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AN ENHANCED PUBLIC TRANSPORTATION PRIORITY SYSTEM FOR TWO-LANE ARTERIALS WITH NEARSIDE BUS STOPS

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Abstract: The Public Transit Priority Systems are currently operated in a half of prefectures in Japan. The PTPS could service either multiple lanes or two-lane arterials. However, when operating along two-lane arterials with nearside bus stop, there are some unsatisfied performances, which need to be improved. This study enhanced the PTPS to service a bus priority along two-lane arterials with nearside bus stops. The proposed system was developed to eliminate lost of green time when bus stops at nearside bus stop during green interval, to minimize negative impact to other traffics and also to switch signal phase with minimizing the interruption to control coordination. The recommended architecture system and additional system control logic were proposed. The enhanced system was compared with typical system to evaluate its performance. Both systems were simulated by PARAMICS on the selected arterial. The results showed that the proposed system performed successfully with significant decreasing average delays of bus and other traffics, especially cross street traffic.

Key Words: Public transportation priority system (PTPS), Two-lane arterial, Nearside bus stop, Micro traffic simulation

1. INTRODUCTION

The bus plays the major role to service the public in many areas of Japan, especially local areas. The bus is also served as a feeder mode for transit passengers in metropolitan areas. However, many bus stakeholders previously encountered the financial problems. They could not gain the benefit from bus operation due to a low number of riderships. Therefore, the Japanese government has attempted to solve this problem by promoting the bus. To achieve this goal, The Public Transportation Priority System, known as PTPS, has been introduced to the public in order to increase a number of riderships. PTPS is the one of the advanced technology systems of Universal Traffic Management Systems of Japan, UTMS. It promotes the bus by providing a priority through the exclusive bus lane, the traffic signal preemption and the warning to a vehicle which is illegally running in the exclusive bus lane. The PTPS has provided successfully a priority to bus with obvious decreasing in bus delay. Currently, more than a half of prefectures in Japan are operating PTPS (UTMS, 2004). The PTPS could service not only along multiple lanes arterials but also along two-lane arterials. Nevertheless, there are some unsatisfied performances of PTPS, which need to be improved, especially operating along two-lane arterials. The high efficiency of providing bus priority and the unsatisfied performance of PTPS could be examined from the operation performance on selected arterials. The summarizations of performance of PTPS operating along the representative arterials are presented in Table1, and could be explained as follows.

Table 1. Summarizing of Operation Performances of PTPS

Movement	**Average Travel Time (sec)**		**Difference (sec)**	**Percent Change**
	Before PTPS Operation	**After PTPS Operation**		
1. Operation along Multiple Lanes Arterial (At Route No. 133 in Chiba Prefecture)				
Bus	471	368	-103	-22%
Cross Street Traffic	195	238	43	22%
Main Street Traffic	451	344	-107	-24%
2. Operation along Two-Lane Arterial (At Route No. 1 in Chiba Prefecture)				
Bus	31	30	-1	-3%

Source: Chiba Police, 2004

- **Operation Performance along a Multiple Lanes Arterial:** PTPS with an exclusive bus lane services along Route No. 133, a four-lane arterial in Chiba Prefecture. It is noticed that the average travel times of bus and main street traffic after operating PTPS were decreased obviously with 22% and 24% decreasing from before operating PTPS as shown in Table 1. However, average travel time of cross street traffic was obviously increased with 22% increasing from before operating PTPS.
- **Operation Performance along a Two-Lane Arterial:** PTPS services along the Route No. 1, a two-lane arterial with nearside bus stops in Chiba; the bus has to travel with mixed traffics. The results reveal that the bus average travel time after operating PTPS was not quite different from before operating PTPS with 3% difference as shown in Table 1.

For operating along the multiple lanes arterial, the PTPS could improve effectively a level of service of bus as well as traffic condition along main street. However, at the same time, it caused somewhat a negative impact to the cross street traffic. Besides, in two-lane arterial with nearside bus stops, the PTPS could not significantly show the benefit of level of service of the bus and traffic condition. The one obvious problem is the lost of green time once bus stop to load/unload passengers at nearside bus stop during green phase.

As previous research, there was no study proposed the strategy to solve the lost of green time at nearside bus stop along two-lane arterials. Only Kim (2005) proposed the bus signal priority algorithm to reduce the negative impacts of nearside bus stops, however, this proposed algorithm has been decided for multiple lane arterials with exclusive bus lane.

Therefore, this study attempted to improve the PTPS to service along two-lane arterials with nearside bus stops.

