A Performance Evaluation of Bus Stop Placements near a Signalized Intersection by a Microscopic Traffic Simulation

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Abstract: In this paper, data from an on-site survey in Seoul, Korea and the microscopic traffic simulation are used to evaluate the performances of Bus Rapid Transit bus stops operated on different placements to their nearest traffic signals: far-side, and near-side. The influence of Bus Priority Signal Systems is also analyzed. The results reveal that a near-side bus stop performs better under the current ordinary signal control situation. However, the performance of a far-side bus stop can be improved more significantly by the adoption of a Bus Priority Signal System and becomes even better (-13.3% average value and -22.2% range of bus travel times) than a near-side bus stop especially under a more congested traffic demand. The results are applicable not only for the practical choice of the placements of new bus stops, but also for improving the existing ones.

Keywords: bus stop placement, bus priority signal, bus lane, BRT, traffic simulation

1. INTRODUCTION

In recent years, BRT (Bus Rapid Transit) system is receiving more and more attentions from urban transportation administrations around the world. It is considered as a possible solution or at least a mitigating measure to the worsening urban traffic congestion problem.

Travel speed is a very important performance index of a bus system. Another serious problem with the existing bus system, even a BRT system, is the punctuality (M. Salicru, et al., 2011). In most cases, buses are running on urban streets mixed with other vehicles such like the personal cars and the trucks. Even a dedicated and exclusive bus lane being provided, buses are still under the influence of the traffic signal controls that are often decided by the total traffic situation that involves the buses and the other private vehicles as well. A good summary of the BRT best practices in the U.S. and the world can be found on Transit Cooperative Research Program (TCRP) Report 90, Vol.1 (TCRP, 2003) and a more recent summary is provided by Weinstock, A., et al. (2011).

Many existing researches (Li, M., 2008, Shrestha, P. K., 2009) have proposed different kinds of measures for improving the bus travel speed and the punctuality. Bus Priority Signal Systems (BPSS) have been adopted around the world and many of the existing deployments are showing the effects of reducing the bus intersection delays and improving the bus service schedule adherence. Especially, as the cost of information and communication technologies is decreasing, there is a noted potential of extending BSPS application in the developing countries as well.

A BPSS cannot work smoothly without correctly predicting the bus arrival time at the traffic signal, which is influenced by many factors other than the simple distance between the bus stop and the traffic signal. Many of the existing BPSS practices use vehicle detection technologies that sense the presence of an approaching bus only at a fixed location. It is found to be usually very difficult to obtain the exact bus arrival time to the intersection in such practices (Li, M, et al., 2008). Even Global Positioning Systems (GPS) are installed, it is still difficult to predict the variance of bus dwell time, which influences the bus arrival times significantly especially for the near-side bus stops to the nearest traffic signals (Shrestha, P. K., 2009). Only recently, some new ITS technologies are found useful to predict the bus arrival times at the traffic signal by using the door closure information of buses to improve limitedly the efficiency of the BPSS at near-side type of bus stops (Wang, et al. 2010).

Therefore the placement of a bus stop to its nearest traffic signal is very important to its performance. The TCRP Report 19 (TCRP, 1996) has provided a however qualitative comparison of the different bus stop placements, far-side, near-side, and mid-block, from the viewpoints of passenger convenience and the traffic operations.

This paper aims to evaluating the performance of different kinds of bus stop placements to the nearest signalized intersection explicitly, by applying the performance measures of bus travel speed and punctuality. The paper concentrates on far-side and near-side bus stops, because mid-block bus stops are further from the intersections and out of our interest on traffic signals.

The paper starts with an introduction of the different placements of a bus stop to its nearest signalized intersection. Their advantages and disadvantages are then described before the priority signal algorithm of the BPSS and the concept of bus arrival time at signals are provided with a description of the target section and the process of the microscopic traffic simulation. Finally we conclude the evaluation of the different bus stop placements on the basis of both of the simulation and the observation results.

2. THE DIFFERENT PLACEMENT OF BUS STOPS

The choice of bus stop placement is very important when designing a bus system. Especially for a BRT system that is supposed to provide a faster and more on-time transit service, more careful considerations are necessary when deciding the placements of the bus stops.

