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A BUS PRIORITY SIGNAL STRATEGY FOR REGULATING HEADWAYS OF BUSES

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Abstract: Since congestion on roads has deteriorated quality of bus service, attractiveness of bus has been weakened. Bus priority signal is a method to shorten control delay of bus at signalized intersections and to improve its service quality, such as reliability, in-vehicle time and waiting time. It may, however, cause congestion in general traffic. For this reason, this study attempts to develop a signal priority strategy to improve bus service quality while little inducing additional delay in general traffic by restricting target buses for priority. The effectiveness of this strategy is evaluated using microscopic simulation model, PARAMICS. The results show that this selected signal priority strategy reduces bus travel time and improves regularity of bus headway, compared with fixed signal control. Furthermore, it may regulate bus headway more powerfully and induce less delay to general traffic than non-selected signal priority.

Key Words: Selected Bus Signal Priority, Bus Headway, PARAMICS

1. INTRODUCTION

Due to boarding and alighting at bus stops, circuitous route and other factors, travel time of buses is longer than one of private cars. Moreover, buses moving on common roads with other vehicles are affected by congestion, so they are uncompetitive compared with subways. For this reason, the mode share of bus has been dropped in Seoul year by year. Low service quality reduces bus uses, which causes more congestion on the road and worsens quality of bus service. Thus actions to improve the quality of buses are needed.

Various approaches, such as installation of exclusive bus lane, adjustment in bus routes, and reform its fare system, to improve bus service quality have been implemented in many cities. Bus priority signal is another one for the same purpose. By adjusting signal timing, it shortens waiting time of buses at signalized intersections. Various signal priority schemes have been developed and implemented in many countries.

In Korea, signal priority for buses has not been implemented yet. It is likely to increase waiting time of vehicles passing in other movements. Hence, in the network that there are various bus routes and the roads are congested, it is hard to give priority to buses due to the concern about increase in delay of other vehicles. Therefore, great attention has been attracted to development of a signal priority approach that provides benefits to buses while reducing the impact on other vehicles.

The selected signal priority approach that gives priority just for buses satisfying particular criterion may be a way to relieve the potential problems under congested network condition. Since the magnitude of disadvantage for non-priority vehicles depends on the frequency of giving signal priority, selected signal priority approach gives less influence on other vehicles. In addition, each priority event is expected to be more effective because the approach gives priority only to buses that need it. Furthermore, depending on specified criterion, the selected signal priority strategy can derive other benefits such as reliability enhancement and headway regularization of buses.

Bus routes on congested network are likely to have poor punctuality or irregular headway, and it lowers bus service quality considerably. If a bus arrives late at a stop due to congestion or control delay, its headway with previous bus tends to be longer at downstream stops, and the bus may even bunch with following bus. In this situation, the delayed bus suffers from large crowdedness in its interior, and passengers' waiting time at downstream stops become longer than expected. Therefore regulating bus headway can contribute to improvement in bus service quality and reliability.

This study aims to develop a selected signal priority strategy to improve bus service quality effectively, without inducing much additional delay to other vehicles under complex bus routes and congested network conditions. To assess this strategy, simulation-based evaluation is conducted and its results are compared with results from other signal control alternatives, non-selected signal priority and non-priority control.

The remaining part is organized as follows: Section 2 introduces concept of common signal priority approaches and proposes a selected signal priority strategy using headway delay as a criterion. In section 3, the evaluation framework and development process of simulation tool for evaluation are described, and the results from evaluation are reported and analyzed. Finally, section 4 represents the main results and conclusions.