2. STATEMENT OF PROBLEMS

Once the PTPS operates along two-lane arterials with nearside bus stops, many problems have been occurred as follows:

- Lost of green times is occurred when bus is stopping to load/unload passengers at the nearside bus stop during a green time interval, in other words, lost of capacity of that signalized intersection approach. This circumstance might effect to the following vehicles, which unable to overtake the stopping bus due to no passing zone. Moreover, some following vehicles illegally take over through the stopping bus; it might cause the traffic accident to road users, especially crossing pedestrians.
- The bus detector system could not monitor the bus location accurately because the bus is always interrupted by other shared-lane vehicles, especially during peak periods.
- There is no compensation for cross street phase when its green time is allocated for providing bus priority phase along main street. It causes increasing delay to cross street traffic.

3. PURPOSES OF STUDY

This study, therefore, aims to propose the concept of enhancing PTPS to address the limitations on the two-lane arterial with nearside bus stops. Objectives of this study are explained as follows:

- To propose the recommended system architecture for PTPS operating along two-lane arterials with nearside bus stops.
- To propose the additional system control logic for bus stop at nearside bus stop cooperating with bus priority control logic for eliminating the lost of green time when the bus stopping to load/unload passengers at nearside bus stop.

4. RECOMMENDATION TO ENHANCE SYSTEM ARCHITECTURE

According to an existing facility of the typical PTPS, there are some recommended facilities that should be provided into existing system to enhance the operation performance along two-lane arterials with nearside bus stops.

- **Area Detector System:** The control system has to monitor the bus traveling with mixed traffics along two-lane arterial, where the bus flow is interrupted by flow of other traffic and waiting queue from stopline. The bus detector system should have an ability to distinguish the bus from other traffic and monitor readily, accurately and continuously the bus location. Therefore, the area detector system (ITS America, 2002), such as GPS, AVL or integration of GPS and AVL should be recommended to apply into this interrupted flow condition.

- **Infrared Beacon at Nearside Bus Stop:** The enhanced control system has to monitor the bus events, e.g. the bus arrival and departure at nearside bus stop. Therefore, the infrared beacon of PTPS should be installed at nearside bus stop where its communication zone covers the bus stop zone as shown in Figure 1.

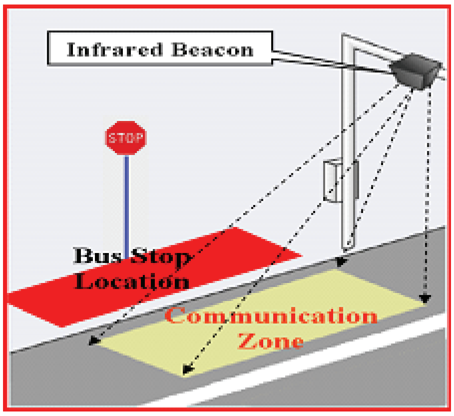

Figure 1. Nearside Bus Stop Installation within Communication Zone

5. ENHANCEMENT OF SYSTEM CONTROL LOGIC

The system control logic of enhanced PTPS has been designed based on the objective that is to minimize the lost of green time along main arterial once bus stop to load/unload passenger at nearside bus stop by switching main street green interval to red interval. Besides, making compensation to the cross street traffic (i.e. the green time is allocated to a cross street phase that was truncated to make up for lost time).

5.1 Development of System Control Logic

The system control logic of enhanced PTPS was developed by adding the new control logic to typical control logic of PTPS as shown in Figure 2. Therefore, the system control logic consists of two main control logics: the additional control logic for nearside bus stop (when bus arrives at bus stop) and the typical control logic for bus priority (when bus arrives at stop line of intersection). The system control logic operates routinely as following steps.

Step 1. The control system routinely updates the location of the traveling buses from the bus detector system.

Step 2. As processing the control logic of the nearside bus stop, the information of bus location is used to estimate the bus arrival time at the nearside bus stop.

Step 3. The control system determines whether the coming bus needs to stop at the nearside bus stop. In case of bus stopping at the nearside bus stop, the control system will continue to process the control logic for nearside bus stop, if not; the control system will pass to the control logic for a bus priority, Step 7.

Step 4. The estimated bus arrival time at the nearside bus stop will be utilized to determine which interval of background timing plan the bus will arrive at the nearside bus stop.

Step 5. If bus will arrive at nearside bus stop during green time interval, the background timing plan will activate the applicable timing plan of Minimizing Lost of Green Time Strategy, if not; it is not necessary to change the background timing plan, in other words, the background timing plan still be continued to service the coming bus.

Step 6. The bus departure time at nearside bus stop (after finishes load/unload passenger) will be monitored by bus detector system (e.g. infrared beacon) or predicted by the dwell time model. The departure time will be used as the phase termination point to terminate the Minimizing Lost of Green Time Strategy.

