A SYSTEMATIC APPROACH TO BUS SIGNAL TIMING IN BUS PASSIVE PRIORITY

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ABSTRACT

This paper designed a practical method of bus signal timing with PASSER and Transyt-7F in order to enhance bus travel speed. We had focused on bus progression control out of bus passive priority to minimize bus travel time, because car travel time was very different with bus travel time for bus dwell time. Purposes of this method are maximizing a bus bandwidth and minimizing a change of car delay time, so that we divided this practical method into three steps. First was a step of estimating bus travel time after considering bus dwell time and bus running time included acceleration/deceleration time. Second was maximizing a bus bandwidth with PASSER in order to increase probability of bus non-stop at intersections. Third was minimizing a car delay time without a change of bus bandwidth by using slack green on Transyt-7F. To evaluate of this combined use, we simulated the bus exclusive lane on median at Goyang-si on VISSIM. This systematic approach had a good effect as the result that bus travel time reduced and car delay time slightly increased.

Keywords: bus signal timing, passive priority, combined use, bandwidth, slack green

INTRODUCTION

Roles of transport are very various, such as improving mobility, increasing accessibility, reducing cost of travel, reducing environmental impact and so on. Own car generally has an advantage about mobility and accessibility, however, own car loses their mobility and lead to increase travel cost and quantity of emission when the traffic are heavy on the road. When considering almost roles of transport, bus has been important as sustainable transport mode; bus is helpful in the reduction of environmental impact and the increase of road capacity. Many people still use their own car in spite of bus merit because they will to pay for good quality services. It is necessary bus policy to enhance quality of service in order to convert car demand into bus demand.

As recent Korean bus policy, Seoul and Gyeonggi-do have several place constructed bus exclusive lane on median and bus rapid transit system. This policy is helpful of stable bus flow through separating bus lane from car lane and preventing an obstruction to a bus flow.

According to data from Seoul, some of bus exclusive lane on median were constructed and others are under construction at 202.8 kilometers on 23 roads in order to enhancing safety, convenience and speed. Gyeonnggi-do lets already operate BRT system at some regions and is constructing at Incheon and Hanam. This bus policy of lane separation had an effect, however, bus travel speed was not very high. We knew that bus travel speed was between 15.2 kph and 24.6 kph at parts of bus exclusive lane on median after analyzing BIS data on 2008. From table 1, bus travel speed is determined from dwell time, number of bus and etc. Running speed except for dwell time was 31.4 kph at Cheonho avenue, this led to need bus signal timing reflecting dwell time. It is necessary to consider bus travel speed included dwell time, because of increasing possibility of bus non-stop. At present, Seoul and Gyeoggi-do are still using signal timing that only calculated by car data. We can often see that bus stops at signalized intersection after boarding passengers.
This paper presented practical bus signal timing from a part of bus passive priority, this was practical method to apply at signalized intersection with bus exclusive lane on median. The concept was a control of managing bus progression, furthermore this considered the impact to car delay time. We proposed the combined use with two model of signal optimization as systematic approach to bus signal timing and evaluated an effect on bus travel speed and car delay time.

