INTRODUCTION OF SIGNAL CONTROL STRATEGY FOR NEARSIDE BUS STOP TO IMPROVE BUS OPERATION ALONG TWO-LANE ARTERIAL*

by Thaned SATIENNAM**, Atsushi FUKUDA*** and Toshiaki MUROI****

1. Introduction

The Bus routes in Japan operate not only along multiple-lane arterials but also along two-lane arterials. According to the Census of Japan Traffic and Highway data in year 1999[1], there are 529 roads that have a bus volume over 100 vehicles per a day in the Tokyo Metropolitan Area. There are only 54 and 46 roads among of them where the bus priority lane and exclusive lane are available, respectively. Approximately, a half of them are two-lane arterials.

To improve the level of service of bus operating in cities of Japan, the PTPS, well-known system integrating of physical improvement, e.g. an exclusive lane with advanced traffic control system, e.g. bus vehicle detector and signal priority system, to give the priority to the bus route. It has achieved considerably and mostly to the improvement of the bus operation[2]. However, when it considers improving bus operation along two-lane, there are somewhat limited to operate the full stage of PTPS since it is unable to establish the exclusive lane for bus and rather impossible to coordinate signal control system among signalized intersections along bus route. Therefore, PTPS seems to be a little satisfactory when it serves the bus operating along two-lane arterial with high traffic congestion during peak periods[3]. Such this circumstance causes that the system could not estimate accurately the bus arrival to the intersection since the bus always is interrupted with other shared-lane vehicles, and less accuracy, in case of bus stop locating approach to the intersection, i.e. nearside bus stop. Consequently, bus route operating along two-lane arterials still not be enough attractive to the private car users since it normally spend time to travel along same paths longer than passenger car.

The authors attempt to increase a level of service of bus operation along two-lane arterials by focusing on such an applicable implementing approach rather than the physical improvement which is limited to implement with two-lane arterial. The authors have therefore found an obvious problem that should be improved. There is a lost of green time when bus stopping to load/unload passengers at nearside bus stop during green time interval, i.e. the following vehicles are not able to pass through this stopping bus due to the no passing zone near to the intersection. Consequently, the system loses the capacity of intersection as shown in Figure 1.Therefore, the authors aim to propose the conceptual strategy to control the signal coordinating with bus stopping at nearside bus stop in order to alleviate the lost of green time for bus operating along two-lane arterials with nearside bus stops. Moreover, the authors consider to decide the proposed signal control strategy being effectively even through bus operates among high traffic congestion.

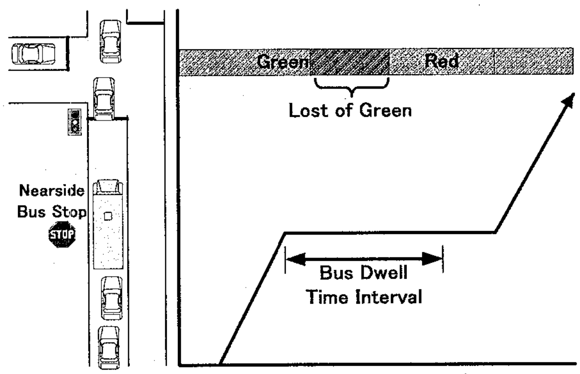

Figure 1. Illustration of Lost of Green Time during Bus Stopping at Near Side Bus Stop

*Keywords: Signal Control Strategy, Nearside Bus Stop and Two-lane Arterial
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The content of this paper consists that the first part introduces the background and lists the existing problem. The second part reviews the previous studies concerning to the signal control strategies for two-lane arterial with nearside bus stop. The third part explains the scope and concept of the proposed signal control strategy. The forth part proposes the control algorithm for application of the proposed strategy with the general signal control system. The fifth and sixth parts illustrate the evaluation process and sensitivity analysis. The seventh part presents the result and discussion. And, the final part presents the conclusion and recommendation.

