case for both V/C ratio of 0.9 and 1.1. Higher traffic volume increases interruption in bus movement and increased distance of bus detection result more uncertainties of bus arrival.

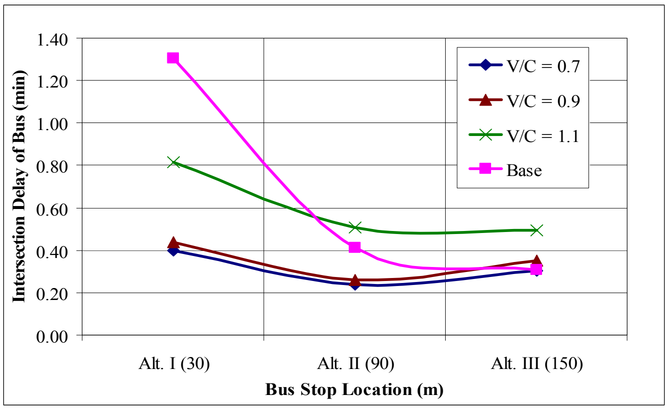

Figure 9 Effect on bus delay from alternative cases of BSP

The increase in traffic congestion, i.e flow capacity ratio of 1.1 resulted higher amount of delay. Alternative II with V/C ratio 0.7 has been able to reduce bus delays by 36% for bus stop location being at 90m, which was selected at the end of observed average maximum queue in the field. Thus, observing Figure 9, the optimum distance of bus stop with bus

Figure 10 Effects on bus speed

being detected after completing service at stop, could be beyond the normal queue for given signal phases.

While Comparing observed increase/decrease in average bus speed for three Alterative cases, increase in average speeds has been observed for all cases if traffic flow is under saturated condition as shown in Figure 10. For traffic flow capacity ratio of 1.1, slight increase in average speed has observed for Alternative case I, where as sharp decrease in average speed for other cases has been observed. The high traffic flow resulted reduction in speed up to 17% with respect to base model, along with standard deviation of up to 8KPh was perceived for alternative case III. Alternative case II seems to be good option as it can give benefit of increasing average speed of 17%. The standard deviation from mean speed is also least for Alternative case II.

4.3 Significance Test

Statistical test was conducted to verify the simulation results for difference in average vehicle delay among three Alternative cases. The *t*-test was used for the proof for the same case with difference mean values (Table 3). The result obtained from simulation showed that Alternative II has least delay. While performing significance test at 5% significance level, it was observed that the mean value of intersection delay obtained from simulation for alternative II is different than that obtained for Alternative I and III.

Table 3 Statistical test among alternative cases

<table>
<tr><th></th><th colspan="2">Alternative I (30)</th><th colspan="3">Alternative II (90)</th><th>Alternative III (150)</th></tr>
<tr><td>Mean</td><td colspan="2">0.439</td><td colspan="3">0.258</td><td>0.350</td></tr>
<tr><td>St. Dev.</td><td colspan="2">0.139</td><td colspan="3">0.106</td><td>0.140</td></tr>
<tr><td>Nos. of Buses</td><td colspan="2">82</td><td colspan="3">85</td><td>85</td></tr>
<tr><td>diff</td><td colspan="3">0.180</td><td colspan="3">-0.091</td></tr>
<tr><td>Null Hypothesis</td><td colspan="3">$\mu_{30}-\mu_{90} > 0$</td><td colspan="3">$\mu_{90}-\mu_{150} > 0$</td></tr>
<tr><td>t_{obs}</td><td>-9.375</td><td colspan="2" rowspan="3">Null hypothesis is rejected (i.e. mean are significantly different</td><td>4.753</td><td colspan="2" rowspan="3">Null hypothesis is rejected (i.e. mean are significantly different</td></tr>
<tr><td>DOF</td><td>165</td><td>168</td></tr>
<tr><td>t_{crit}</td><td>1.96</td><td>1.96</td></tr>
</table>

