STUDY ON BUS-PREEMPTION UNDER ADAPTIVE SIGNAL CONTROL ENVIRONMENTS FOR AN ISOLATED INTERSECTION

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Abstract: This study developed integrating bus-preemption with adaptive signal control system that uses of the information from traffic beacons. The primary objective of this research was to develop an optimal control system that can compute best signal settings in real time for an isolated intersection by improving the existing adaptive signal control. The dynamic programming (DP) is used to compute controls at the intersection. However, this method is no practical use, because it takes a lot of time to compute signal setting. A heuristic algorithm that searches gaps of platoons and selects the best signal setting among them was developed for the speed-up. We got the results that the difference between heuristic solution and optimal solution is less than 1%. The calculating time for the heuristic programming approach was less than that of dynamic programming approach by 36-95%. Heuristic method extended for two intersections with bus-preemption. This method could not minimize only vehicle delay, but also passenger delay by changing the parameter.

Key Words: Adaptive Signal Control, Bus-Preemption, ITS

1. INTRODUCTION

With the development of the recent Intelligent Transport Systems, the communication technology that exchanges information between vehicles and road is spreading. Advanced signal control can be developed by using the information of an individual vehicle such as vehicle size, velocity, or destination. Next-generation control logic to utilize this kind of information is a very promising subject in the field of ITS. Then, this study developed a real-time bus priority signal control technique by using the sensing technology.

Over the past several decades, several studies related to bus preemption strategies have been conducted. Many of bus priority signal control techniques for an isolated intersection are methods based on extension of the green time and shortening of the red time. For example, Chang (1996) used a hill climbing method that extended or shortened the green time by a unit time. Shimomura (1977) and Khasnabis (1996) proposed similar techniques that extended or shortened the green time that had been decided in advance. Alexander (1998) showed the way to get the local optimum solution with TRANSYT. However, these methods can't guarantee the optimality for obtaining extended or shortened time.

This study applyies the dynamic programming (DP) approach to bus priority signal control. Dealing with signal timing discretely and searching the best signal phase combination to minimize the total delay at an intersection. Type of a car, four-leg intersection, left and right turn, and pedestrians are considered

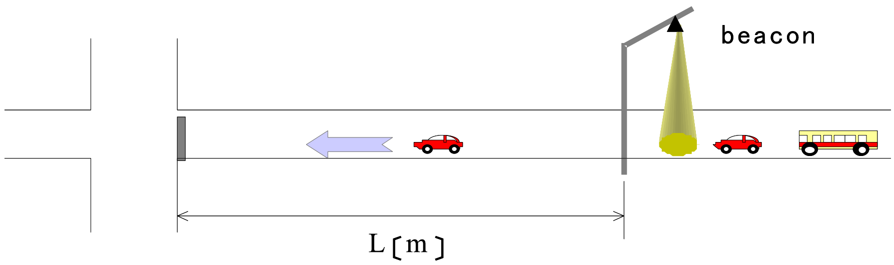

Fig. 1 Method of predicting arrival time

in the study. It guarantees the optimality of the solution, but long calculation time is disadvantageous. Then, the heuristic programming approach is developed. Though the optimality is inferior, this method shortens the calculation time. By introducing the bus priority signal control into this heuristic programming approach, the shortening effect of bus delay time is measured.

2. METHODOLOGY

2.1 Traffic simulation model

When the signal control is discussed, a traffic simulation model that describes vehicles movement is necessary and a simple microscopic traffic simulation has been developed. Time-space diagram and cumulative curve are used in order to calculate the delay of each vehicle as in Fig.2. The delay is defined as the difference between departure time and virtual arrival time that is calculated when physical extent of the queue had been eliminated.

Each vehicle starts at a given velocity under the traffic beacon located in the upstream of an intersection, and their departure intervals follow the Poisson distribution that depends on traffic volume per hour. The velocity differs by car type, and then platoons whose fronts are trucks and buses are formed at the intersection while they run from the beacon to the stop line. This simulation model predicts an arrival time at the stop line one by one from the head vehicle. Arrival time is easily to be obtained by dividing the distance L[m] by the velocity if the vehicle does not follow the leading vehicle. Minimum time headway is supposed to be two seconds. When calculated time headway is less than two seconds, two seconds is substituted for it. Departure time of the vehicle that had stopped at the intersection is determined considering the departure loss and the order of the car. As we deal with unsaturated traffic flow that does not cause blocking, vertical queue is used for waiting vehicles at an intersection.