Step 7. Once the bus is approaching to stop line, the control logic for a bus priority will be processed. The control system will determine whether the coming bus needs a priority. For example, the bus arrival time at the nearside bus stop will be compared with the bus schedule to determine either the bus delay. In case of the bus delay, the control system will continue to process the control logic for a bus priority, if not, it is not necessary to change the background timing plan.

Step 8. The bus arrival time at stop line is estimated by the bus travel time from the nearside bus stop to the stop line of intersection.

Step 9. The control system will determine which interval in background timing plan the bus will arrive at the stop line.

Step 10. If the bus will arrive during green time interval, the background timing plan still be continued to service the coming bus, if not; the signal control strategy for a bus priority will be implemented.

Step 11. To process the bus priority, the control system will determine which in applicable thresholds (e.g. Green Extension Strategy, Phase Insertion Strategy or Early Green Strategy) the bus will arrive at stop line. For example, the bus will arrive during the applicable threshold of Green Extension Strategy, the timing plan of Green Extension Strategy will activated to service the coming bus.

Step 12. After the control system finish to service the current bus, the control system will repeat continually to service the next coming bus as the same sequential steps, from Step 1. to Step 12.

5.2 Signal Control Strategy

In developed system control logic, there are two functional types of signal control strategies, consisting of the signal control strategies for the bus arriving at the nearside bus stop, Minimizing Lost of Green Time and Phase Termination Strategies (proposed additional signal control strategies for nearside bus stops), and the signal control strategies for bus arriving at stop line, Green Extension, Phase Insertion and Early Green Strategies. Their objectives and operation functions are revealed as follows.

- **Minimizing Lost of Green Time Strategy**: This study proposed this additional signal control strategy to avoid the lost of green time, when the bus stops to load/unload passenger at nearside bus stop during green interval of main street. This strategy will eliminate the priority green phase of main street and switch to non-priority green phase for cross street traffic. Besides, making compensation to the cross street traffic (i.e. the green time is allocated to a cross street phase that was truncated to make up for lost time).

- **Phase Termination Strategy:** This additional signal control strategy was proposed to terminate the Minimizing Lost of Green Time Strategy, once the bus finishes to load/unload passengers at nearside bus stop.

- **Green Extension Strategy:** To make the bus pass through intersection without stop when bus approaches the intersections by extending main street green time.

- **Early Green Strategy:** To make a bus passing through intersection without stop when bus approaches the intersections by returning early to main street green phase.

- **Phase Insertion Strategy:** To give the priority to bus by inserting the special phase into the background timing plan. The special phase can only be inserted when a transit vehicle is detected and requests priority for this phase.