2. DEVELOPMENT OF A SELECTED SIGNAL PRIORITY APPROACH

2.1 Concept of Selected Signal Priority

The early approaches of signal priority intended to reduce waiting time of bus by setting the phase longer than normal or setting offsets coordinated with bus speed, but a few buses moving in that direction can achieve the benefit. It has been evolved into active signal priority schemes that detect buses approaching at intersections and adjust signal timing plan to pass the bus through without stopping. (Furth *et al*. 2000, Davol 2001) As detection and control techniques progress, the priority approaches that can incorporate with real-time (or adaptive) signal control are being developed and implemented. (Chang *et al*. 1995, Merchandani *et al*. 2001, Dion *et al*. 2002)

General signal adjusting schemes for bus priority include Green extension, Red truncation (or Early green), Phase insertion, Phase skipping, and Queue jumping, etc. If a bus is expected to arrive at an intersection just after its green time ends, the controller gives green extension that extends the green time for the bus to pass through without stopping. If a bus reaches to an intersection during its red time, the controller gives red truncation that shortens green time of the prior phase and reduces waiting time of the bus. The two are most popular since they neither add clearance intervals by adding another phase and nor confuse drivers by not changing the order of phases. Therefore, the proposed strategy in this study uses only the two signal adjusting schemes.

If a signal priority is provided, waiting time or delay of vehicles in other movements is increased. In the case of providing it frequently, excessive delay is added to those vehicles. To relieve this problem, a selected (or conditional) signal priority approach that restricts the target bus was developed. It may reduce negative effects for vehicles that move toward other directions by giving priority to the buses that satisfy predefined criterion. Additionally, it may increase efficiency of signal priority by advantaging bus lines that have more necessity, especially where various bus lines are passing through an intersection. It needs, however, additional advanced detecting equipments and complex control schemes.

The criterion that determines target bus can be specified using various measures, such as total delay in network, queue length on each approach, passenger loading of the bus and schedule delay. Because the effects of selected signal priority strategy depend on the specification of criterion, it should be specified coinciding with purpose of that signal priority strategy. In the case that criterion is based on deviation between scheduled headway and actual headway or difference from timetable, the signal priority strategy is expected to improve regularity of bus headway or adherence to timetable as well as to reduce bus travel time. Furth *et al*. (2000) proposed that a conditional signal priority can be a tool to adjust schedule delay directly, and they introduced an approach that provided signal priorities to the buses late for their schedule. Their experimental results showed that the strategy improved punctuality a lot though it increases bus speed a little. Also, it made less influence on other vehicles compared with other signal priority strategy that didn't restrict its target.

2.2 Criterion for Providing Signal Priority

For bus lines that have short headways, headway regularity is more appropriate than timetable adherence as a measure of service quality. On the contrary, for bus lines that have long headways (more than 15 minutes is suggested in HCM), adherence to timetable is more important. (HCM (2000)) Taking into account that many bus lines have relatively short headways in Seoul, the signal priority strategy proposed in this study aims to regulate bus headway.

Since this strategy aims to regulate bus headway, its criterion that decides target buses is based on ratio of headway delay, expressed as equation (1).

$$R_h(i_k) = \frac{h(i_k) - h_k}{h_k} \tag{1}$$

where, $R_h(i_k)$ = headway delay ratio of i th bus in line k

h_k = scheduled headway of bus line k

$h(i_k)$ = expected headway between i th bus and $i-1$th bus in line k

In terms of substantial service headway for passengers waiting at stops, an expected headway at next bus stop rather than headway at the detected point is used. In other words, when an approaching bus is detected at a detection point, its arrival time at the next stop is estimated and corresponding headway is predicted by using recorded arrival time of preceding bus.

If it is predicted that the bus line will arrive at the next stop with a long headway, i.e. headway delay ratio is expected to exceed the predefined threshold, it gets a right of priority. Since the frequency of priority depends on the threshold, the threshold should be determined considering level of priority to be required or traffic condition. When an approaching bus satisfies the criterion, an applicable signal adjusting scheme, one of green extension and red truncation, is distinguished according to current signal state, signal timing plan and queue forward. When the signal priority scheme is expected to succeed, the scheme is called.

2.3 Process of Bus Travel Time Estimation

To determine headway delay ratio, detection of approaching bus, prediction of arrival time at the next stop and record of bus arrival time at each stop are needed. They are conducted using various equipments. Most commonly used methods to sensor approaching bus are loop detection and telecommunication. In the former detection system, each bus has a tag, and loop detector in road surface discerns it. In the later system, a transponder or an emitter that transmits data via infrared, microwave or radio wave is equipped on each bus. Beacons or other receivers placed on roadside or at intersection receive the data and send them to controller. Since loop detectors are installed at fixed locations, the current location of bus on detecting time is known. On the other hand, in the later way, the current location of bus can be found by receiving GPS data from buses or by estimating using the angle of received wave.