2. Previous Studies on Signal Control Strategies for Two-lane Arterial with Nearside Bus Stop

There are several previous studies proposed the signal control strategies for multiple lane arterials with exclusive bus lane and nearside bus stop. Each of them proposed its own strategies for achieving in different purpose. Such that Kim and Rilett[4] attempted to reduce the uncertainty in bus dwell time by proposing their strategy to estimating more accurately bus stop dwell time, Hsu et al.[5] developed their approaches to address bus delay along bus lane at multiple lane intersection. However, as this study, the authors have found out the distinctive problem of signal control system along two lane arterial with nearside bus stop (i.e. a lost of green time when bus stopping to load/unload passengers during green time interval) that could be improved and has proposed their own idea to lessen this lost of green time. The authors have former proposed many signal control strategies dealing with this problem[6], however, some of them are not likely to be applicable due to the limitation of existing vehicle detecting system (low accuracy to detect the bus moving along shared lane). The authors have later reconsidered and proposed the signal control strategy that would be more applicable under capability of existing detector system since it detects the bus once bus stopping at nearside bus stop, i.e. no interrupt from other lane shared vehicles. The authors have already proved its effectiveness through modeling on a prototype intersection[7), 8)]. At this time, this study has further attempted to prove its operation performance on the real bus operation route.

3. Scope and Concept of Signal Control Strategy for Nearside Bus Stop

The scope of the study on this time focuses on the proposal of the signal control strategy for nearside bus stop that serves the bus operation along two-lane arterial with 2 phase signalized intersections connected by minor two-lane roads. This proposed strategy has been decided in order to improve the bus route along a particular direction, such as an improvement of the level of service of bus route along inbound direction during morning peak period and outbound direction during evening peak period.

The concept of this signal control strategy attempts to reduce the lost of green time of main road, i.e. ineffective green time while bus stopping to load/unload passenger at nearside bus stop, by shortening that ineffective green time of main road phase, in other words, starting early green interval of cross road phase. The main road phase that its green time has been shortened will be compensated the green time by extending the green interval of the main road on the next cycle in order to balance the Green Ratio. The concept of proposed signal control strategy is shown comparatively with normal strategy as Figure 2. Interestingly, one outstanding advantage of this proposed strategy is its algorithm determining to change the signal timing plan after the bus stops, therefore, its algorithm is not be influenced by surrounding traffic congestion.

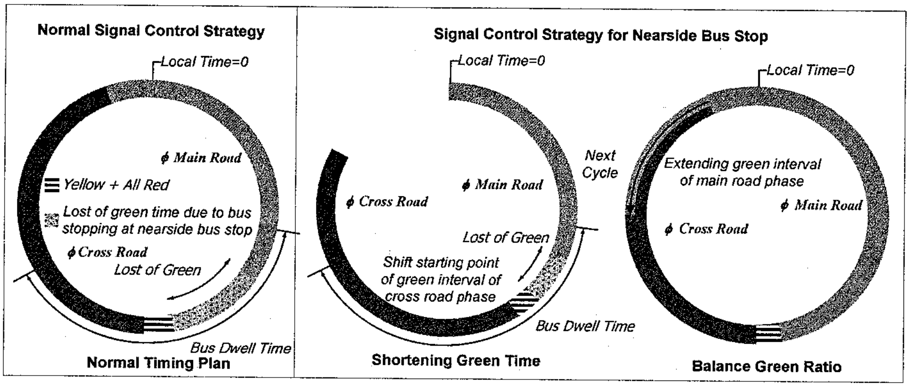

Figure 2. Concept of Signal Control Strategy for Nearside Bus Stop

The advantage of application of the proposed strategy could be proved by comparison its delay with that of normal signal control strategy. The delay resulted from proposed and normal strategies would be expressed through the cumulative vehicle - time chart that includes two curves of arriving and departing vehicles. It depicts the delay into 3 graphs according to traffic flow of each direction, e.g. a flow on the direction improved by proposed strategy, a flow on opposite direction and a flow of cross road direction as illustrated in Figure 3A. For the purposes of illustration of this research, the rate of arrivals is assumed to be uniform in each direction. However, since this strategy planned to improve the bus route on the direction of main road that there is the most congested traffic, therefore, it is assumed that the overflow exists on the improving direction of main road in every signal cycle, and there is no overflow on other directions.