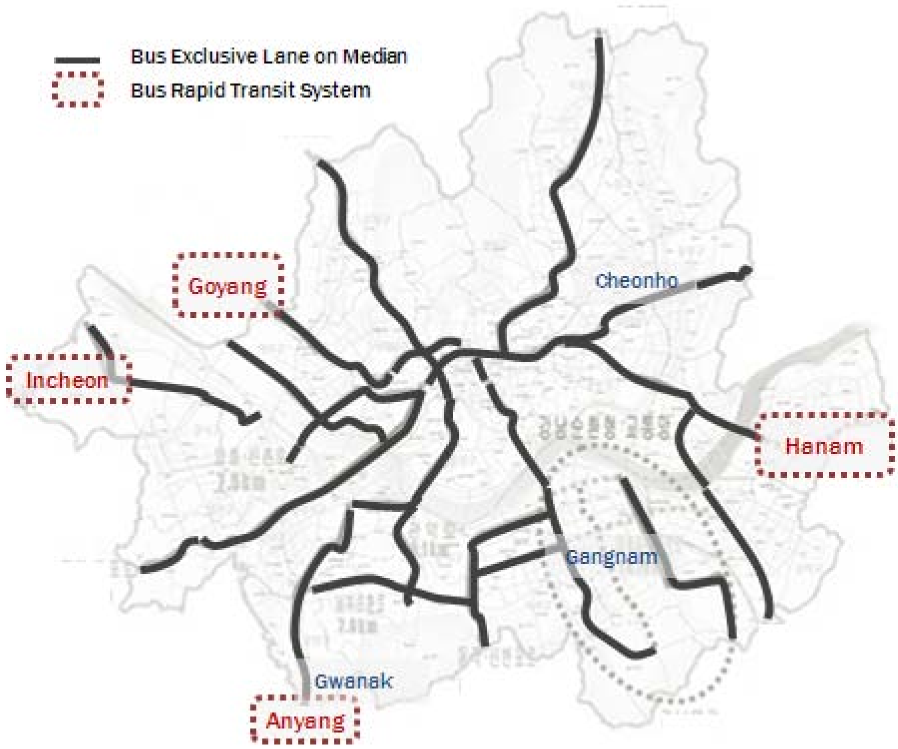


Figure 1 – Bus Exclusive Lane on Median at Seoul and Gyeonggi-do

Table I – Bus Travel Speed from BIS data

City	Avenue	Travel Speed [kph]	Dwell Time [sec]	No. of Bus [veh/cycle]	Bus Lines	Distance [meter]
Seoul	Cheonho	24.6	25	4	9	550
Seoul	Gangnam	15.2	43	9	22	500
Anyang	Gwanak	16.6	22	5	15	350

CONCEPTS OF BUS PROGRESSION CONTROL

Generally, signal timing is a result of minimizing delay time or maximizing bandwidth with car data. This paper had focused on the signal optimization model of maximizing bandwidth in order to compare the bus travel time. We assumed test bed that based on real site of BRT system at Goyang, there were 9 signalized intersections included three bus stops on median and was bus exclusive lane on median. We divided three steps of optimizing signal timing in order to explain concepts of bus progression control; that is a key point of systematic approach to bus signal timing.

We optimized signal timing to maximize car bandwidth, this signal timing had functions to offer a higher possibility of car non-stop and increase car travel speed as of improving bus progression efficiency. Although the effect on car was good when using this signal timing at test bed, the effect on bus is not good. Bus often stopped at the signalized intersection located bus stop on median because bus had stop for a moment to carry passengers. Dwell time that occurred at bus stop influenced bus travel time, so car already passed through and light changed to red when bus arrived at signalized intersection. The travel speed of bus was different with that of car because of dwell time, even though the desired speed was same between car and bus. From figure 2, we knew the large difference of travel time between car and bus. It took a short time for a degree of 'A' when car drove from node 1 to node 9. Differently, it took a long time for a degree of 'B' when bus moved as the result of three stops at bus stop; node 2, node 6 and node 8. Bus travel time was over twice of car travel time as bus travel speed lower on account of dwell time.