2.2 The signal control technique by the DP

DP is a mathematical technique used for the optimization of multistage decision process. In the process, the decision-making (the timing of switching the signal phase) is optimized stage by stage rather than simultaneously. This is done by dividing the original decision problem into small sub-problems that can be handled much more efficiently from a computational standpoint. DP is a systematic procedure for determining the combination of decisions that maximizes overall effectiveness or minimizes overall disutility, based on the principle of optimality enunciated by Bellman (1957).

This signal control technique seeks signal phase series that minimize total delay time in the evaluation time, when the passage time series of vehicles that arrive the intersection is given. This study expands signal control technique proposed by Nishida (1986). To begin with, the effect by large size cars, pedestrian, and right- or left-turning vehicles are considered. Secondly, an intersection is extended to a four-leg intersection with four approaches. Furthermore, this model distinguishes between large-sized cars, and passenger cars, and establishes signal control systems that consider the priority vehicles.

The recursive optimization function shown in Nishida (1986) is given by the following equation.

$$D(k,T) = \min_{phase(k)} [d(S(k-1,T-phase(k)),phase(k))+D(k-1,T-phase(k))] \quad (1)$$

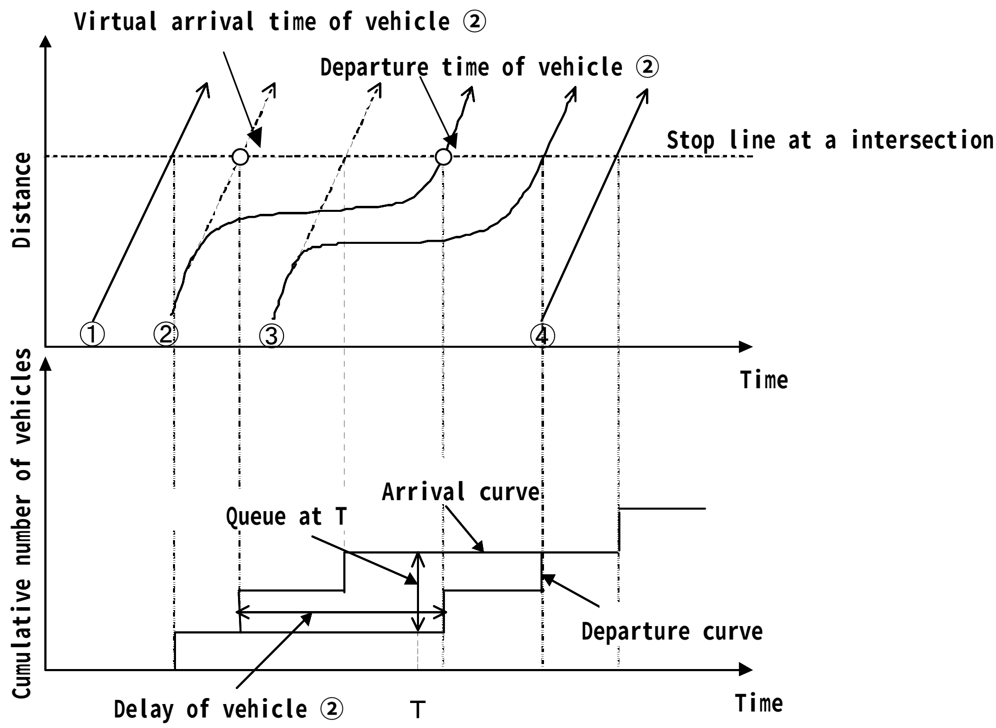

Fig.2 Estimation of delay

where k : phase number,
T : evaluation time,
phase(k) : phase time of k th phase,
S(k,T)= [phase(1),···,phase(k)] : optimum signal phase series of phase number k and evaluation time T,
D(k, t) : the smallest total signal delay time of phase number k and evaluation time t,
d(S(k-1,t-phase(k)),phase(k)) : signal delay in k phase in giving the phase(k) as k phase after a traffic flow was processed by S(k-1, t-phase(k)).

The procedure to get the optimum solution is shown as follows:

1) Find D(1,T) when evaluation time is from 0 to T. Obviously D(1,T) becomes T.

2) Next, the case of two phases will be calculated. S(2,T) is selected to minimize total delay D(2,T) from the combination that satisfies the condition of phase(1)+ phase(2) = T. Furthermore, D(2,t) $0<t<T$ are also calculated in order to get a solution for more than three phases.

3) The approach of DP is required to get the optimal solution with more than three phases. Finding the best combination that satisfies the condition of phase(1)+ phase(2) + phase(3) = T is equal to finding one from the best combination of two phases whose evaluation time is T-phase(3) and of phase(3). As the best combinations of two phases has already obtained, it is easy to find the best combination of three phases by increasing the length of phase(3) one by one.