2.1 Definitions of Different Placements of Bus Stops

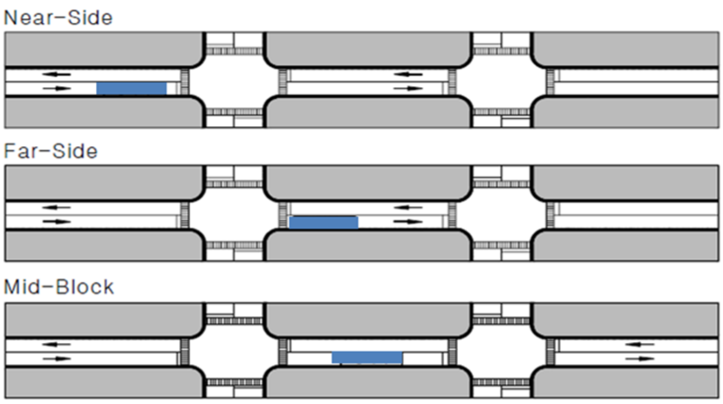


Figure 1. Different Placements of Bus Stops

As shown in the Figure 1, the placements of a bus stop include the following three types: far-side, near-side, and mid-block, as summarized below (TCRP, 1996).

1) Far-Side Bus Stop – bus stops immediately after passing through an intersection;
2) Near-Sid Bus Stop – bus stops immediately prior to an intersection; and
3) Midblock Bus Stop – bus stops within the block

2.2 Advantages and Disadvantages of the Different Placements of Bus Stops

Each of these 3 types of bus stop placements has its own advantages and disadvantages. In the practical field many factors are considered when choosing the placement of a bus stop, such as the bus routes, bus signal priority provision or not, the impact on intersection operations, the adjacent land use and activities, and so on.

Below is a brief summary of the major advantages and disadvantages of the 3 types of placements from a viewpoint of both bus operation and road traffic (TCRP, 1996).

1) Far-Side Bus Stop
   - *Advantages*: minimizes conflicts between right turning vehicles and buses, provides additional right turn capacity, create shorter deceleration distances for buses since buses can use the intersection, buses can use the gaps in traffic flow created by the signal;
   - *Disadvantages*: may result in the intersection being blocked during peak periods by stopping buses
2) Near-Sid Bus Stop – bus stops immediately prior to an intersection; and
   - *Advantages*: minimizes interferences when traffic is heavy on the far side of the intersection, allows passengers to access buses closest to crosswalk, allows passengers to board and alight while the bus is stopped at a red light;
   - *Disadvantages*: increase conflicts with right-turning vehicles, may block the through lanes during peak period with queuing buses;
3) Mid-block Bus Stop – bus stops within the block
   - *Advantages*: may result in passenger waiting areas experience less pedestrian congestion,
   - *Disadvantages*: encourage patrons to cross street at midblock, increases walking distance for patrons crossing at intersection.

When exclusive median bus lanes are used (as in Seoul), near-side bus stops are found to be more convenient for the passengers because they allow passengers to board and alight while the bus is stopped at a red light. By doing so, the general travel speeds of buses can be improved, if compared with the far-side or mid-block bus stops. It is why in Seoul (Seoul City, 2011), when a bus stop has to be built near a signalized intersection, usually the near-side placement is preferred. However this preference of near-side bus stop limits the freedom of choice in many cases when land-use limit exists.

In this paper, a microscopic traffic simulation is carried on with and without BPSS to evaluate and to compare explicitly the two different types of bus stop placements, near-side or far-side, from a viewpoint of bus performance measures of bus travel speeds and the punctualities. A major objective is to find whether the application of BPSS can improve the performance of far-side bus stops.

3. ALGORITHM OF THE BUS PRIORITY SIGNAL SYSTEMS (BPSS)

Here a simple algorithm of BPSS is applied to evaluate its influence on the performance of different bus stop placements. The fundamental methodology is a simplified version of the BPSS proposed in a previous research of the authors (Wang, et al. 2010), which involves giving extended green time or reduced red time to an approaching bus by predicting its arrival time at the intersection just as in this paper. The difference is that in the previous paper, the door closure information of buses was used, as it is not true in this paper. The flowchart of the BPSS methodology is shown in the Figure 2.

3.1 Minimum Green Interval

Here the minimum green interval (G_{min}) is calculated by using the method suggested in the HCM2010 (TRB, 2010).

$$G_{\min} = 3.2 + \frac{L}{v_p} + \left(0.81 \frac{n_p}{w_e}\right) \tag{1}$$

where,

L : width of the intersection (m),
v_p : average walking speed (m/s),
w_e : width of the crosswalk (m), and
n_p : number of pedestrians.