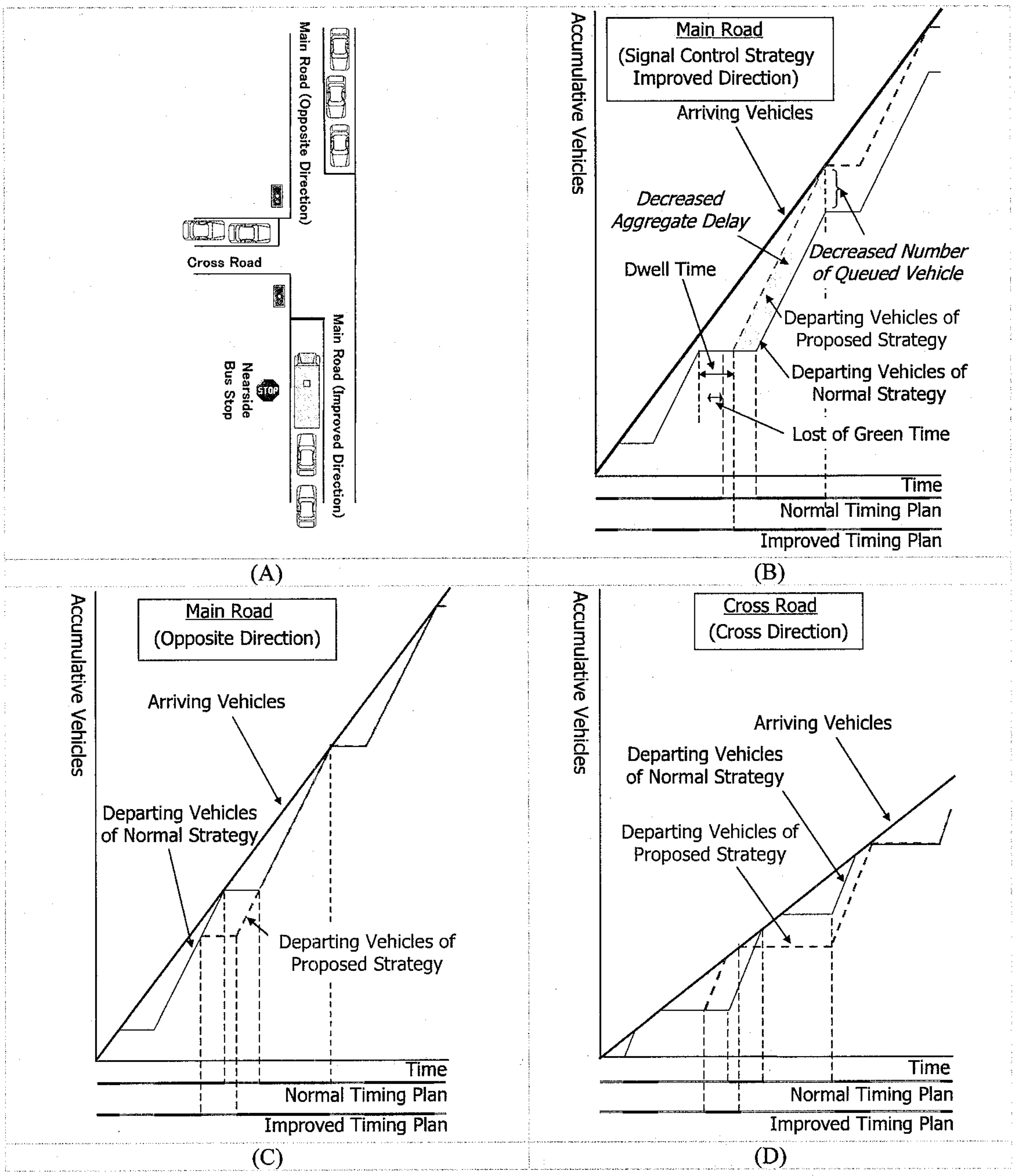

Figure 3: Cumulative Vehicle - Time according to each Flow Direction

According to the delay of improved direction of main road as shown in Figure 3B, once the dwell time of bus is on green interval of main road phase, the system will lost of green time; the proposed signal strategy will shorten the ineffective green time. It results that the vehicles on this direction, i.e. bus and following vehicles, are not waited for red interval. After bus finishing to stop, they are discharged ahead when compared with normal strategy. Consequently, at the end of implemented cycle, the system could decrease obviously the aggregate delay as area between the arrival and departure curves, or the total number of queued vehicles as vertical vehicle scale difference between the arrival and departure curves.