4.4 Finding Optimal Option

A number of performance measures can be obtained from simulation analysis to evaluate the performance of bus signal priority integrated with other bus operation methods. Travel time, travel delay, control delay, average speed, bus headway, service frequency and waiting time etc are few measures of performance that can be used for evaluation purposes. Also, these measures of performances influence various stakeholder in positive or negative ways. Bus signal priority benefits buses by reducing delay at signalized intersection at the expense of additional delay to non-priority vehicles. At the same time, when priority is given to buses at signal, the vehicles in priority direction are also benefited. Accordingly, two objective functions i.e. decrease in delay to vehicles in priority direction and increase in delay to vehicles in non-priority direction are to be considered simultaneously during evaluation process. The signal priority option should produce least negative impact to vehicles in non-priority direction and maximum positive impact to the vehicles in priority direction.

Section 3.1 has explained different alternatives cases of BSP with bus stop located at different distances from intersection stop line and for different traffic flow ratio have been explained. The purpose of this study is to find optimal option and recommend for deployment. Since there are more than single objective functions, there will not be clear optimal case. Trade off between two objectives functions is necessary to find the optimal option. This analysis process may lead to finding a set of Pareto-efficient cases since it is not possible to improve in any objective function without worsening other. Based on these non-dominated combinations, a multiple-criteria decision-making process should be used to evaluate and select the compromised solution.

While plotting two objective functions (Figure 11) i.e. decrease in delay to vehicles in priority direction and increase in delay to vehicles in non-priority direction, different non-dominated or Pareto optimal solutions can be observed. Optimal solution is a case with least normalized shortest distance (Table 4). Since the two measures of performance have different magnitude or units, they were first converted into normalized value and then normalized shorted distance for each set of solution was calculated. The optimal solution is the one with minimum normalized shortest distance which belong to Case a. Second shortest distance belongs to case d. However, it was observed from section 4.2 that Case d has least bus delay. Since the two objective function considered above does not include the weightage for the numbers of passenger transported by bus and general vehicles, Case d may be possible optimal solution, which has least bus delay.

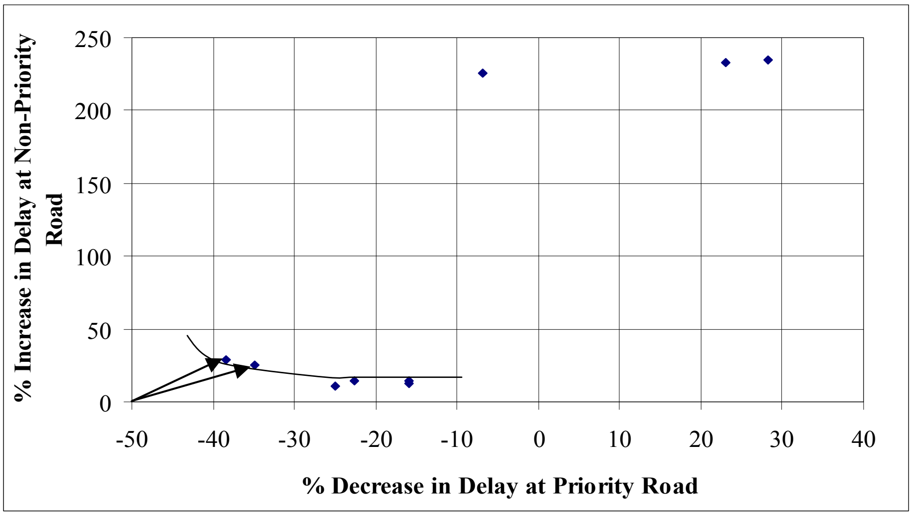

Figure 11 Determination of optimal case

Table 4 Normalized shortest distance hod for searching optimal solution (vehicle delay)