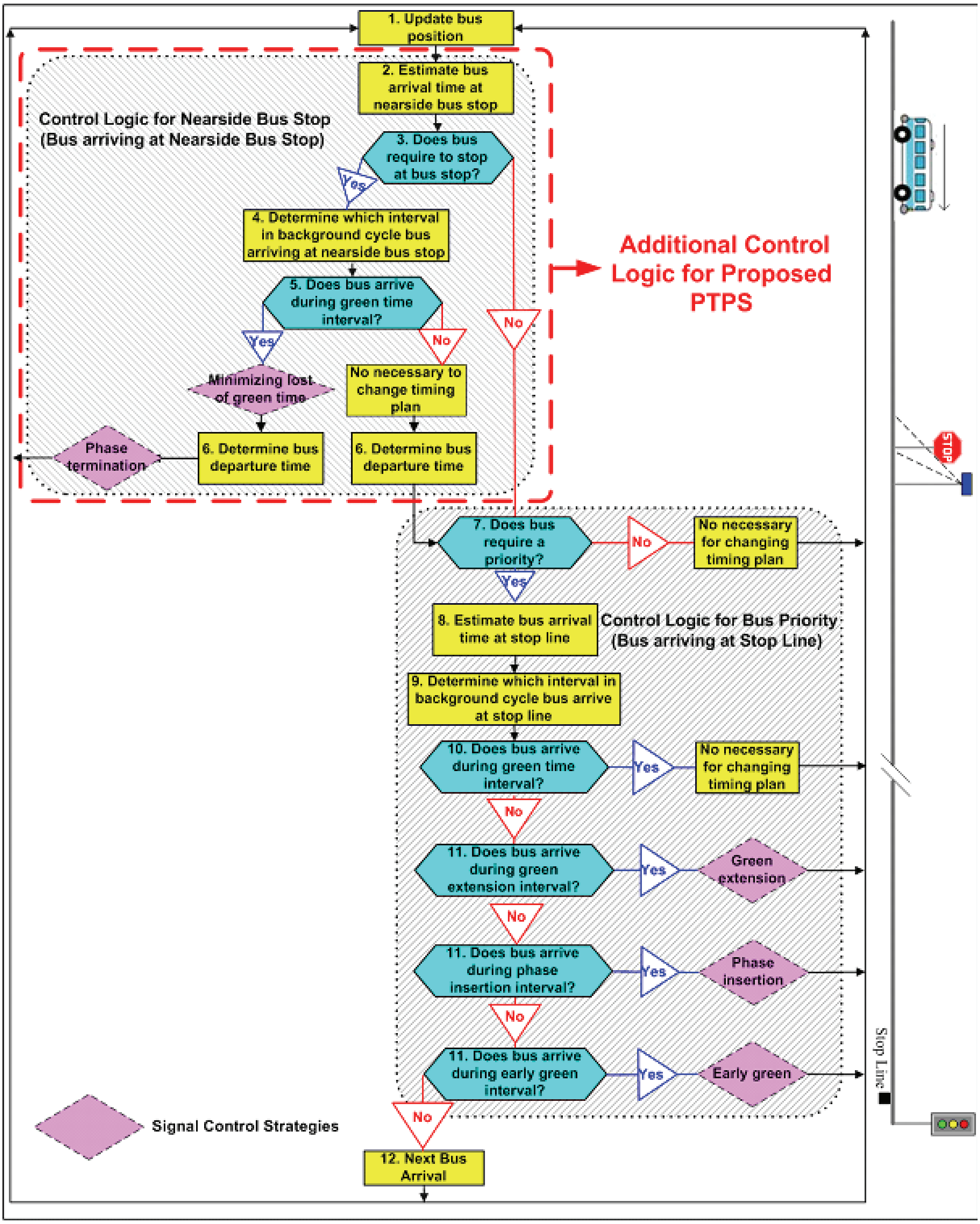

Figure 2. Flow Diagram of System Control Logic for Enhanced PTPS for two-lane arterials with nearside bus stops

6. DEVELOPMENT OF SIGNAL TIMING PLAN

6.1 Development of Background Timing Plan

This study proposed an approach to develop the signal timing plans for being a background timing plans of enhanced PTPS. In other words, as a passive strategy, these developed signal timing plans would be applied to give a priority to bus, giving a bus priority without operating PTPS. The background timing plans were designed based on the coordination control for multiple intersections in order to provide synchronization and emphasize a vehicle platoon along a main arterial.

To develop the background timing plans, the TRANSYT-7F was applied due to its high performance and flexible functions. Although TRANSYT-7F enables to develop signal timing plans based on various signal policies, The Link-Weighted Delay and Stops Policy was selected to develop the signal timing plan according to a recommendation of Manual of TRANSYT-7F (Hale, 2004) and a previous study (Skabardonis, 2000). The objective and objective function of Link-Weighted Delay and Stops Policy are explained as follows.

- **Link-Weighted Delay and Stops Policy:** It develops the signal timing plan to minimize the stops and delays of entire system and simultaneously emphasizing a bus priority along the main arterial by weighting bus links with weighting factors. The objective function is shown in equation 1.

$$DI = \sum_{i=1}^{n} \left(w_{d_i} d_i + K w_{s_i} s_i \right) \tag{1}$$

  Where w_{di} is the delay weighting factor on link (i), d_i is the delay on link (i), K is the stop penalty factor, S_i is the stops on link (i), w_{si} is the stops weighting factors on link (i) and n is the number of link.

For this study, the bus link that services to a higher number of bus passengers would be given a higher priority through the specific weighting factor. The weighting factor of each link would be determined from the average number of daily bus passengers along that link.

6.2 Development of Thresholds of Signal Timing Plan

After the background timing plan would be developed, this study decided to develop the thresholds in the applicable timing plans of signal control strategies. They could produce the applicable timing plans that kept the phase durations as close as possible to their background timing plan. The thresholds were developed to insure that the following criteria are satisfied:

- Providing the signal control strategies with minimizing the disruption of signal coordination through maintaining the constant cycle length and without skipping a phase in the background timing plan.
- Maintaining minimum and maximum green time of background timing plan.
- Each phase, if activated, must provide at least its minimum green phase plus its clearance interval.

Figure 3 shows the established thresholds, while Table 2 summarizes the formulas applied to compute each threshold. After established, the thresholds were also used to determine which signal control strategy should be used to service an arriving bus.