COSMOS, the actuated signal control system in Seoul, uses loop detectors to estimate queue length at approaches. Considering it, this paper assumes that loop detectors installed on approaches of intersections and they can discern buses from other vehicles. Additionally, bus arrival times are recorded at each stop, so controllers can know arrived time of preceding buses at the next stop. This needs detectors or beacons installed at stops and communication system that transmits bus location data to the controller. As bus information system is being constructed or being operated in many cities recently, recording of bus arrival time at stops is probably easy.

Next, travel time estimation method that is suitable for predicting when will the detected bus arrive at next stop is developed. To estimate travel time between stops, existing bus information systems have used previous bus travel time method, moving average method, regression model, time series model, neural network model or Kalman filtering. Since they cannot consider the effect of signalized control explicitly, they are not suitable to estimate travel time between detection point and next stop. The time needed for a detected bus to arrive at the next stop is divided into two parts, from detection to passing the intersection and from intersection to arriving at next stop. The former part is estimated by considering vehicles in front of the bus and signal timing plan, and the latter part is assumed to be the same as that of the previous bus on that route.

Chang *et al*. (1995) estimated queue length using inflow and outflow of detection interval. By assuming that loop detectors are installed at stop lines, the number of vehicles passing each stop line during certain interval can be counted. For this signal priority strategy, therefore, an interval on each link from intersection to certain location in upstream is set to a priority interval. The number of waiting vehicles in front of the detected bus is estimated using counts of vehicles that enter into and exit from the interval.

Time needed for a detected bus to pass the stop line is predicted considering current signal state and discharge headways that are time intervals to pass the stop line of preceding vehicles. In many researches, it is shown that variation is appeared in discharge headway according to the order of vehicles. Due to start-up lost times, first several vehicles have large discharge headways, and the headways tend to converge to saturation headway. In this paper, the values of discharge headways according to order in queue are defined referring to the values of HCM (2000).

If the detected bus can move within current phase, the number of vehicles that can pass during left green time is estimated as following.

$$m(i_k) = \left[\frac{G(p_k) - t}{H_d(n(t_k)) - H_d(o(t))} \right] \tag{2}$$

where, $m(i_k)$ = number of vehicles that can pass during left green time
t = passed green time of current phase
p_k = phase that bus line k can move
$G(p)$ = green time of phase p
$o(t, i_k)$ = number of vehicles passing the stop line in the same direction as the bus during passed green time of current phase
$n(i_k)$ = number of vehicles in front of the bus and i_k itself
$[x]$ = greatest integer less than a real number x
$H_d(n)$ = sum of discharge headway of n vehicles

Sum of discharge headways of the bus and preceding vehicles are calculated using discharge headway distribution. For discharge headway of q th vehicle, h_q, it is computed as

$$H_d(n) = \sum_{q=1}^{n} h_q \ .$$

If detected bus is expected not to pass the stop line in current phase, i.e. $m(i_k) \leq n(i_k)$, $t_l(i_k)$ is predicted as follows. Only if the preceding vehicles are few, then whether the bus can pass in current phase is predicted comparing the time needed to reach stop line at free flow speed and left green time.

$$t_l(i_k) = (C - t) + H_d(n(i_k) - m(i_k)) \tag{3}$$

where, $t_l(i_k)$ = time needed for a detected bus to pass the stop line
C = cycle time

If the detected bus cannot move in current phase (in red time), $t_l(i_k)$ is predicted by adding red time interval to sum of discharge headways of ahead waiting vehicles.

$$t_l(i_k) = \left\{ \sum_{p=p_0}^{p_k'-1} G(p) - t \right\} + H_d(n(i_k)) \qquad (4)$$

where, if $p_k < p_0$ then $p_k' = p_k + P$ (P is number of phases in a cycle)
otherwise $p_k' = p_k$
in $G(p)$ if $p > P$ then let p as $p - P$