Cases		% Decrease in Vehicle Delay on Priority (sec)			% Increase in Vehicle Delay on Non-Priority		Normalized distance $\sqrt{(X^2+Y^2)}$
		X	(50+X)	Normalized Value	Y	Normalized Value	
a	Alt I, V/C = 0.7	-38.389	11.611	0.148	28.650	0.122	0.192
b	Alt I, V/C = 0.9	-15.905	34.095	0.436	14.440	0.061	0.440
c	Alt I, V/C = 1.1	-15.951	34.049	0.435	12.753	0.054	0.439
d	Alt II, V/C = 0.7	-34.937	15.063	0.193	24.953	0.106	0.220
e	Alt II, V/C = 0.9	-25.019	24.981	0.319	11.099	0.047	0.323
f	Alt II, V/C = 1.1	-22.662	27.338	0.349	14.677	0.062	0.355
g	Alt III, V/C = 0.7	-6.784	43.216	0.552	225.263	0.958	1.106
h	Alt III, V/C = 0.9	23.069	73.069	0.934	232.957	0.991	1.362
i	Alt III, V/C = 1.1	28.243	78.243	1.000	235.106	1.000	1.414

Hence, the similar procedure was repeated again for further confirmation of the optimal option considering both bus passenger and vehicle users delay. The decrease in person delay is the weighted sum of reduction in delay to the vehicles and buses users on priority road. Similarly, Increase in delay is calculated as the sum of increase in delay to the vehicles and buses on non-priority direction. The weight for bus was calculated as the proportion of total occupancy of the bus to the assumed occupancy of the general vehicles. Average occupancy observed for bus and general vehicles are 35 and 1.5 respectively. Decrease in person delay on priority and increase in person delay on non-priority direction were plotted (Figure 12). The case d i.e. BSP with bus stop at 90m for V/C ratio of 0.7 has least normalized distance. It means this case has minimum increase in person delay on non-priority direction and maximum decrease in person delay on priority direction. Also, the bus stop position beyond the normal queue (here beyond 90m) is best solution among the cases with V/C ratio of 0.9 (i.e. existing traffic situation) too.

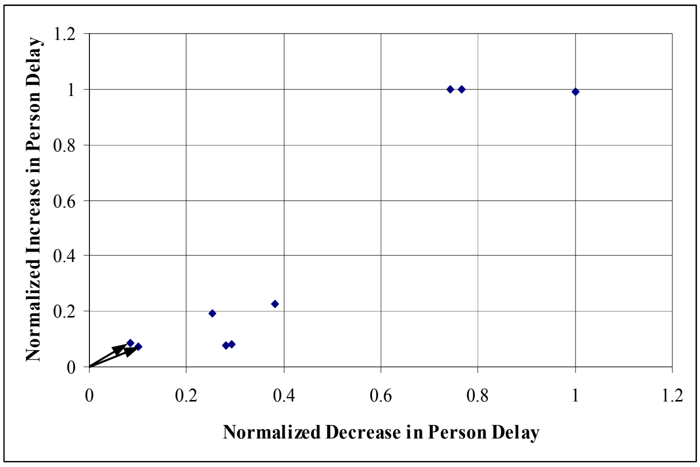

Figure 12 Determination of optimal case (considering total person delay)

Table 5 Normalized shortest distance method for searching optimal solution (person delay)

Cases		Decrease in Person Delay on Priority (sec)			Increase in Person Delay on Non-Priority		Normalized distance $\sqrt{(X^2+Y^2)}$
		X	(30000+X)	Normalized Value	Y	Normalized Value	
a	Alt I, V/C = 0.7	-13529.20	16470.77	0.253	4188.75	0.194	0.319
b	Alt I, V/C = 0.9	-5070.45	24929.55	0.383	4876.47	0.226	0.445
c	Alt I, V/C = 1.1	35116.85	65116.85	1.000	21332.15	0.989	1.406
d	Alt II, V/C = 0.7	-24491.20	5508.83	0.085	1802.73	0.084	0.119
e	Alt II, V/C = 0.9	-11629.00	18370.95	0.282	1687.18	0.078	0.293
f	Alt II, V/C = 1.1	18303.94	48303.94	0.742	21576.57	1.000	1.245
g	Alt III, V/C = 0.7	-23435.80	5748.41	0.101	1537.49	0.071	0.123
h	Alt III, V/C = 0.9	-10952.00	19047.96	0.293	1713.13	0.079	0.303
i	Alt III, V/C = 1.1	19952.31	49952.31	0.767	21562.70	0.999	1.259