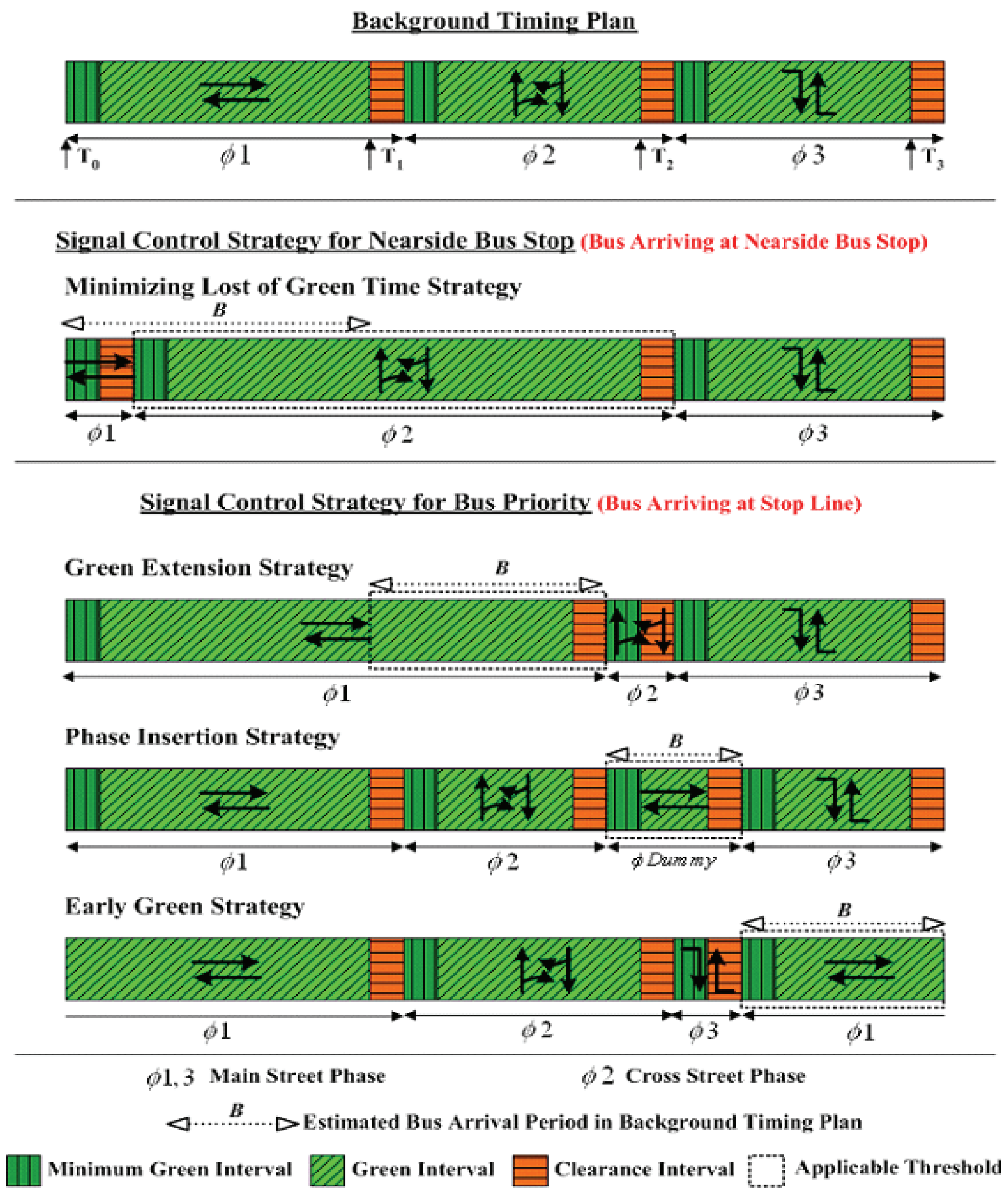

Figure 3. Period in Background Timing Plan where Arriving Bus Being Served by Different Signal Control Strategy

Table 2. Computation of Threshold for Signal Control Strategy

Signal Control Strategy	Lower Threshold	Upper Threshold
1. Minimizing Lost of Green Time	$(MIN + CI)_1$	$T_2 + CI_2$
2. Green Extension	T_1	$T_2 – MIN_2 – CI_1$
3. Phase Insertion	$T_2 – MIN_2 – CI_1$	$T_2 + CI_2 + (MIN + CI)_3$
4. Early Green	$T_2 + CI_2 + (MIN + CI)_3$	C

Where,

T_0 = The start time of background timing plan

$T_{1,3}$ and T_2 = The time in timing plan where main street phase(1, 3) and cross street phase (2) are force-off by the coordinator (sec)

$CI_{1,3}$ and CI_2 = Clearance interval (yellow interval + all red interval) of main street phase (1, 3) and cross street phase (2)

$MIN_{1,3}$ and MIN_2 = The minimum green interval of main street phase (1, 3) and cross street phase (2) (sec)

C = The Cycle Length (sec)

For the activation of signal control strategy for the nearside bus stop, if the bus would be expected to arrive at nearside bus stop during main street green phase of background timing plan, the signal control system would activate the Minimizing Lost of Green Time Strategy to eliminate the lost of green time due to the stopping bus at nearside bus stop, if not, the bus will be serviced by the background timing plan.