If the bus cannot pass in upcoming p_k th phase due to many preceding vehicles, i.e. $G(p_k) < H_d(n(i_k))$, the number of left vehicles ahead of the bus and itself, $m(i_k)^1$, is calculated. Then $t_l(i_k)$ is predicted considering additional cycle time and sum of discharge headway of $m(i_k)^1$ vehicles.

$$m(i_k)^1 = n(i_k) - \max\{\ m : G(p_k) \ge H_d(m),\ m \text{ is integer } \} \qquad (5)$$

where, $m(i_k)^1$ = number of left vehicles after current cycle

$$t_l(i_k) = \left\{ \sum_{p=p_0}^{p_k'-1} G(p) - t + C \right\} + H_d(m(i_k)^1) \qquad (6)$$

The time needed to reach the next stop after passing the stop line is assumed to be the same as the previous bus of that line. Therefore the time needed for a detected bus to reach the next stop can be written as

$$t_a(i_k) = t_l(i_k) + t_s(i - 1_k) \qquad (7)$$

where $t_a(i_k)$ = time needed for a detected bus to reach the next stop
$t_s(i - 1_k)$ = time needed to reach the next stop from the stop line

After all, $h(i_k)$, that is used to determine $R_h(i_k)$, is

$$h(i_k) = T_a(i_k) - T_a^r(i - 1_k) = T + t_a(i_k) - T_a^r(i - 1_k) \qquad (8)$$

where, $T_a^r(i - 1_k)$ = recorded arrival time of $i - 1$ th bus of route k at the next stop
T = the present time

2.4 Priority Call and Its Management

If $R_h(i_k)$ is greater than predefined threshold, one of green extension and red truncation is called after consideration about signal state and predicted travel time. In this process, some restrictions are put on not to cause excessive delay of other vehicles and disruption of signal operation. A restriction is upper limit of the extension and truncation time, and another restriction is minimum green times for all phases.

In case phase p_k is current green when a bus is detected, required green extension time, t_{GE}, is calculated using sum of discharge headway of preceding vehicles and left green time. If the required time satisfies all restrictions, green extension for p_k is called. Otherwise, red truncation for maximum truncation time is called for the phase in next cycle.

$$t_{GE} = \{H_d(n(i_k)) - H_d(o(t,i_k))\} \tag{9}$$

$$t_{RT} = \min\{\max RT,\ G(p_k - 1) - \min G\} \tag{10}$$

where, t_{GE} = required green extension time

t_{RT} = required red truncation time

In case phase p_k has green indication when a bus is detected, t_{RT} is calculated. If the bus expected to pass the stop line in current cycle and all the restrictions are satisfied, red truncation is called. Otherwise, green extension is examined, and then it is called or not.

Most signal priority approaches developed or evaluated in previous studies are implemented to a corridor or a particular bus route. (Lin *et al*. 1995, Khasnabis *et al*. 1997, Chandrasekar *et al*. 2002) If signal priority is provided for all the bus line where there are many bus lines moving various directions in many large cities, such as Seoul, confliction between signal priority calls for different bus routes can be occurred. For example, when green extension for p th phase and red truncation for $p+1$ th phase are called in a cycle, the calls are incompatible. When green extension for p th phase and red truncation for ($p+2$)th phase are called together, the green time of ($p+1$)th phase may get less than minimum green time.

To remove the confliction between priority calls, priority necessity of each called priority is determined when conflicting signal priorities are called for two or more phases. Priority necessity is determined based on ratio of headway delay as the following specification.

$$P(p) = \sum_{\forall i_k \in p} \{h(i_k)/h_k - 1\} \cdot \{GE(i_k) \cdot w_{GE} + RT(i_k)\} \tag{11}$$

where, $P(p)$ = priority necessity of p th phase

$GE(i_k)$ = indication of green extension call

1 if green extension is called, otherwise 0

$RT(i_k)$ = indication of red truncation

1 if red truncation is called, otherwise 0

w_{GE} = weighting factor of green extension (≥ 1)

Since green extension can reduce waiting time of bus more effectively, it is able to differentiate the two signal priority schemes by introducing weighting factor w_{GE} of green extension, dummy variables, $GE(i_k)$ and $RT(i_k)$, that indicate which priority scheme is called. If w_{GE} is set to be greater than unity, green extension has higher necessity than red truncation. The priority necessity of a phase is calculated by summing the values of all the buses moving in the phase when two or more buses exist in a priority interval on an approach link. The greater the value of $P(p)$ is, the higher the priority level is, and only one of the calls that have higher priority level is provided.