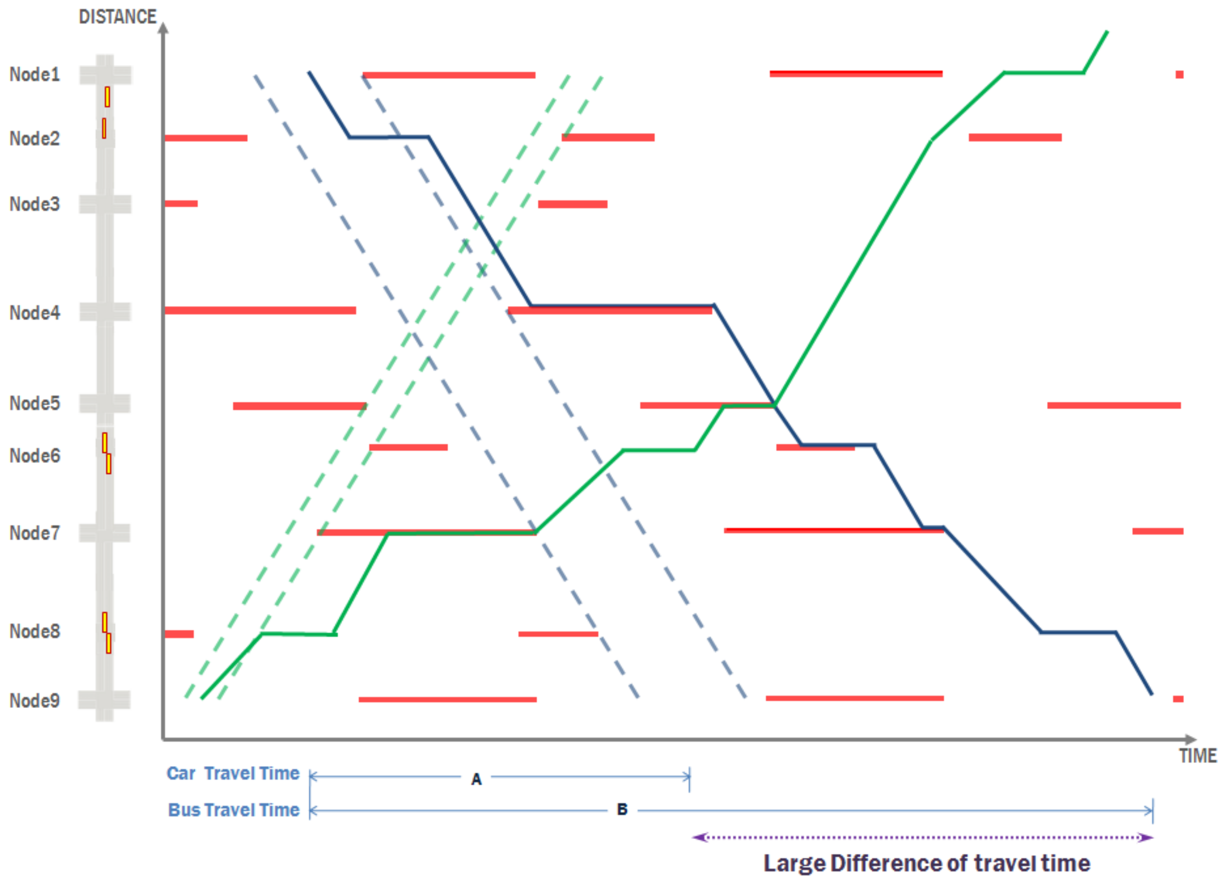


Figure 2 – Time Space Diagram on Maximization of Car Bandwidth

Maximization of Bus Bandwidth

The signal timing of maximizing car bandwidth was unsuitable on bus exclusive lane on median. The purpose of constructing bus exclusive lane on median is a policy to enhance quality of bus service. It is necessary bus priority enough to fully satisfy this purpose as a way of increasing bus travel speed. This paper used signal timing of maximizing bus progression efficiency as bus passive priority because we wanted to design a practical bus priority easy to apply without special equipment. In order to obtain a good effect of bus passing through at signalized intersections, offset was changed according as light turned on green after consuming bus dwell time. It is possible to change other variables of signal timing like cycle length, phase sequence and green split in order to maximize bus bandwidth.

When we optimized signal timing by using this concept on test bed at Goyang, all of signal timing variables were changed comparing with prior signal timing. On view of outbound, it was a particularity like as the start point of green time at node 2, node 6 and node 8 were very different with prior one. We knew that the difference of travel time became smaller because car travel time increased a little and bus travel time decreased properly from figure 3. It would be needless to optimized signal timing that had an effect on all vehicles; bus and car, in fact, it was very difficult to obtain this signal timing. We had focused on bus effect to enhance bus travel speed while car effect became worse than prior one. We kept going to studied a good signal timing on bus and car, so we used a meaning of slack green to reduce car travel time.