For the activation of signal control strategy for the bus priority, the predicted bus arrival time at bus stop would be compared to the threshold values to activate the appropriate signal control strategy for bus priority. If the bus would be expected to arrive during main street green phase before the Green Extension threshold, the bus would be serviced by the background timing plan. If the bus was predicted to arrive during the applicable Green Extension threshold, the signal control system would extend main street green phase for the coming bus. If the bus was predicted to arrive after the upper applicable threshold of Green Extension Strategy but before the lower applicable threshold of Early Green Strategy, the control system would apply the Phase Insertion Strategy by inserting dummy phase for bus priority. However, if the bus was predicted to arrive during Early Green threshold, the signal control system would return early to main street green phase when the bus arrives at the stop line.

7. SYSTEM EVALUATION

The enhanced PTPS would be compared with the typical PTPS in order to evaluate its operation performance. The control operations of both systems would be simulated on PARAMICS. Since the objective of proposed system is to reduce the lost of green time due to bus stop at nearside bus stop during green interval, which leads to an increased an average delay for vehicles at the intersection, the average delay was selected as the comparative measure of effectiveness of both systems.

7.1 Experimental Arterial

To simulate the operation performance of enhanced and typical system, both systems would operate a bus priority on the experimental arterial. The selected arterial was a road section of the Route 296, a two-lane signalized arterial with 17 nearside bus stops in Chiba Prefecture as shown in Figure 4. The bus routes with 30 veh/hr bus volume serviced through a selected arterial. The information of traffic flow and bus service operation used to simulation was collected in the morning peak period, from 7 AM to 9 AM. The saturation flow rate was 0.6 during this study period.

7.2 Systems Simulation

At first, the background timing plan of both systems would be developed by the proposed method, developed based on Link-Weighted Delay and Stops Policy in TRANSYT-7F. Then, the enhanced and typical systems would be simulated by PARAMICS due to its availability of high performance function, known as API. The PARAMICS API was applied to simulate the complicate functions of system control logic. The bus headway, dwelling time and bus delay would be simulated based on the historical data. The collected mean head way and reaction time would be applied to calibrate the developed models. For validation of simulation models, the degree of saturation at intersections would be compared with the degree of saturations at site. After achieving the reliable simulation models, since PARAMICS is a microscopic stochastic simulation model, at least 100 simulation runs with different seed values would be conducted as follow a recommendation of QUADSTONE (2003). The operation results of simulations would be started to record after warm-up time, 5 minutes. The average delay of bus, cross street traffic, main street traffic as well as entire system obtained from simulation were used to compare the operation performance of both systems.

7.3 Statistical Analysis of Results

The statistical analysis was utilized to compare the average delays of enhanced PTPS with typical PTPS. The distribution of average delays outputted from running simulations would be plotted. The Kolmogorov-Smirnov Test with 95% level of confidence would be used to test the distribution of average delays through SPSS program. In case that distribution of average delays is not follow the normal distribution, the simulations with different seed values still were continued in order to obtain more samples. After obtained enough samples with normal distribution, the comparison between average delays of bus and other traffics of enhanced and typical systems was conducted by Independent-Sample T-Test with 95% level of confidence.