Because there is time lag between priority decision and its action, the call waits for adjusting signal timing. When a call for a detected bus is called, whether another waiting call conflicts with it or not is examined. If there exist confliction, one of the calls can be withdrawn after comparison between priority necessities.

Though green extension and red truncation do not change the sequence of phases, they change the green time/cycle time ratio that is assigned depending on traffic volume of each phase. Since it decreases capacity of non-priority approach links, it may induce excessive delay in high traffic volume condition. To reduce this negative effect, compensation of green time is carried out in next cycle. The green time that is curtailed in a cycle is lengthened in the next cycle to balance green time ratio. When another conflicting priority is called in next cycle, however, compensating process is omitted because providing of signal priority overrides balancing of green time. Furthermore, minimum green time of each phase is guaranteed in any compensating process.

3. ASSESSMENT OF SELECTED SIGNAL PRIORITY APPROACH

3.1 Framework of Analysis

To assess proposed signal priority approach, simulation-based evaluation is conducted with a hypothetical network. The network consists of two major roads and four minor roads, as shown in Figure 1, and the distance between any two intersections is specified consistently as 400m (Corresponding to average distance between intersections in Seoul). Five bus routes are set to account for the case that many bus lines move in various directions. All the bus stops are located at far side of intersection to prevent the inclusion of bus stop in priority interval and disturbance of right turn due to stops.