4.5 Effect on Control Delay, Stop Time and Maximum Queue

The final result of control delay, stop time and maximum queue for all three alternative cases from simulation were aggregated for vehicles on priority and vehicles on non-priority direction. To find the effect of traffic congestion, those performance indicators were aggregated for traffic flow ratios of 0.7, 0.9 and 1.1. The Figure 13 (a) and (b) to Figure 15 (a) and (b) shows percent increase/decrease in control delay, stop time and maximum queue at intersection approaches due to bus signal priority. In general bus signal priority resulted reduced control delay, stop time and maximum queue at intersection for V/C ratio of 0.7 & 0.9 to buses and other vehicles on priority direction while increased delay to vehicles on non-priority direction. For V/C = 1.1, there has been greatest increase in control delay per vehicle, total stop time and maximum queue. Thus signal priority has determintal effects rather than beneficial at oversaturated condtion. Care is to be taken to apply BSP in case of saturated traffic condition. From Figure 13 (a) and (b) to 15 (a) and (b), bus stop beyond the normal queue and bus being detected after departure from bus stop for BSP is still appear to be beneficial as it has less negative effect to vehicles on the non-priority direction while providing increased benefit to the vehicles on priority.

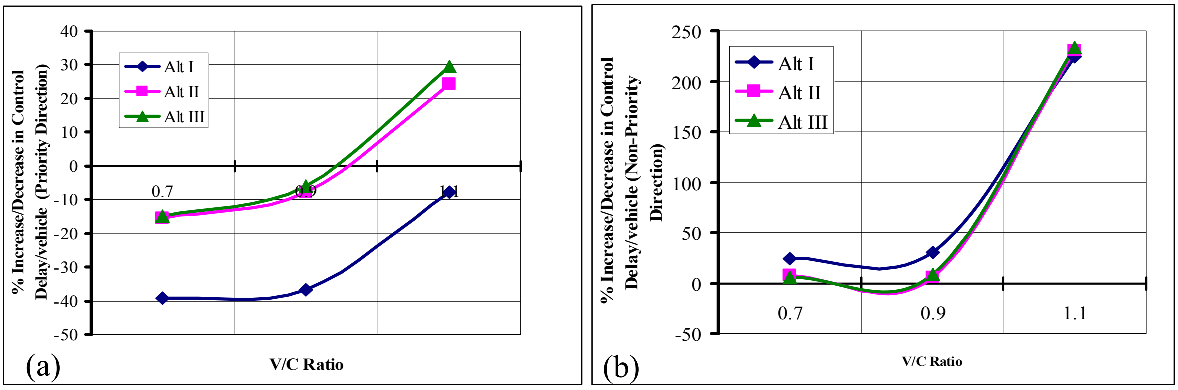

Figure 13 (a) & (b) Effect on control delay per vehicle

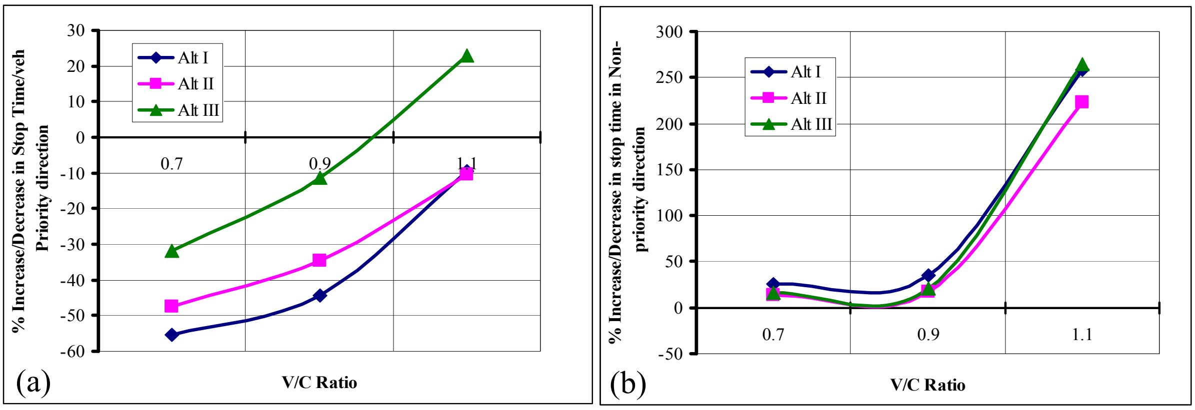

Figure 14 (a) & (b) Effect on total stop time per vehicle

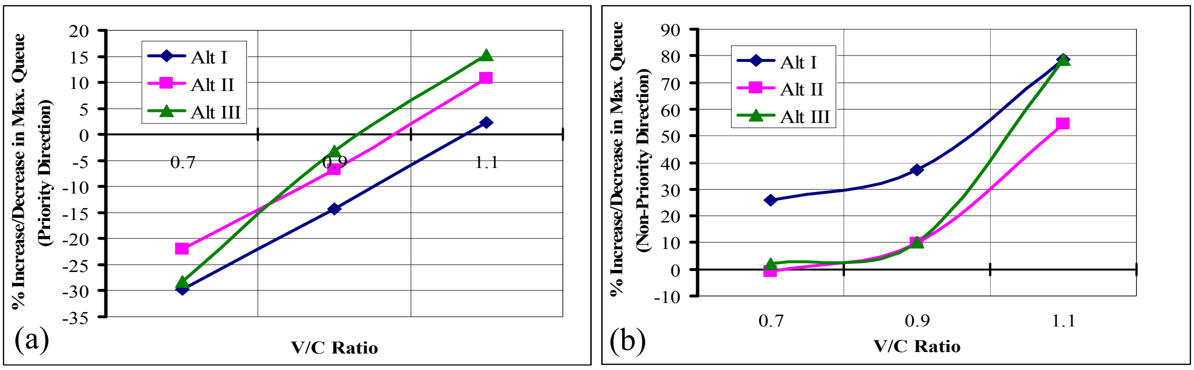

Figure 15 (a) & (b) Effect on maximum vehicles in queue

5. CONCLUSION

Near side bus stop has potential of utilizing red time of signal for serving passenger, provide easy access to the passenger near to the cross walk etc. Hence, this paper has considered the various positions of bus stop for finding optimal near side bus stop position using simulation method. Three alternative positions of near side bus stop were selected and evaluation was carried out considering three