3.2 Green Extension

When the left green interval is less than the bus arriving time, Green Extension is implemented if the extended green time will be less than the maximum green interval (G_{max}) that can be calculated according to Equation (2).

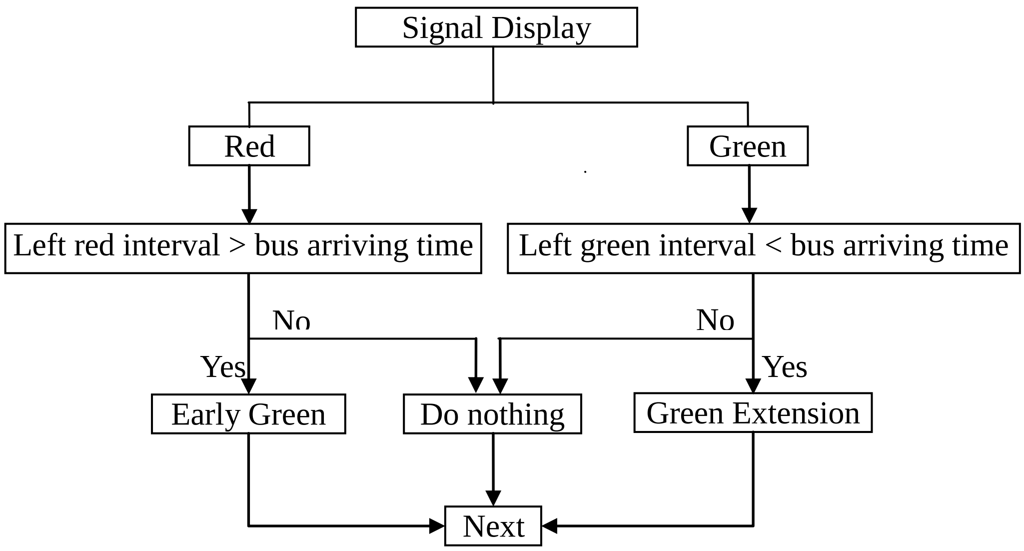


Figure 2. Algorithm of the BPSS

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

where,

G_{max}	: maximum green interval (sec),
C	: cycle length (sec),
G_i	: the i^{th} green interval (sec),
Y	: yellow interval (sec), and
A	: all red interval (sec).

The calculation results of the Green Extension for the simulation are shown in Figure 3.

3.3 Early Green

When left red interval is larger than the assumed bus arrival, early green (G_{early}) will be implemented only if the minimum green interval of the cross road can be guaranteed.

$$G_{early} = C - \left[(G_1 + I_1) + \left\{ \max(G_{\min,2}, t_2) + I_2 \right\} + (G_3 + I_3) \right] \quad (3)$$

where,

G_{early}	: early green interval (sec),
C	: cycle length (sec),
G_i	: the i^{th} green interval (sec), and
I_i	: the i^{th} inter-green interval (sec),

The calculation results of the Early Green for the simulation are shown in Figure 4.

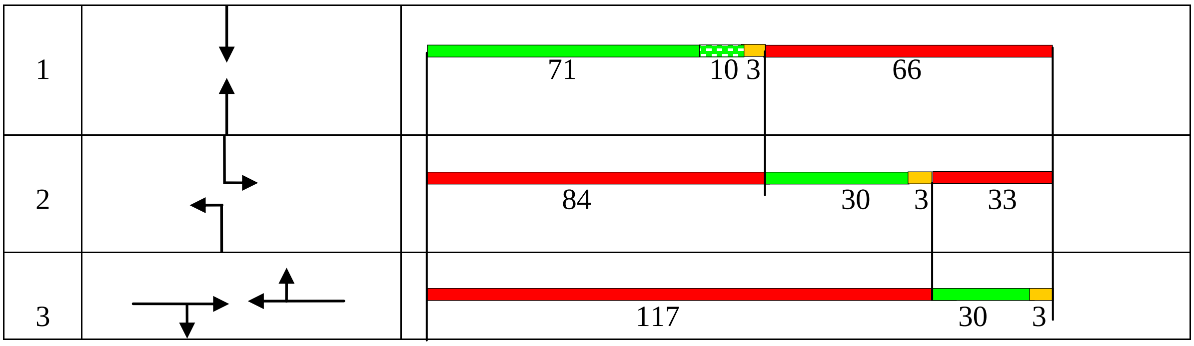


Figure 3. Calculation Results of Green Extension (sec)