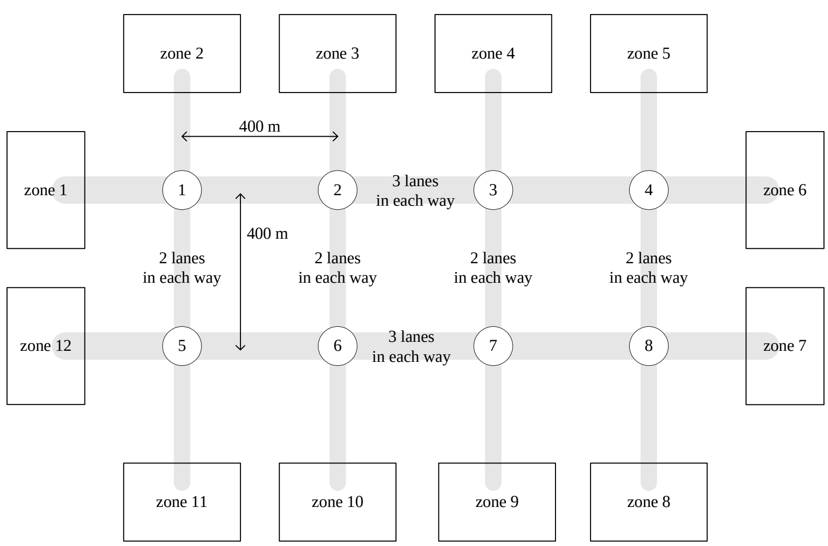

Figure 1. Network for Evaluation

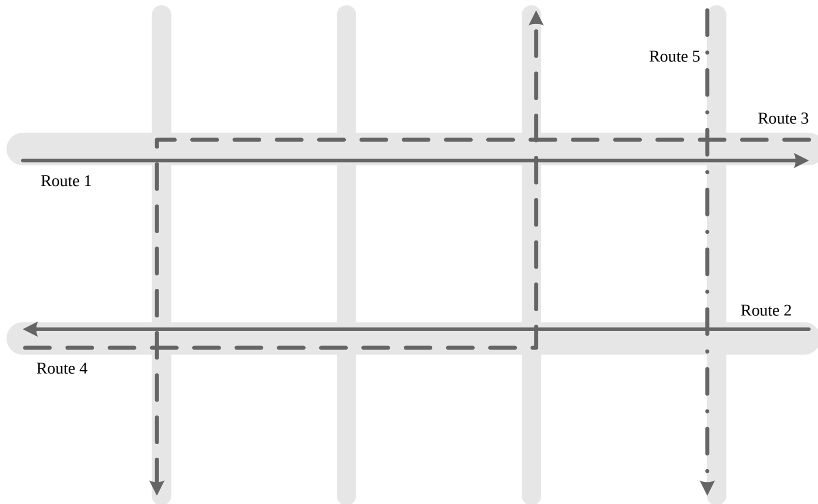

Figure 2. Bus Routes for Evaluation

Evaluation is conducted for nine scenarios classified by signal control methods and traffic volume conditions. The signal control method alternatives are composed of base signal, selected priority, non-selected priority. The base signal timing planning is determined by TRANSYT-7F, a signal timing optimization model, and the selected signal priority strategy is applied to base signal. To evaluate effects of signal priority, MOEs from selected signal priority strategy are compared with MOEs from base signal. In addition, to identify the effects from restricting target of signal priority, they are compared with MOEs from non-selected signal priority strategy that does not restrict target bus. Moreover, effects of each signal control strategy are evaluated for three different traffic volume conditions to examine difference depending on network volume conditions.

3.2 Simulation Model Design

In practice, applying the proposed priority strategy to real network and evaluating its effects have many risks. For this reason, this paper uses simulation-based evaluation by PARAMICS, a microscopic simulator. Each scenario is represented in PARAMICS, and MOEs are evaluated from the simulation process. To represent signal priority strategies in the simulator and to collect required data, external program was added to it using API (Application Programming Interface) functions provided by PARAMICS.

The external program consists of several main functions. A function controls signal state and another function detects approaching buses in all approach, examines the criterion for signal priority and, if the criterion is satisfied, requests green extension or red truncation. The other is the function that inquiries current signal state and applies requested signal priority scheme.

To give priorities to detected buses without fail, accuracy of arrival time estimation should be assured. In order that prediction about whether the bus can pass in certain cycle does not fail, calibration of the predefined values of discharge headways was conducted. When a detected bus is not given a signal priority because it is expected to pass in this phase, but actually the bus may not be able to pass in this phase. To prevent from this case, the values of discharge headways were specified with larger values than the values suggested by HCM (2000). After the calibration, the probability that estimated values are consistent with actual values, that is, hit ratio of estimation whether a detected vehicle can pass in certain phase was more than 97 %. Moreover, since the accuracy of estimation may be affected by volume condition, validations are conducted in various traffic volume levels and the hit ratio is confirmed more than 95% for all conditions.

The overall process of signal priority provision in simulating is shown in Figure 3.