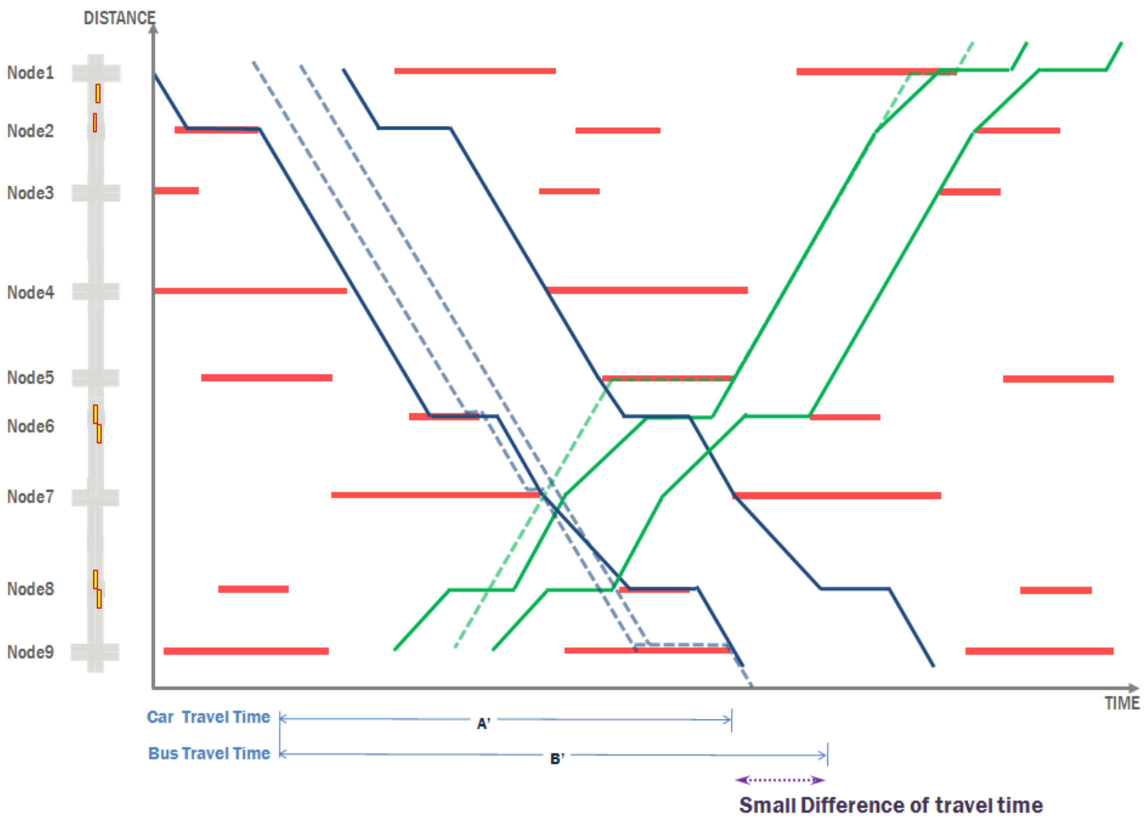


Figure 3 – Time Space Diagram on Maximization of Bus Bandwidth

Minimization of Increased Car Delay Time

Slack green means a time from end of red time to beginning of bandwidth from MAXBAND model. As the result of optimizing based on maximizing bus bandwidth, there were three nodes that had slack green time; node 1, node 8 and node 9. We would like to accomplish two principal concepts; one was decreasing travel time of bus and the other was reducing the degree of increased delay time of car. In order to improving of an effect on car, we adjusted offsets within the range of slack green time at signalized intersections. Travel time of car reduced even though the degree of offset adjustment seems very slightly.
We evaluated the goodness and badness of this bus progression control from figure 4. As the result of comparing three cases, car travel time increased a little and bus travel time decreased a lot. It was important to reduce car travel time without change of bus travel time by adjusting only offset. We defined bus progression control as satisfying two purposes; to enhance bus travel speed and to reduce the car delay time increased after maximizing bus bandwidth. We expect this bus signal timing would be a good control at bus exclusive lane on median and BRT system, of course the degree of difference would be different.
On next chapter, this paper would present a practical method to apply this bus progression control.