traffic flow ratios 0.7, 0.9 and 1.1 accordingly. The impact of BSP for different position of bus stop and traffic flow ratio were measured in terms of measures of performances such as bus delay, bus speed, travel delay, queue, average speed etc. It can be deduced that compared to Base case, alternative II with traffic flow ratio of 0.7 has least intersection delay of bus. Bus delay tends to increase either of distance of bus stop location from intersection stop line or traffic flow capacity ratio is increased. BSP has increased average speeds for all cases if traffic flow is under saturated condition with alternative case II has maximum increase. Similar to bus delay, average bus speed also tends to decrease for increase in bus stop location as well as saturated traffic flow condition.

The calculated performance measures were compared among vehicles on priority and non-priority directions for the purpose of recommending an optimal stop position. Since there is more than one measure of performances, Pareto-optimal situation arises. The optimal solution was obtained by searching shortest normalized distance to the set of Pareto-optimal sets. It was observed that alternative II the bus stop position beyond the average queue length with traffic flow ratio of 0.7 shows better performance reducing total person delay in priority directions and with minimum increase in total person delay in non-priority direction. The increase traffic flow ratio tends to give more dominant type of solution with detrimental affect to non-priority vehicles. Also, while assessing near side stop for other measures of performances such as control delay, total stop time and maximum vehicle queue, the model appear to be promising in terms of impoved performance measures to vehicles in priority direction for low traffic situation. Where as adverse impact to vehicles on non-priority direction due to BSP has been reduced for alternative II which is the case of BSP with bus stop right after normal queue and bus is being detected immediately after departrue from stop.

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