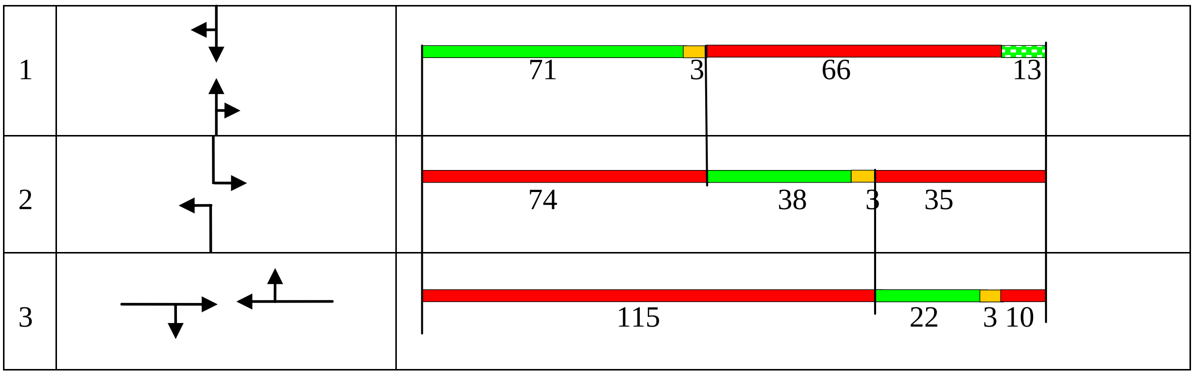


Figure 4. Calculation Results of Early Green (Sec)

4. MICROSCOPIC TRAFFIC SIMULATION FOR EVALUATING THE BUS STOP PLACEMENTS

A microscopic traffic is implemented in this research to evaluate and compare the performances of the different bus stop placements, with and without BPSS and at different levels of traffic demands. The performance measures are travel speeds of buses, the average values and the distributions, i.e. the punctualities of buses. A real intersection in Seoul, Korea is used in the simulation.

4.1 Target Intersection

The target intersection, Guemcheon intersection, is on a major street connecting the suburb, sub centers, and the downtown CBD (Central Business District) of the great Seoul area. The street is generally about 40m wide with 8 lanes while the median 2 lanes have been used as bus exclusive lanes, along most of the total 17km long street since 2005.

BPSS are not provided on most of the BRT routes in Seoul (Seoul City, 2011). However in the simulation, the influence of BPSS is also evaluated to show the different sensitiveness of the bus placements: far-side or near-side.

This street has a large volume of bus traffic demand, varies from 66 to 448 buses/hour during the different time periods of a typical workday. Both near-side and mid-block types of bus stops can be found on the route, but no far-side bus stops are available currently. However, during the traffic simulation, the effects of hypothetical far-side bus stops are also evaluated and compared.

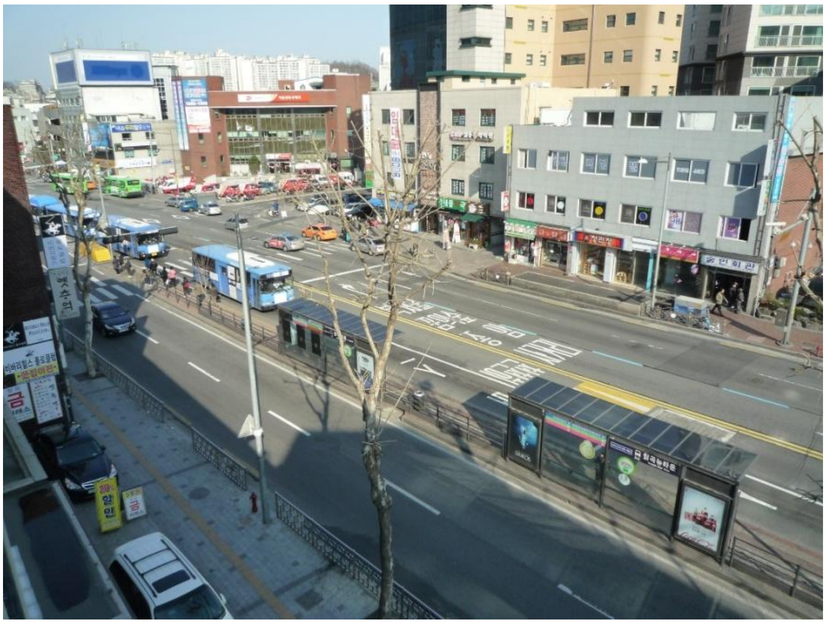


Figure 5. Bus Stop near the Target Guemcheon Intersection

4.2 On-Site Survey

On 08:00~09:00am, March 29, 2012, an on-site video survey is carried on to collect the necessary traffic, signal parameters, and road geometric data that are necessary for the simulation research. Table 1 is a summary of the collected traffic data of the intersection, for all vehicles and buses, in addition to the travel times of all vehicles and dwell times of buses.