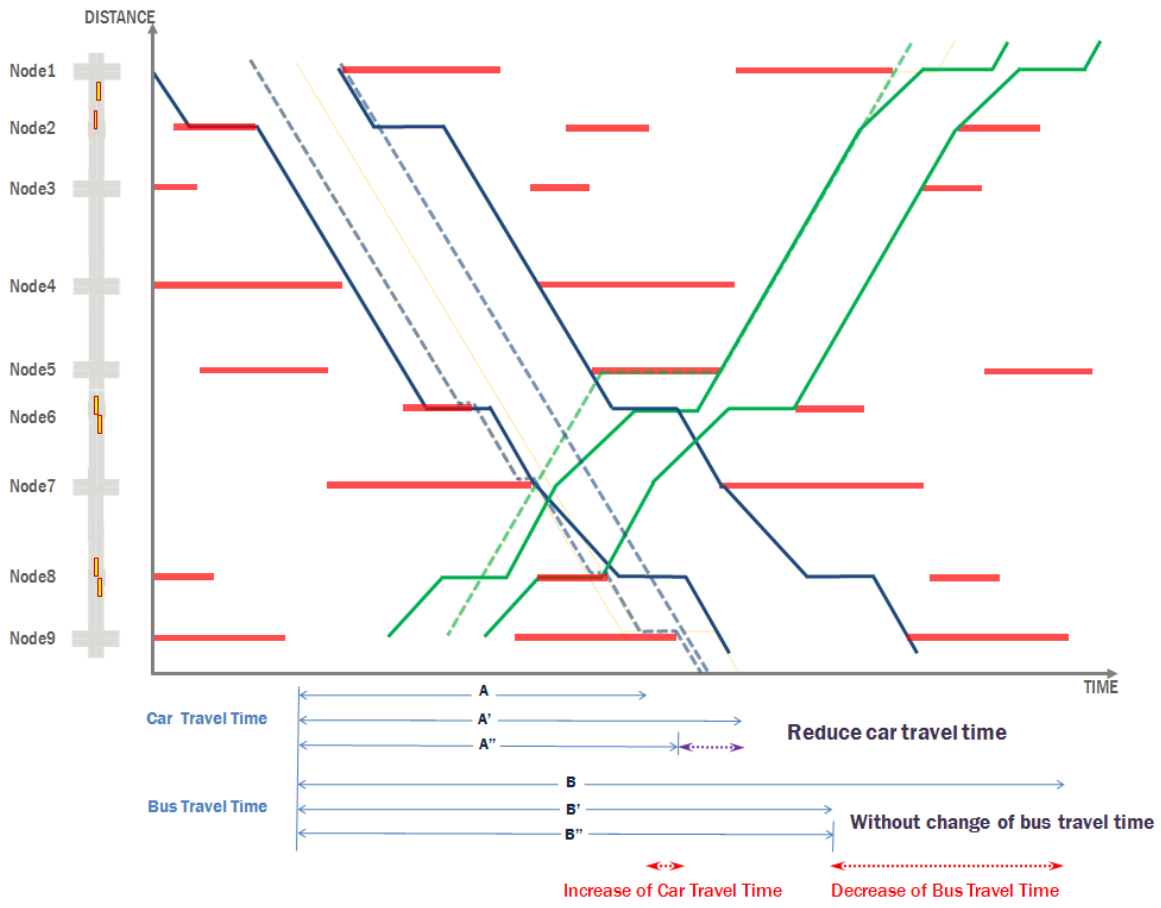


Figure 4 – Time Space Diagram on Adjusting Offset to Minimizing Car Delay Time

OPTIMIZATION OF BUS SIGNAL TIMING

We had studied the practical method to optimize bus signal timing that could accomplish bus progression control. Through this control, we divided three stages about calculating bus signal timing.

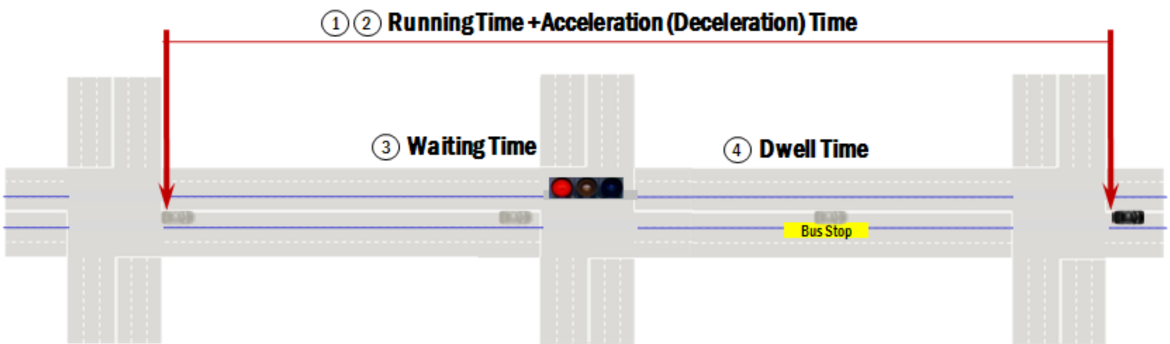
1. First - It is necessary to estimate travel speed of bus after considering running time, acceleration time, waiting time at signalized intersections and dwell time on bus stops.

2. Second - We optimize signal timing to decrease bus travel time using a signal optimization model of maximization bandwidth.

3. Third - We adjust offsets to reduce the change of car delay time before and after using a signal optimization model of minimizing delay time.

Estimation of Bus Travel Speed

It is very important to estimate bus travel speed because we can get accurate signal timing of bus when having similar travel time with real one. This paper considered only four variables of bus travel time as running time on free flow speed, acceleration time following the correlation with other elements, waiting time at signalized intersections and dwell time at bus stops to carry passengers.
There were two ways to estimate bus travel time. One was a way of using BIS data, the other was a way of using micro simulation. When using the former, that value was influenced by all elements of impacting to bus travel time. This paper used the latter, so we assumed that free flow speed was similar to limit speed and dwell time was fixed constant; originally dwell time is calculate with number of passengers, crowdedness of bus and etc. We regarded waiting time as zero because it was unnecessary to stop at signalized intersection within bus bandwidth.



$$TT_{bus} = \frac{L}{V_f} + t_{acc,dcc} + t_w + t_d$$

Figure 5 – Definition of Bus Travel Time

Combined Use with PASSER and Transyt-7F

Many studies used combined use to supplement weakness of each signal optimization model. The main goal of bus progression control was a widen bandwidth supply to bus in order to enhance bus travel speed. And then we wanted to reduce car delay time with maintenance of the best travel speed of bus. We designed combined use of bus progression control that compounding with PASSER and Transyt-7F. PASSER has a strong point to offer good signal timing in view of maximizing bandwidth and Transyt-7F has a good merit to optimize as possible as minimize delay time.