Beside, the delay of opposite direction, as illustrated in Figure 3C, the influence from the shortening of green interval of main road causes that end part of vehicle patrol is forced to be waited. It results that the aggregate delay increases a bit; however, after the compensation of green time on the next cycle, the waiting queue is finally released being equal to that of normal strategy.

Regarding to delay of the cross road direction as presented in Figure 3D, the vehicles are released earlier than that of normal strategy because of shortening of red interval of cross road. It results that the aggregate delay initially decreases when compared with normal strategy, however, the compensation of green time to main road causes later the aggregate delay increases.

4. System Architecture and Control Algorithm for Application of Signal Control Strategy for Nearside Bus Stop

Since the objective of this study is to propose the concept of signal control, rather than to decide the specific control system, this study therefore describes the general concept for the control system applicable with proposed signal control strategy. The proposed signal control strategy could be introduced by applying with general facilities of signal control system. The requirement is the control system could detect the bus arrival at nearside bus stop and also receive the signal from the bus which specifies whether bus will load/upload passenger. The Infrared Beacon[9] is one applicable system that has a two-way interactive communication function which could detect the bus arrival at nearside bus stop through down-link infrared ray and receive the signal from bus through up-link infrared ray. The Infrared Beacon would be installed overhead at the nearside bus stop where its workable zone covering the bus stop zone. For system determining whether passenger will get on/get off, it may determine from either automatically the opening of the door or bus driver push the bottom. The control algorithm of proposed strategy is illustrated as Figure 4.

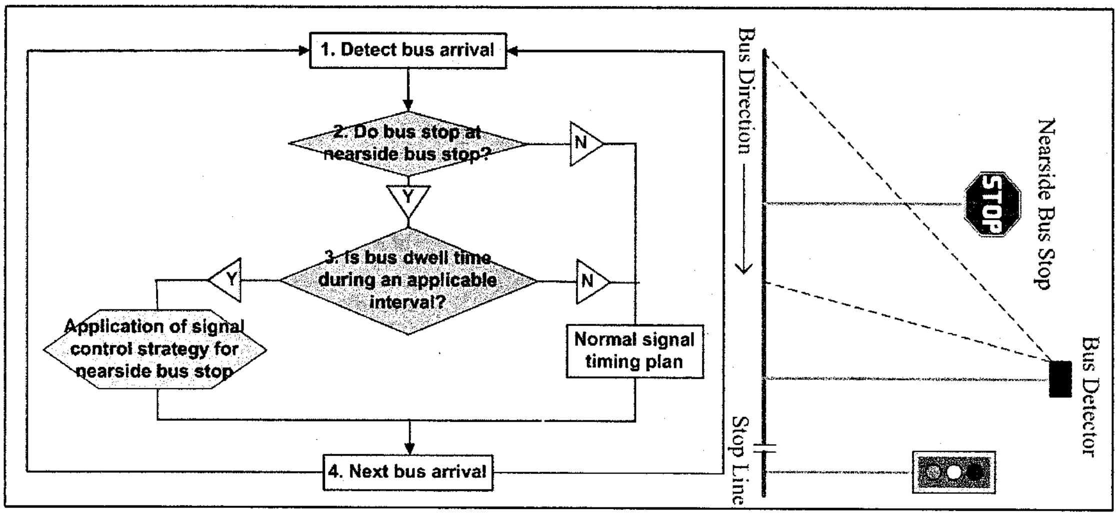

Figure 4: Control Algorithm for Applying Signal Control Strategy for Nearside Bus Stop with General Signal Control System

The system operates routinely as following steps.