4) The solution for more than four phases is also similar to that for three phases. An optimal signal phase series is easily obtained from combination of the existing one and of a new phase.

DP is the technique for deciding the optimum solution of complicated multistage systems. As it follows principle of optimality and avoids unnecessary searches, the calculation time can be shorter than the complete enumeration method considering all combination. And, the search range narrows more by setting the smallest green time. However, there is a problem in calculation time for practical use, when evaluation time becomes longer or the number of intersections becomes larger.

2.3 Simulation experience of dynamic programming approach

In a four-leg intersection with unilateral one traffic lane, capacity of each approach is about 800 vph if traffic volume of each approach is almost the same. This research assumes that, upper limit of traffic volume is 800 vph and we try to find the optimum signal setting in 200, 400, 600, and 800 vph. The evaluation time is one hundred seconds and calculation was carried out for one hundred kinds of arrival patterns. We carry out one hundred kinds of calculation here because optimum signal timing and total delay are different among different arrival pattern with the same traffic volume, and because distribution shape becomes smooth by the 100 times calculation.

There are many factors that determine the total delay. Total delays are calculated based on the simulation of dynamic programming approach when traffic volume, right or left turn ratio, large size car ratio, and number of pedestrians vary as follows:

a)	Trafficvolume	200,	400,	600,	800	[vph],
b)	Ratio of right or left turn	0,	10,	15,	20	[%],
c)	Ratio of large size car	10,	15,	20		[%],
d)	Number of pedestrians	90,	180,	360		[people/hour].

We should have shown all combinations in which values of each factor are different. When value of one factor changes, values of other factors are the same and figures that have underlines are used for this calculation.

Fig.3 shows the frequency distribution of average delay when traffic volume changes from 200 to 800 vph. The frequency differs greatly even if traffic volumes are the same. With the increase of traffic volume, the delay time increase. Fig.4 shows the frequency distribution of total delay when ratio of right or left turn changes from 0 to 20%. With the increase of traffic volume, the delay time increases. Fig.5 shows the frequency distribution of total delay when ratio of large size car changes from 15 to 20%. of