They were essential input data as travel speed and distance that influenced to signal control variables like offset. In order to optimize signal timing on a basis of bus, we used bus travel time and distance between signalized intersections and bus stops. Other variables were used with car data; volume, number of lanes, minimum green time and so on because it was reasonable to calculate green split time on a basis of car. After input data of bus and car, we selected the best signal timing as considering bus progression efficiency and other results.

On next step, it was necessary to re-optimize offset to reduce car delay time. When running Transyt-7F, we differently used travel speed of car because of minimizing car delay time. It was important to input constraint of bus bandwidth, as we used slack green time to reduce delay time of car. Under accomplishing this stage, signal timing was optimized to reduce increased car delay time with keeping higher travel speed of bus because it did not change bus bandwidth.

This paper designed the process of calculating bus signal timing with combined use in order to increase bus travel speed and reduce car delay time. At first, accurate travel speed of bus was estimated from BIS data or micro simulation. Secondly, we calculated first signal timing of bus with PASSER in order to maximize bus progression efficiency. Finally, it was necessary to adjust offset with Transyt-7F by using slack green time.

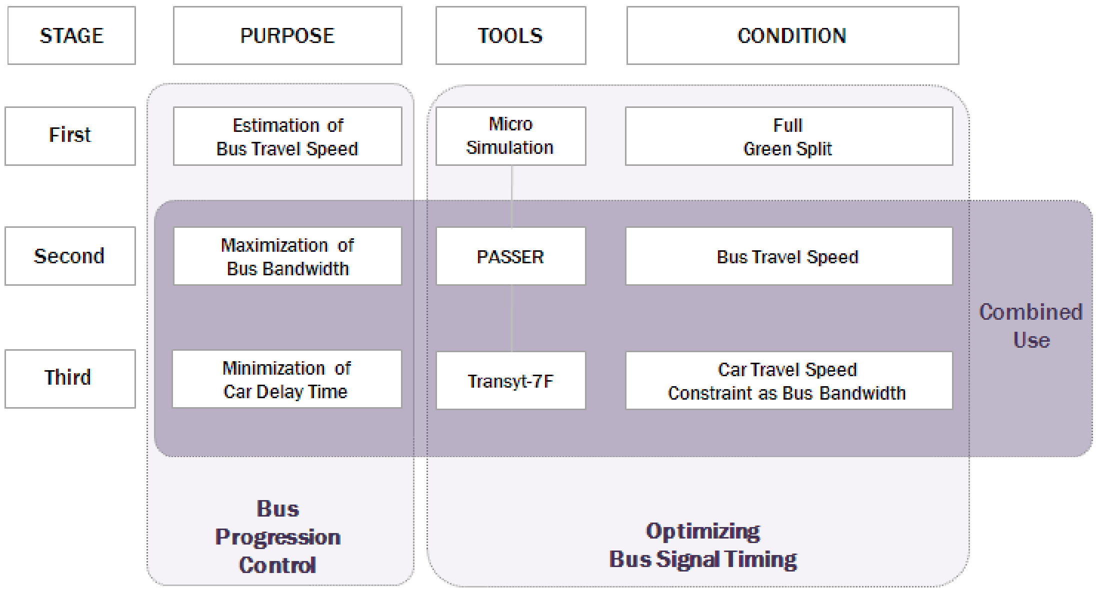


Figure 6 – Process of Calculating Bus Signal Timing

ANALYSIS

We analyzed the effectiveness of this method with micro simulation named VISSIM. We made test bed based on real BRT systems in Korea, we mentioned this site on chapter of concepts of bus progression control. It was necessary to select measures of effectiveness to evaluate the effect of this method. We regarded the best MOE of bus as travel speed and the proper MOE of car as delay time. Of course, person delay time is the best to compare the effect of bus priority, however, this paper used just delay time of vehicle for recognizing easily.

Comparative Analysis

We made test bed for comparative analysis, this site was constructed by copying real BRT system at Goyang. This sample network was a 2km road which included six signal intersections and three bus stops, the distance between signal intersections was 120 meters to 300meters. We regarded the bus stops as signal intersection because there were pedestrian cross-walks. Seung-Jeon Avenue had three car lanes on average and one bus exclusive lane on median. The traffic volume was used vehicles on the am-peak hour which was higher on outbound. We analyzed the result of various signal timing that optimized each scenario by used data and used tools. We added scenario 1 and scenario 2 as contrast of scenario 3. This paper had focused on the result of scenario 3, 4 and 5 to compare effect of bus progression control.