Table 1. Traffic Demand Data on the Guemcheon Intersection

Items			All Vehicles	Buses
Sec. 1	Major Route Volume (vhe/h)	South to North	1,930	110
		North to South	2,183	114
	Cross Route Volume (vhe/h)	East to West	301	N/A
		West to East	281	N/A
Sec. 2	South to North		1,945	110
	North to South		2,201	114

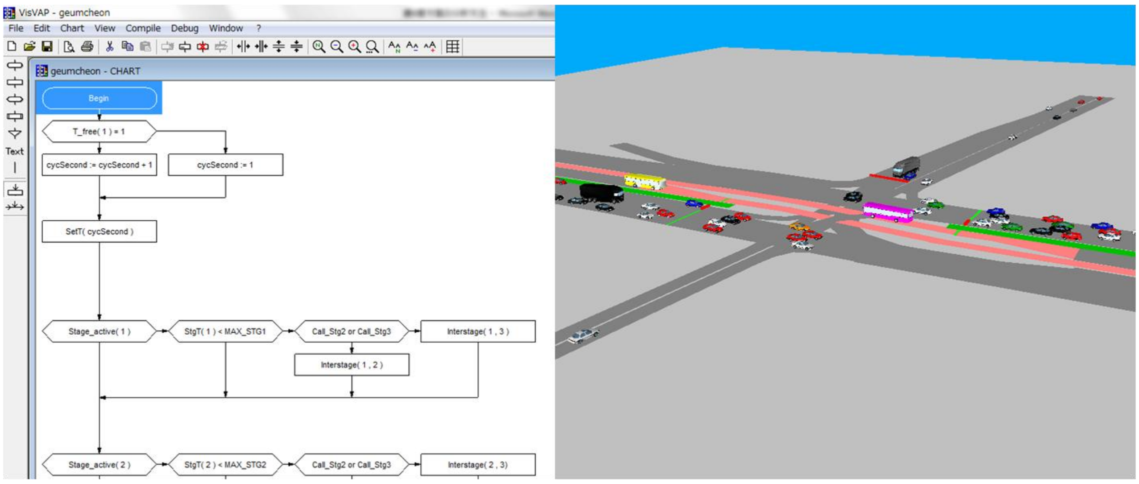
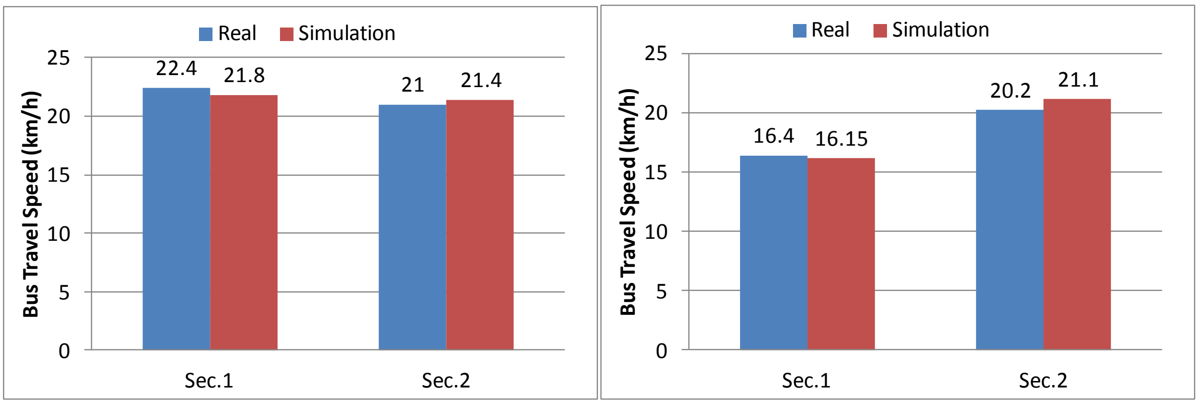


Figure 6. Simulation of the Guemcheon Intersection



a) Average Bus Speeds b) Average Ordinary Vehicle Speeds

Figure 7. Comparison between Real and Simulated Travel Speeds

4.3 Microscopic Traffic Simulation

On the basis of the on-site survey, micro traffic simulation of 1-hour morning peak (8:00am – 9:00am) is carried on under a well recognized traffic simulation platform (PTV, 2012), as shown in Figure 6.