1. The Infrared Beacon installed at nearside bus stops detects routinely the bus arrival.
2. Once the system could detect bus arrival to nearside bus stop through the Infrared Beacon, it further determines whether bus requires stopping to load/upload the passenger through signal sent from bus. If bus stopping for load/upload the passenger, the system will continue the next step for application

of signal control strategy for nearside bus stop, if not, the system will continue to apply the normal signal timing plan to serve the bus.

3. While bus stopping at nearside bus stop, the system will determine whether bus dwell time interval is during applicable interval (i.e. a particular part of green interval of main road phase, alternatively, a part of ineffective green time, see Figure 2 for illustration of applicable interval). If yes, the system will activate the proposed strategy to reduce ineffective green time. If no, the system will continue to apply the normal signal timing plan to serve the bus.
4. After the system finish to service the current bus, it will repeat continually to service the next arriving bus as the same sequential steps, from Step 1. to Step 4.

It is noticed that this control algorithm determines to apply the appropriate signal control strategy while bus stopping at nearside bus stop when monitoring of bus event is not disturbed by other shared lane vehicles, therefore, it could determine accurately to change signal timing plan for serving the bus even operating under high congestion.

5. Evaluation of Signal Control Strategy for Nearside Bus Stop

The proposed signal control strategy would be compared with the normal signal control strategy, i.e. normal signal timing plan, in order to evaluate its operation performance. The road section of the Route 296 in Chiba Prefecture has been selected as the experimental arterial as shown in Figure 5 since it needs the improvement because it encounters the severe traffic congestion, especially inbound direction during morning peak period. Along this two-lane arterial, there are almost 3-leg signalized intersections connected by minor roads and there are the bus routes with nearside bus stops operating along both directions.

The proposed signal control strategy for nearside bus stop would be applied to the bus route along inbound direction with higher traffic congestion to improve its operation performance. The existing signal timing plan of this arterial is applied as the representative of normal signal control strategy. The existing and improved signal control conditions would be simulated with PARAMICS. 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 collected mean head way, reaction time and degree of saturation at intersections would be applied to calibrate and validate the developed models. The average travel time passing through this arterial section of bus and other vehicles along improved direction, opposite direction, cross road as well as entire system obtained from simulation were used to compare the operation performance of both conditions. The characteristics of experimental road section are summarized as Table 1.