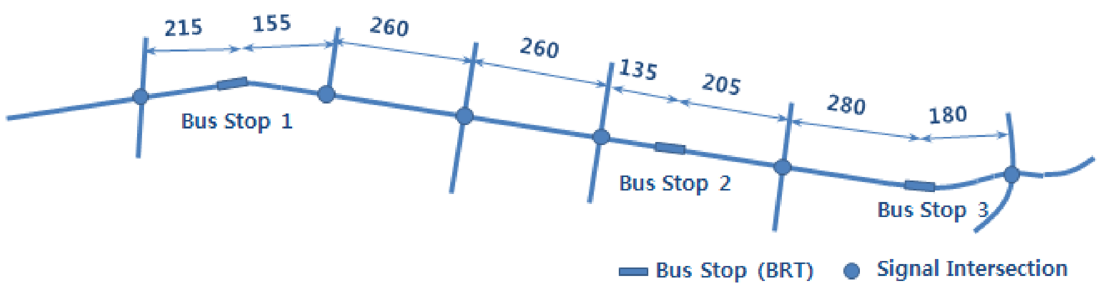


Figure 7 – Test Bed : Seung-Jeon Avenue Line Drawing in Goyang

Scenarios	Tools	Algorithm		Data
Scenario 1	PASSER Ⅴ	PASSER ⅠⅠ	Maximization of Car Bandwidth	CAR
Scenario 2	Transyt-7F	PROS	Maximization of Car Bandwidth	CAR
Scenario 3	Transyt-7F	DI	Minimization of Car Delay Time	CAR
Scenario 4	PASSER Ⅴ	PASSER ⅠⅠ	Maximization of Bus Bandwidth	CAR & BUS
Scenario 5	PASSER Ⅴ Transyt-7F	PASSER ⅠⅠ DI	Maximization of Bus Bandwidth Minimization of Car Delay Time	CAR & BUS

Figure 8 – Scenario Composition with Purposes and Data

Results of Travel Speed and Delay Time

We simulated each scenario with VISSIM as micro simulation. We sampled the result of travel time between node 1 and node 9 on both directions. From figure 9, the axis was divided three parts of direction as both directions, eastbound and westbound. There are results of five scenarios within one part, upper bar graph shows a result of bus travel speed and travel time. After applying bus signal timing of combined use, bus travel speed increased a degree of nine point six percents. From lower bar graph on figure 9, car travel speed increased a degree of two point one percents by using slack green time without change of bus travel speed. This graph showed that this method had a good effect on bus.
From figure 10, we knew the degree of car side effect. Car delay time increased a degree of eleven point nine percents after decreasing a degree of eight percents after using combined use.