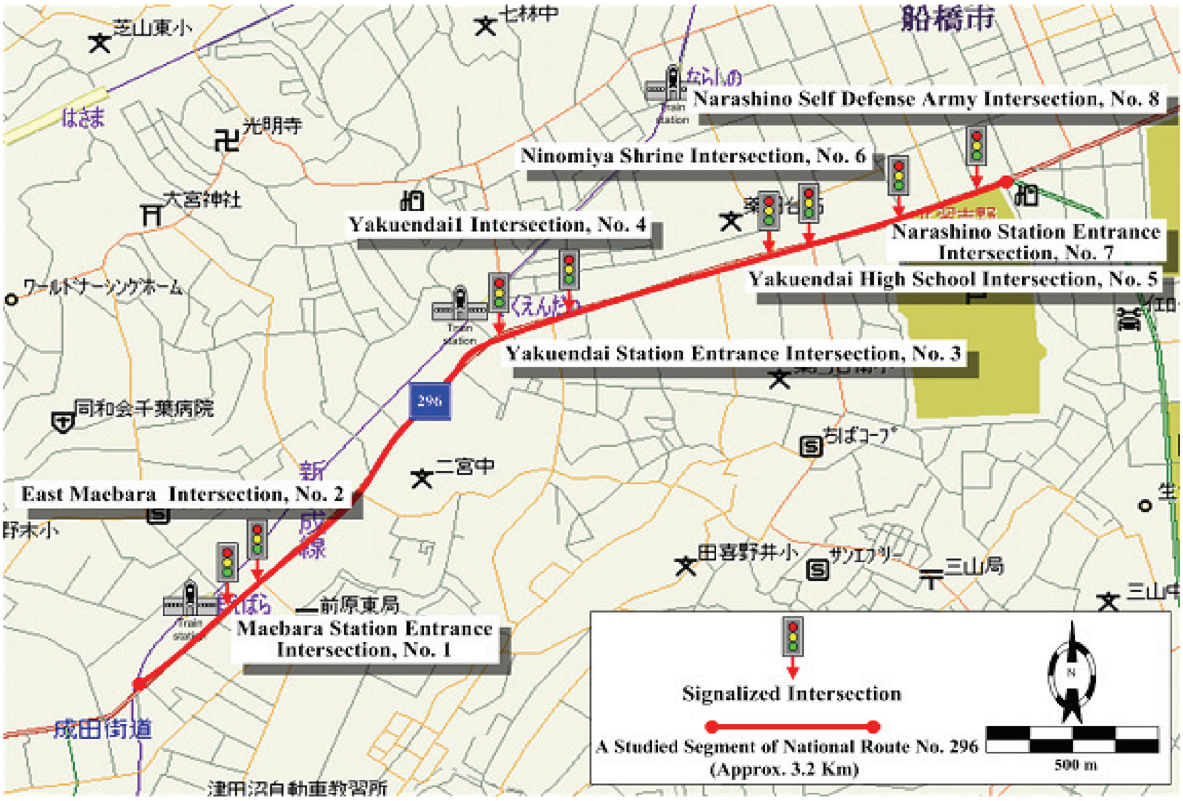

Figure 4. Experimental Section of Route 296

8. RESULTS AND DISCUSSIONS

The results from the simulation of enhanced and typical systems, delays of bus and entire system were plotted comparatively as the cumulative graphs as illustrated in Figure 5 and 6. In addition, the results of statistical analysis are illustrated in Table 3.

As results in term of bus delay, the cumulative average bus delay of the enhanced system was less than the typical system at the end of simulation time as shown in Figure 5. In addition, the comparative results in Table 3 reveal that the enhanced system could successfully decrease a bus delay with 10% significant decreasing from the typical system. This improvement resulted from the proposed additional control logic of nearside bus stop, including the Minimizing Lost of Green Time Strategy and the Phase Termination Strategy, eliminating lost of green time of bus when bus stopping at nearside bus stop.

For delay of other traffics, the cumulative average system delay of the enhanced system also was less than typical system at the end of simulation time as illustrated in Figure 6. In addition, the comparative results in Table 3 that the enhanced system could also successfully decrease the delays of other traffics with 10%, 5%, 9% significant decreasing average delay of cross street traffic, main street traffic and entire system from the typical system, respectively. These exceptional improvements could be explained that the cross street traffic was less delayed from implementing the Minimizing Lost of Green Time Strategy, which switched from the main street green interval to red interval, simultaneously provided the green interval for cross street traffic. For the main street traffic, its delay was decreased from implementing The Minimizing Lost of Green Time Strategy as well through reducing the event, which following vehicles were waiting for the stopping bus at the nearside bus stops during green interval.