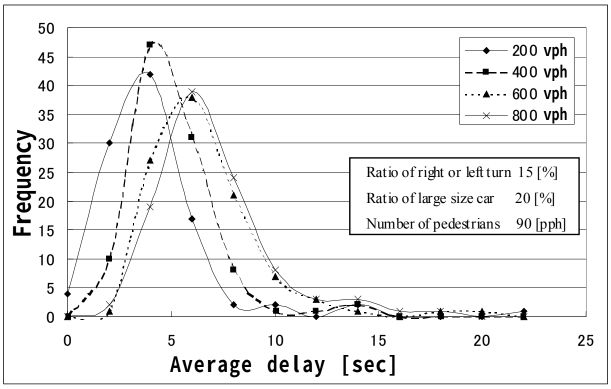

Fig.3 Average delay as traffic volume changes

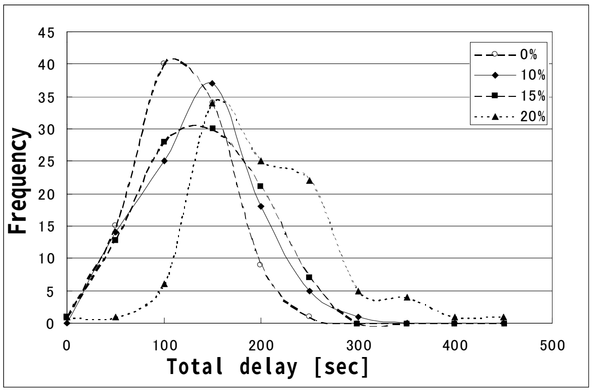

Fig.4 Total delay as ratio of right or left turn changes

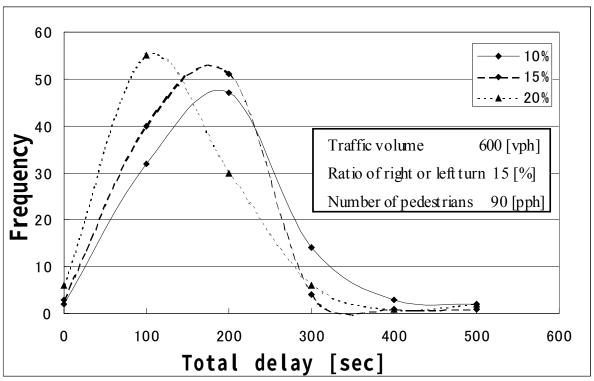

Fig.5 Total delay as ratio of large size car changes

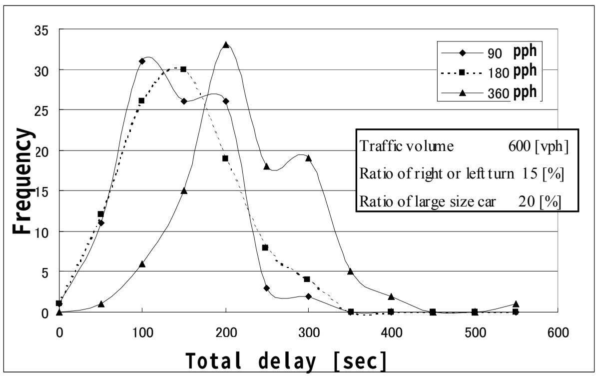

Fig.6 Total delay as number of pedestrians changes

Table. 1 Signal Delay

Traffic volume	[VPH]	200	400	600	800
Average delay	[sec./vehicle]	0.59	0.69	0.80	0.94
Ratio of right or left turn		0%	10%	15%	20%
Total delay	[sec.]	142.2	161.8	162.1	224.7
Ratio of large size car			10%	15%	20%
Total delay	[sec.]		247	208	199
Number of pedestrians	[people/hour]		10%	15%	20%
Total delay	[sec.]		166	171	251

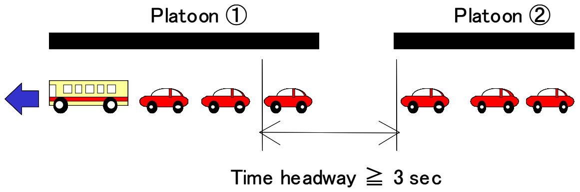

Fig.7 Definition of platoon

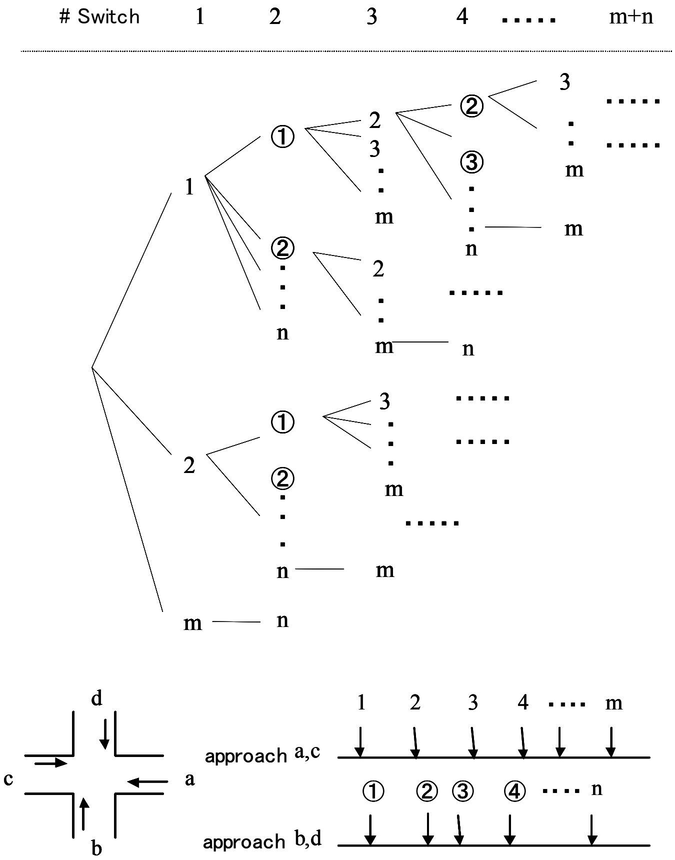

Fig.8 A search tree

With the increase of ratio of large size car, the delay time decreases. That's because platoons are easily formed and the time in the blank increases with the increase of ratio of large size car. Fig.6 shows the frequency distribution of total delay when the number of pedestrians changes from 90 to 360 people per hour. With the increase of number of pedestrians, the delay time increases. Table.1 shows the summary of the signal dely.

2.4 Heuristic programming approach

Dynamic programming (DP) approach guarantees the optimal solution, but takes long time for calculation. The heuristic programming approach, which does not guarantee the optimum, has been developed in order to solve this problem of calculation time. DP approach deals with each vehicle one by one, but in this heuristic technique the platoon, which is formed by the diffrent speed among various kinds of cars, is controlled as one unit (Fig.7). Two vehicles whose time headway is over three seconds are considered to belong to different platoons, because time headway of the following car assumes to be two seconds. All gaps of platoon are candidacies for switching the signal timing, and combination of the signal timing that minimizes delay is searched based on a search tree as in Fig.8.