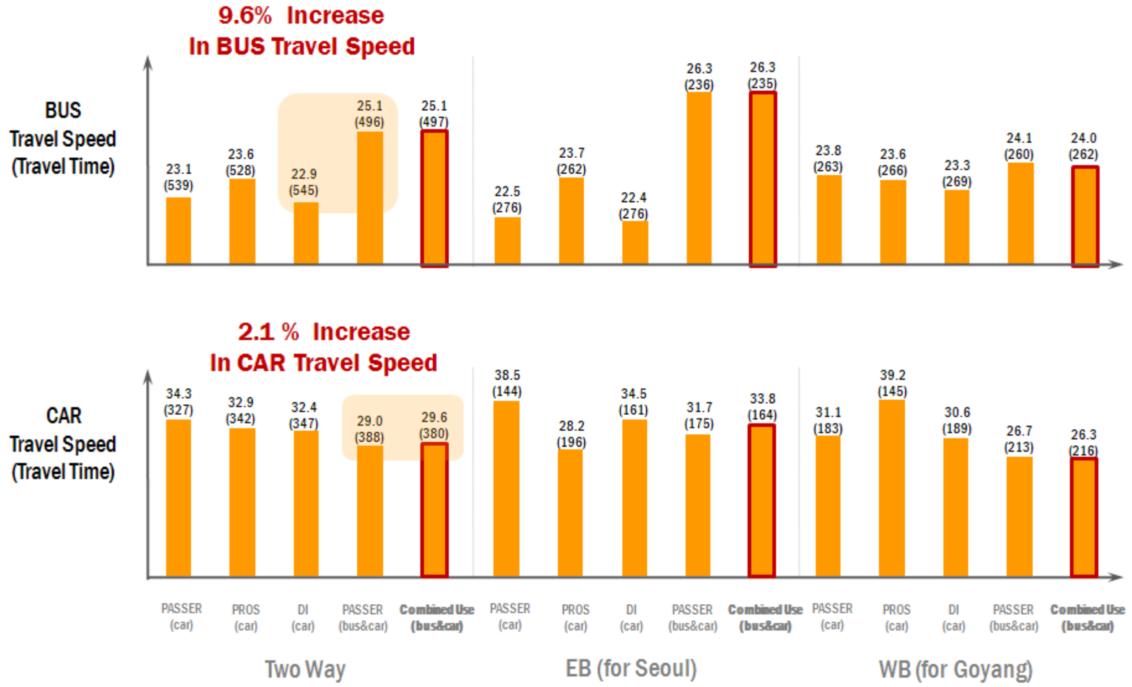


Figure 9 – Results of Travel Speed and Travel Time on each Scenario

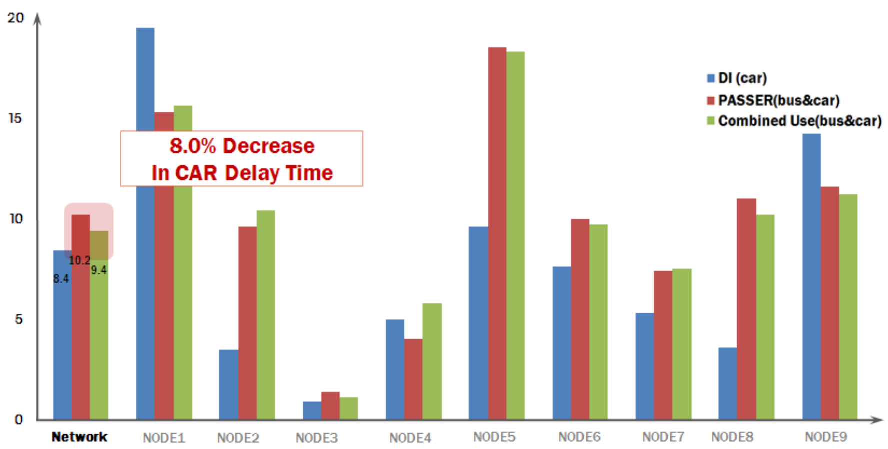


Figure 10 – Results of Delay Time of Car on three Scenarios

Sensitive Analysis

We simulated this practical method on another test bed that was constructed the BRT system included bus signal priority at Incheon. There were over fifty signalized intersections on 23.1 km road within three regions as Seoul, Bucheon and Incheon. We applied bus passive priority with this bus progression control at two sections. After we simulated whole section on VISSIM, we sampled the result of bus travel speed at the sections applied bus passive priority. On each section, travel speed of bus increased a degree of 16.2 percents as a minimum and 81.8 percents as a maximum. Overall this priority had an effect of increase at 48 percents.

Table 2 – Results of Bus Travel Speed at Incheon

Section	Region	Sub Area	Travel Speed of Bus	
			Bus Progression Control	Maximization of Car Bandwidth
A	Incheon	1	26.2 kph	21.2 kph
		2	21.7 kph	15.1 kph
		3	34.9 kph	19.2 kph
B	Seoul	1	26.0 kph	14.8 kph
		2	29.4 kph	25.3 kph

According to the result of simulation, delay time of car increased a degree of 2.1 percents as a minimum and 12 percents as a maximum. Differently delay time reduced at Seoul, we estimated that the change of car delay time was different under various volume and capacity ratio.

Table 3 – Results of Car Delay Time at Incheon

Section	Region	Sub Area	Delay Time of Car	
			Bus Progression Control	Maximization of Car Bandwidth
A	Incheon	1	12.2 sec	11.2 sec
		2	29.7 sec	29.1 sec
		3	23.3 sec	20.8 sec
B	Seoul	1	32.0 sec	35.2 sec
		2	22.0 sec	26.9 sec

From the result of comparative and sensitive analysis, we knew that practical method with bus progression control had an effect of increasing bus travel speed and reducing a change of car delay time.

CONCLUSIONS

This paper introduced concepts of bus progression control that was different with existing bus passive priority, because we considered the impact of car delay time and added the way to reduce the side effect. We showed the theoretical effect through comparing the change signal control variables on time space diagram. In order to design a practical method easy to apply and use, we developed combined use with PASSER and Transyt-7F. As the result of evaluation on travel speed and delay time, this method had a good effect.
According to sensitive analysis, it would be possible to apply on various site and various time. The strong point of this method was various design, it could apply at real site only on wanted period of time similar to TOD plans as pre-timed control. Moreover, we could know the section that needed bus active priority because that needed more green time. We expected that they would get the good effect of bus and smaller side effect to car at bus exclusive lane on median and BRT system.

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