4.3.1 Representation of the Current Situation

The representation of the current situation is carried on to calibrate and validate the simulation. A comparison of the observed and simulated travel speeds of both buses and ordinary vehicles is shown in Figure 7. The Pearson correlation coefficients of the 4 pairs of simulated and real bus travel speeds are all greater than 0.90. It suggests that there is no significant difference between the real and simulated travel speeds either for buses or for the ordinary vehicles.

4.3.2 Scenarios of the Traffic Simulation

Two different scenarios of signal control strategies with/without BPSS are simulated for the 2 different types of bus stop placements, each under 2 different levels of traffic demand patterns. The details of the scenario setting are shown in Table 2 where there are totally 8 cases, *a* through *h*. Because the real current traffic demand on the field survey day is far less than the supposed capacity, the cases of +30% demands are also included in the traffic simulation.

Table 2. Scenarios of the Traffic Simulation

Scenarios	Bus Stop Placements	Traffic Demands	Case No.
1) Ordinary Signal (without BPSS)	Near-side Stop	Current	Case *a*
		+30%	Case *b*
	Far-side Stop	Current	Case *c*
		+30%	Case *d*
2) Signal with BPSS	Near-side Stop	Current	Case *e*
		+30%	Case *f*
	Far-side Stop	Current	Case *g*
		+30%	Case *h*

4.3.3 Results of the Traffic Simulation

The results of the traffic simulation include both the average values and the ranges of travel times for the total 8 cases (*a* through *h*) are shown in Figure 8. The comparisons between two different types of bus stop placements (near-side vs far-side), between current or +30% traffic demands, and between with or without the proposed BPSS, are shown in Table 3 through 5. Chi-square tests are carried on to show the difference are significant or not (at 0.1 level).

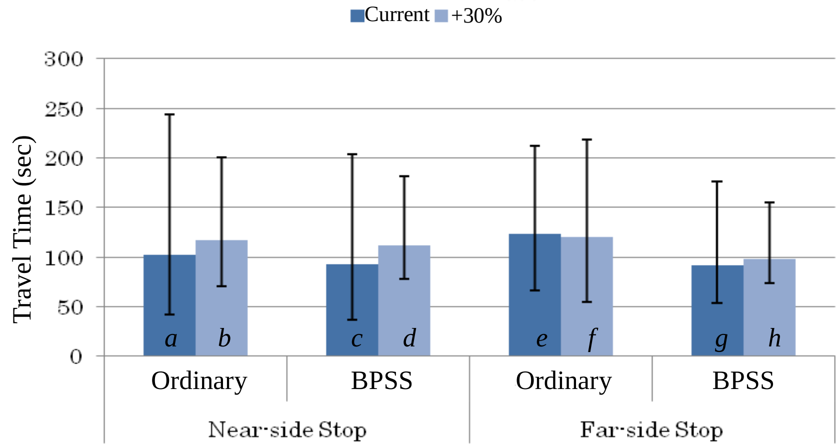


Figure 8. Summary of Average Values and Ranges of Travel Times of 8 Cases

Table 3. Changes of Average Values and Ranges by different Traffic Demands
(Current Traffic vs +30% Traffic)

	Near-Side				Far-Side			
		Average Values	Ranges	Cases		Average Values	Ranges	Cases
Ordinary Signal	O	+12.7%	-36.3%	(*a* vs *b*)	×	-4.0%	+11.4%	(*e* vs *f*)
BPSS	O	+27.0%	-36.8%	(*c* vs *d*)	×	+10.1%	-32.8%	(*g* vs *h*)

Table 4. Changes of Average Values and Ranges by Different Signal Controls
(Ordinary vs BPSS)

	Near-Side				Far-Side			
		Average Values	Ranges	Cases		Average Values	Ranges	Cases
Current Traffic	×	-12.7%	-16.2%	(*a* vs *c*)	O	-28.8%	-16.1%	(*e* vs *g*)
+30% Traffic	×	-1.7%	-16.9%	(*b* vs *d*)	O	-18.3%	-49.4%	(*f* vs *h*)