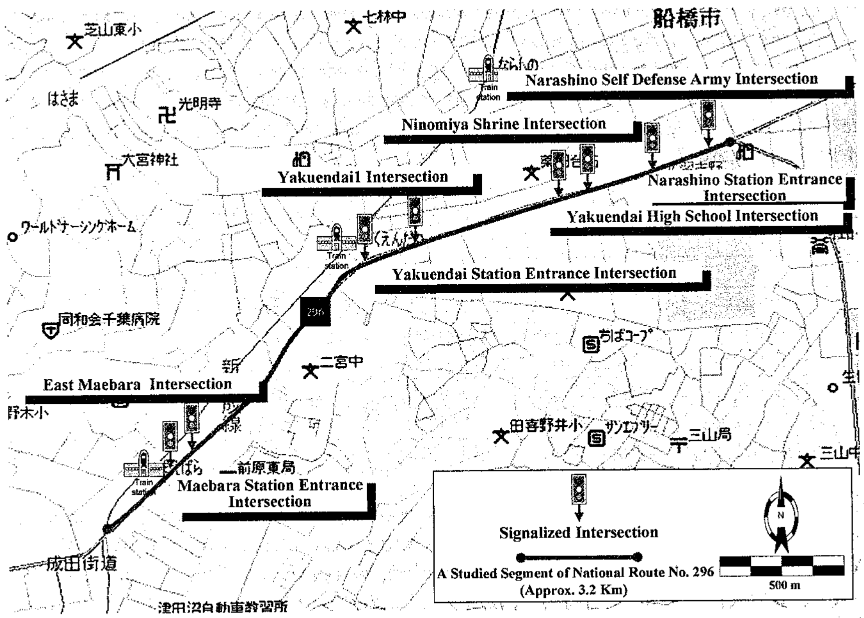

Figure 5: Experimental Section of Route 296

Table 1: Characteristics of Experimental Road Section

Characteristic Items	Amount
Number of Signalized Intersections	11
Average Traffic of Main Road (veh/hr)	950
Average Traffic of Cross Road (veh/hr)	300
Average Signal Cycle Length (sec)	120
Average Green Interval of Main Road (sec)	84
Average Green Interval of Cross Road (sec)	25
Number of Nearside Bus Stops	10
Average Distance from Stop line to Nearside Bus Stop (m)	30
Average Bus Service (veh/hr)	12
Average Bus Dwell Time (sec)	30
Saturation Flow Rate of Entire Road Section	0.8

6. Sensitivity Analysis

It has been expected that it would be many traffic characteristics influencing to the performance of proposed signal control strategy. However, for this time, this study focuses on the most influencing expected factor that is the traffic volume. The sensitivity analysis under various traffic volumes would be conducted. The existing traffic volume of experimental road section, 0.8 saturation flow (100%), would be used as mean values. The Table 2 presents the summarization of the scenario for sensitivity analysis. It would be noted that the sensitivity analysis upon other expected influencing factors, probably, e.g. number of bus service, distance from stop line to nearside bus stop and etc., would be the issue for further study.

Table 2: Scenarios of Sensitivity Analysis

Traffic Parameters	Analysis Scenarios
Traffic Volume (%)	90, 100 (mean) and 110

7. Result and Discussion

The results from the simulation are summarized as the reduction of average travel time after implementation of proposed strategy. The reduction in average travel time, in seconds and percentage, on various traffic volumes have been classified according to bus and other vehicles on each direction as shown in Table 3. In addition, the curves of percentage of reduction in average travel time in according to each mode and direction are plotted comparatively on the percentage of reduced average travel time - dwell time graph as illustrated in Figure 6.

Table 3: Summarization of Reduction in Average Travel Time

Traffic Volume (%)	Reduction in Average Travel Time, sec (%)					
	Bus on Improved Direction	Other Traffic on Improved Direction	Bus on Opposite Direction	Other Traffic on Opposite Direction	Cross Road Traffic	Entire System Traffic
90	-104 (-8%)	-30 (-24%)	18 (3%)	3 (8%)	-3 (-3%)	-1 (-14%)
100	-147 (-11%)	-23 (-20%)	3 (1%)	2 (5%)	-10 (-11%)	-7 (-9%)
110	-678 (-47%)	-29 (-30%)	11 (2%)	2 (7%)	3 (3%)	5 (10%)

As considering the results operation performance as shown in Table 3, under an existing traffic volume (100% of traffic volume), the average travel time of bus and other traffic along improved direction is reduced significantly with 11% and 20% from existing condition, respectively. This results causes from that the improved condition shortens the ineffective green time of main road phase when bus stopping at nearside bus stop, consequently, the bus and following vehicles are able to go earlier. Its approval could be seen in the former Cumulative Vehicles-Time Chart, Figure 3B. And, the average travel time of bus and other traffic along opposite direction is increased insignificantly with 1% and 5% from the existing condition. This insignificant impact to opposite traffic causes from that the green time of main road is shorten by implementation of proposed strategy, it causes that end part of vehicle patrol is forced to be waited, however, after the compensation of green time on the next cycle, the waiting queue is finally released soon, its approval shown as the former Figure 3C. For the cross road traffic, its travel time is reduced significantly with 11% from existing condition. It is resulted from when the proposed strategy is shortening green time of main road, simultaneously; the red time of cross road is being shortened. The waiting vehicle therefore could go earlier, its approval revealed as in the former Figure 3D. In totally, the average travel time of entire traffic of improved condition is deceased significantly with 9% from existing condition.