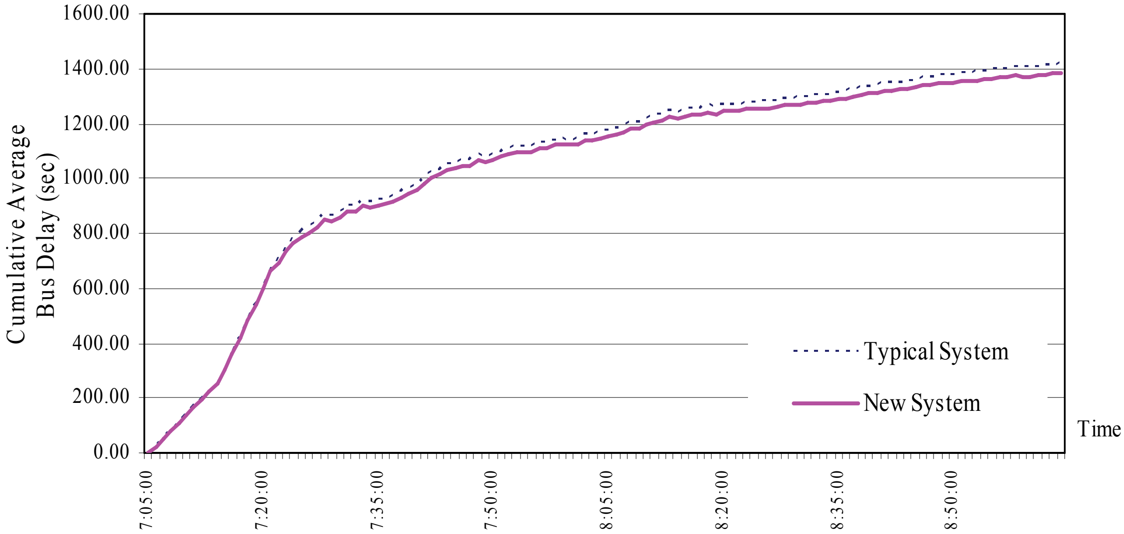

Figure 5. Cumulative Average Bus Delays

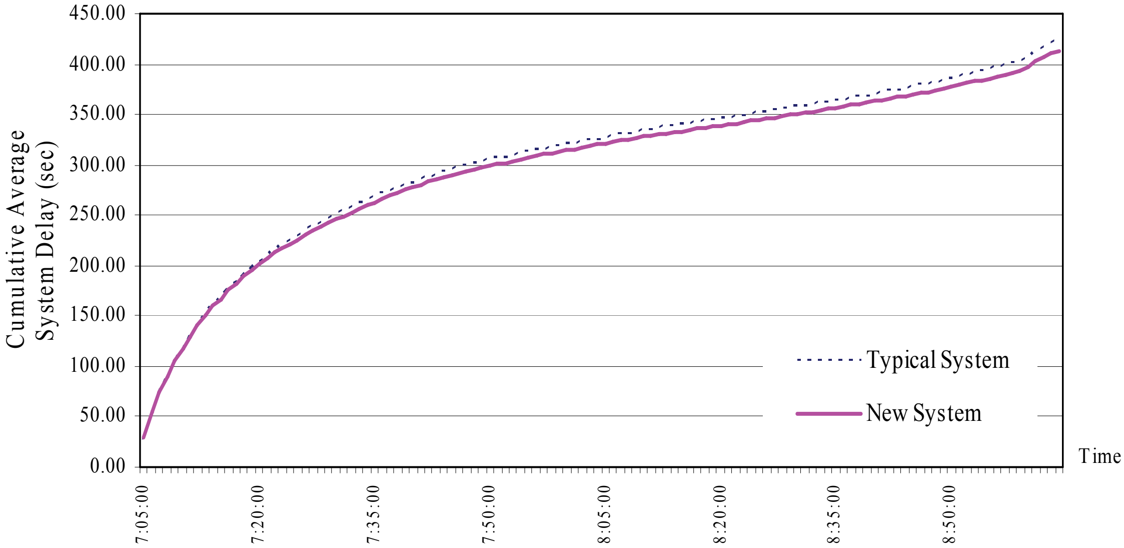

Figure 6. Cumulative Average System Delays

Table 3. Summarization of Results of Comparison between Typical and Enhanced Systems

Movement	Average Delay, sec/veh		Difference, sec/veh (%)	Results of T-Test
	Typical PTPS	Enhanced PTPS		
Bus	20	18	-2 (10%)	Significance
Cross Street Traffic	86	77	-9 (10%)	Significance
Main Street Traffic	21	20	-1 (5%)	Significance
System	43	39	-4 (9%)	Significance

9. CONCLUSIONS AND RECOMMENDATIONS

This paper proposed the concept of enhancement of PTPS to operate along two-lane arterials with nearside bus stops. The proposed system consists of 1) the recommended system architecture, to provide higher performance to monitor bus location and 2) the additional control logic for nearside bus stop (including the Minimizing Lost of Green Time Strategy and the Phase Termination Strategy), to eliminate the lost of green time when bus stopping at nearside bus stops. The enhanced system was compared with typical system in order to evaluate its performance. Both systems were simulated to operate a bus service through PARAMICS. The results of comparative analysis reveal that the enhanced system performed successfully under existing traffic condition with significant decreasing delays of bus and entire system traffic, especially cross street traffic.

The further studies should consider into following issues; the evaluation of proposed PTPS in more various conditions and a feasibility study on integration of the proposed PTPS with actual real-time traffic control system such as MODERATO (Sakakibara et al., 1999) to operate along two-lane arterials with nearside bus stops.

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