Table 5. Changes of Average Values and Ranges by Different Bus Stop Placements
(Near-side vs Far-Side)

	Ordinary Signal				BPSS			
		Average Values	Ranges	Cases		Average Values	Ranges	Cases
Current Traffic	O	+22.5%	-27.0%	(*a* vs *e*)	×	0.0%	-26.9%	(*c* vs *g*)
+30% Traffic	×	+4.3%	+27.7%	(*b* vs *f*)	O	-13.3%	-22.2%	(*d* vs *h*)

Chi-square test: O significant, × insignificant at 0.1 level
An example of Calculating the Changes: (*a* vs *c*) = *(c–a)/a×100%*

4.3.4 Evaluations of the Comparison

The simulation results are evaluated mainly from three viewpoints: 1) influence of increased traffic demand, 2) influence of BPSS, and 3) influence by the different bus stop placements.

1) Influence by Increased Traffic Demand (Table 3.)
   Since the current real traffic demand is too low, the +30% traffic demand of ordinary vehicles is also used in the traffic simulation. The average values of bus travel times significantly increased (+12.7% and +27.0%) for the near-side bus stops, while the ranges of travel times decreased (-36.3% and -36.8%). On the contrast, the far-side bus stops are not influenced significantly by the increased traffic demand. It suggests that the far-side bus stops are less fragile to traffic congestions.

2) Influence by BPSS (Table 4.)
For all cases, BPSS can reduce both average values and the ranges of bus travel times, although significant influence of BPSS can only be found from the far-side bus stop. As mentioned in the earlier section, passengers are supposed to use the red light time to board or alight from the buses on near-side bus stops. It is why near-side bus stops cannot benefit too much from the application of BPSS, especially without a correct prediction of the bus arrival time at the intersection.
An important result is that the range of bus travel times (corresponding to the punctuality) are improved more by the adoption of BPSS, especially for the far-side bus stops under the +30% traffic demand (-49.4%). It justified many of the practical cases, where punctuality rather than the average travel speed is the real goal a BPSS (TCRP, 2003).

3) Influence by the different bus stop placements (Far-Side Bus Stop) (Table 5.)
At current traffic situation without a BPSS, the near-side placement is significantly better than the far-side placement. But after applying BPSS, the difference between the two types of bus stop placements becomes insignificant. Especially, with BPSS and under the +30% traffic demand situation, the far-side bus stop placement becomes significantly better than the near-side placement for both the average value (-13.3%) and the range (-22.2%) of bus travel times.

5. CONCLUSIONS

Bus, especially a BRT system, is currently arousing vast interest in both the developed and the developing worlds. In Seoul, Korea, the bus system had undergone a tremendous reform in the year of 2004 in order to improve the levels of services of the existing bus routes. An important measure is the provision of median bus exclusive lanes on the major radial transportation corridors that connecting the major sub centers with the downtown CBD of the city.

According to the survey carried on by the Metropolitan Government of Seoul City (2011), bus travel speeds on the radial corridors have been improved by 2.0% to 9.0%, to reach the current 19.98km/h averagely in the city. The reform has tremendously improved the efficiency and other LOS measures of the Seoul bus system. However, most bus stops in Seoul are either the near-side type (26% of Total) or the mid-block type (73% of Total), the far-side type of bus stops consist a mere 1% of the total bus stop population.

In this paper, an explicit evaluation of the 2 different types of bus stop placements, near-side and far-side, is carried on under the current and the proposed BPSS scenarios at the different levels of traffic demands. We have found that the performance of the far-side type of bus stops can be more significantly improved to a similar or even better level of the near-side type of bus stops, by applying the proposed BPSS. In other words, the usage of BPSS is eligible to increase the freedom of bus stop placement choice to better meet the requirements of passengers and the local land use patterns. The practical applicability of this study is obvious.

ACKNOWLEDGEMENT

This work was supported by JSPS KAKENHI Grant (Number 23360220, “Developing a

Simulation System for the Design and Evaluation of Intelligent Bus Rapid Transit Systems", Research Representative: Fumihiko Nakamura). It is also highly appreciated that Mr. Baek Sung Hyun, the Metropolitan Government of Seoul, Korea, kindly provided the precious support through the local survey.

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