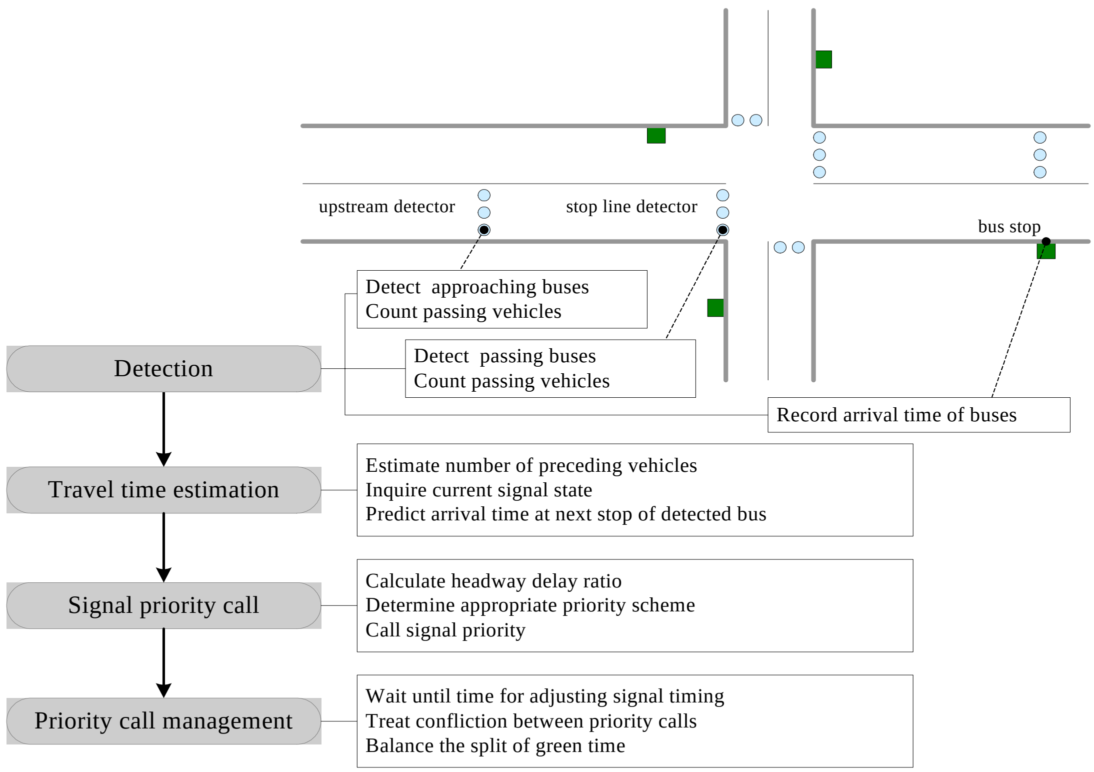

Figure 3. Process of signal priority provision

3.3 Results

Various measures such as bus service reliability, passengers' waiting time, the number of passengers and travel time or delay of buses and of all vehicles, can be used for evaluating bus signal priority. Several measures of them that identify effects of selected are evaluated by using data collected in simulating process. They are calculated using data collected from one-hour simulation after warming up time of 30 minute, because network is empty when simulation starts and the vehicles move at free flow speed for some time.

As the main feature of proposed priority strategy is to adjust headways of bus on the basis of arrival times at stops, measures related to headway were calculated. Table 1, 2, 3 present the mean, standard deviation and deviation from scheduled headway of observed headways at all the bus stops. They show that the selected signal priority strategy may not greatly reduce the mean of headways, but it can decrease deviation of headways. Especially in high volume condition, it was appeared that the strategy could avoid long and irregular headways more effectively. On the other hand, the results support the opinion that non-selected signal priority may cause more irregular headways in high volume condition.

Table 1. Mean of Arrival Headways at Stops (sec)

	Base signal	Non-selected priority	Selected priority
Low volume	299.28	300.01	299.13
Medium volume	300.91	300.64	302.16
High volume	306.43	306.58	302.13

Table 2. Standard Deviation of Arrival Headways at Stops (sec)

	Base signal	Non-selected priority	Selected priority
Low volume	75.35	63.22	55.32
Medium volume	88.19	86.95	84.35
High volume	124.00	126.51	115.51

Table 3. Deviation from Scheduled Headway (sec)

	Base signal	Non-selected priority	Selected priority
Low volume	65.23	54.86	45.99
Medium volume	79.15	73.19	71.72
High volume	104.68	106.23	90.90

In this simulation process, all the dispatch headways of buses are set to five minutes. Thus headways of buses at upstream stops are relatively regular, but they tend to be distinctly irregular at downstream stops due to the influence of signal control and congestion. Table 4 contains measures evaluated by aggregating headways observed at last stop of all the bus routes. The measures imply that, among the three signal control method alternatives, the selected signal priority strategy produce headways closest to scheduled headway. This effect is remarkable for routes by way of minor roads, such as route 3 and route 5.