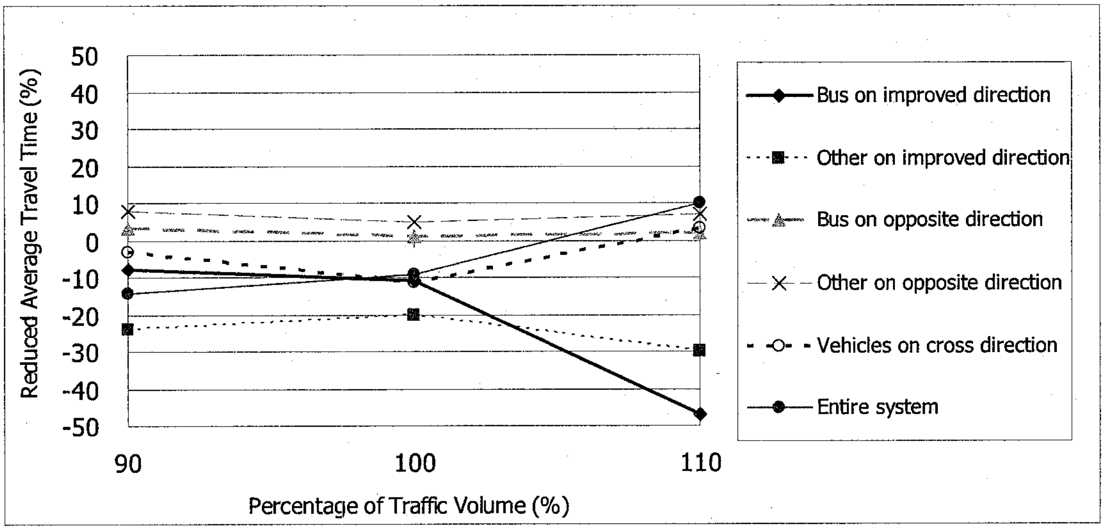

Figure 6: Percentage of Reduced Average Travel Time under Different Traffic Volume

As considering the tendency of results operating under various traffic volumes as shown in Figure 6, it reveals that when traffic volume is increasing, the trend of reduction in average travel time of bus and other vehicles along improved direction is decreasing continuously with significant percentage when compared with existing condition. It means that the proposed strategy could improve more operation performance of bus while bus is operating under more congestion. This result causes from that the proposed strategy monitors the bus while bus stopping at nearside bus stop when the detector does not be interrupted by other shared lane vehicles, therefore, it can activate the signal timing plan correctly. And, while traffic volume is increasing, the trend of reduction in average travel time of bus and other vehicles along opposite direction is not being changed. However, the trend of reduction in average travel time of cross direction vehicles is increasing; it means that the proposed strategy has less efficiency to improve performance of vehicles on cross direction while traffic volume is increasing.

8. Conclusion and Recommendation

This paper proposed the signal control strategy for bus operating along two-lane arterial with nearside bus stop. Its objective is an attempt to improve level of service of bus route. The proposed concept is reduction of lost of green time when bus stopping at nearside bus stop by shorting the ineffective green time and extend the green time back on the next cycle in order to balance green ratio. To evaluate its performance, the proposed signal control strategy was compared with the normal signal control strategy by simulating them along existing arterial. The results of comparative analysis reveal that operation under existing high traffic congestion, the proposed strategy could improve significantly the operation performance of bus and other vehicles along improved direction of main road. It could also improve the performance of traffic along the cross road. And, it does not effect significantly to traffic performance on the opposite direction. Moreover, it could be noticed this proposed strategy could improve the operation performance of bus and other vehicle along implemented direction even operation under higher congested condition. However, it would impact to the traffic on other directions, especially cross road direction.

For the further study, it should conduct more sensitivity analysis upon other expected factors influencing to the performance of proposed strategy. Moreover, it should research on the strategy enabling to deal with more complicated conditions, such as two-lane arterials with large 4 leg intersections and high pedestrian crossing volume as well as two-lane arterial with a group of close intersections.

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This paper proposed the signal control strategy for bus operating along two-lane arterial with nearside bus stop. The proposed concept is a reduction of lost of green time when bus stopping at nearside bus stop by shorting the ineffective green time and extend the green time back on the next cycle in order to balance green ratio. To evaluate its performance, the proposed signal control strategy was compared with the normal signal control strategy through simulation. The results reveal that proposed strategy could improve significantly the bus operation performance and other traffic under existing high traffic congestion.