Table 4. Arrival Headways at Last Stops (sec)

		Base signal	Non-selected priority	Selected priority
Low volume	Mean	301.20	301.94	299.31
	Standard deviation	81.79	74.85	58.63
	Deviation from scheduled headway	77.31	73.40	56.98
Medium volume	Mean	296.62	301.10	300.37
	Standard deviation	109.26	107.67	96.92
	Deviation from scheduled headway	106.16	105.30	95.01
High volume	Mean	307.61	305.51	301.35
	Standard deviation	145.56	146.38	134.56
	Deviation from scheduled headway	141.79	142.17	131.37

The headways of a bus route are closely related with passengers' waiting time at stops. If passengers are assumed to arrive at stops with uniform rate, the expected waiting time of passengers that wait particular bus route is proportional to square of headway of the route.

Therefore, for simplicity, if it is assumed that the number of passengers at each stop is identical for all the routes and that passengers at each stop arrive following uniform distribution, total passengers' waiting time is proportional to the sum of squares of all the headways. Comparing the sum of squares of headways in Table 5, though the difference is small, the value corresponding to selected priority is smaller than others.

Table 5. Sum of Squares of Arrival Headways (sec^2)

	Base signal	Non-selected priority	Selected priority
Low volume	94,296.34	93,058.09	91,591.07
Medium volume	96,355.09	95,969.56	96,439.20
High volume	104,175.96	104,882.03	99,539.30

In general, bus signal priority approaches are expected to shorten travel time of buses while adding delay to other vehicles. To examine these effects, average travel time and speed are aggregated for buses and other vehicles, as presented in Table 6 and Table 7. The values show that non-selected signal priority can shorten more travel time of bus, but it induces additional delay to other vehicles. On the other hand, the selected signal priority strategy brings smaller improvement in travel time or speed of bus compared with non-selected strategy, but it has less influence on other vehicles. While differences among signal control alternatives are not significant in low volume condition, in high volume condition, the differences are augmented and non-selected priority causes the largest additional delay to other vehicles.

Table 6. Aggregate Travel Time (sec)

		Base signal	Non-selected priority	Selected priority
Low volume	Other vehicles	242.72	246.67	243.91
	Buses	381.68	345.59	365.37
	Total vehicles	243.98	247.57	245.02
Medium volume	Other vehicles	269.42	282.15	277.59
	Buses	394.53	344.78	367.17
	Total vehicles	270.47	282.67	278.33
High volume	Other vehicles	303.50	334.49	317.36
	Buses	441.08	411.31	411.74
	Total vehicles	304.53	335.06	318.05

Table 7. Aggregate Speed (km/hr)

		Base signal	Non-selected priority	Selected priority
Low volume	Other vehicles	27.58	27.30	27.54
	Buses	15.22	16.96	15.95
	Total vehicles	27.37	27.13	27.43
Medium volume	Other vehicles	24.60	23.45	23.83
	Buses	14.64	16.69	15.68
	Total vehicles	24.49	23.36	23.72
High volume	Other vehicles	21.54	19.07	20.25
	Buses	12.89	13.72	13.69
	Total vehicles	21.44	19.04	20.19

4. CONCLUSIONS

This paper proposed a selected bus signal priority strategy to improve regularity of buses headway and evaluated its effects using microscopic simulator, PARAMICS. By restricting target bus with the criterion based on headway delay, the approach sought to reduce negative effects of signal priority and to relieve problems caused by irregular headways of buses, such as increase of passenger waiting time and crowdedness in bus and deterioration of buses reliability. Specially, it can be applied to intersections where many bus routes move in various directions.

From measures of effectiveness using data achieved from simulation, effects that adjust headways of buses, shorten travel time of buses and increase speed of buses were confirmed. While non-selected priority tended to disturb headways of buses in high volume condition, selected priority improved regularity of their headways and added little delay to other vehicles even in high volume condition. This implies that we'd better specify some criteria when we implement signal priority signal control.

To get persuasive reasons for introducing bus signal priority, many aspects like travel time, waiting time, operating cost and emission of pollutant of all the travelers or vehicles should be considered. Therefore, it is needed to develop and evaluate comprehensive measurement. Furthermore, it will be more practical results when the proposed approach is simulated not on a hypothetical network, but on a real network. Prior to this, it is required that the simulator gets ability to represent real network with reality. Additionally, the study that develops and evaluates the selected signal priority strategy based not on fixed signal control but on adaptive signal control will have useful meanings.

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