In switching the signal, the useless time that cannot pass any vehicles of all approaches occurs. Therefore, it is more efficient to switch the signal phase in the timing that a platoon has passed rather than in the timing that vehicles in a platoon arrive continuously. Then, by searching the switching position of the signal in the every discontinuity of platoons, more efficient control can be possible without losing the optimality.

Optimum signal phase series that minimize total delay are obtained from the combination of the gaps of the platoons that arrive in the evaluation period. A search tree like Fig.8 is shown in order to simply handle this problem. A depth-first search, which searches toward tip of a branch and searches other branches after reaching the tip, is used for search procedure. This is easily implemented by making use of recursion function, an algorithmic technique that calls itself with some part of the task. FORTRAN 90 is used as a programming language, because it has function of recursive.

This search procedure checks all possible combinations, and then search range seems to become enormous. However it is possible to reduce search area, since some platoons can be combined by stopping at an intersection for signal control.

2.5 Simulation experience of heuristic programming approach

1) The verification of the optimality

We use the optimum solution by DP approach as a benchmark in order to examine the optimality of the solution by the heuristic programming approach. Fig.9 shows the comparison between the total delay time by DP approach and by heuristic programming approach. The simulation was carried out one hundred times on the condition traffic volume is 800 vph, which proved that the solution by the heuristic approach was almost equal to the optimum solution.

Table.2 shows the proportion of cases that the optimum solution was not obtained by the heuristic programming approach and relative error between the two approaches. The simulation was calculated

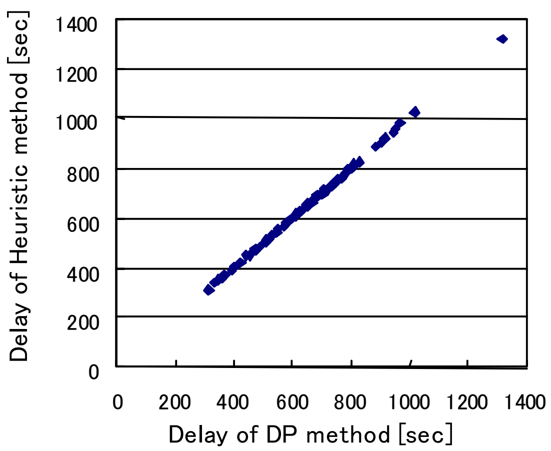

Fig.9 Correlation of delay between DP and heuristic method

Table. 2 Verification of optimality

Traffic Volume		200vph	400vph	600vph	800vph
Rate of non-optimal solution [%]		0.0	12.0	31.0	42.0
Total Delay	DP [sec]	33.1	143.0	314.4	644.9
	Heuristic [sec]	33.1	143.7	317.3	647.1
	Rerative error [%]	0.00	0.49	0.92	0.34

Table. 3 The decreasing rate of calculation time

	DP [sec]	Heuristic [sec]	Decreasing rate [%]
200vph	532.4	25.6	95.2
400vph	533.6	338.5	36.6
600vph	543.0	312.6	42.4
800vph	560.1	145.9	74.0

one hundred times in order to get the optimum solution. Relative error is defined as the difference between the total delay by heuristic programming approach and that by dynamic programming approach over that of dynamic programming approach. The proportion of the non-optimum solution is distributed from 0 to 40 %, and the value becomes large as traffic volume increased. However, the relative errors between the two solutions are less than 1% for all traffic volumes. We can say the solution obtained by the heuristic programming approach has enough accuracy for practical use.

2) Shortening effect in the calculation time

Table.3 shows the shortening effect on calculation time by using heuristic programming, which is from 36% to 95%. Especially, in 200 and 800vph, the effects were big. There is small number of platoons when there are small traffic volumes, and some big platoons are formed when there is large traffic volume. On these two cases, the number of platoons is small, so the range of search becomes narrow and calculation time also becomes short. This study used a personal computer whose central processing unit is Pentium III with 500MHz is used.

3. BUS PRIORITY SIGNAL CONTROL

3.1 Bus priority signal control method

In this chapter we evaluate a bus priority signal control method that changes signal phase according to bus passage at an intersection. In the former heuristic programming approach, the gap of the platoon was modified to be a candidate for switching the signal phase. For the bus priority control method, the immediate time after the bus passage will also be a candidate for the switching, when the bus exists in the middle of the platoon. Fig.10 shows the candidate for the switching signal phase in bus priority signal control.

In addition, parameter α is given to the bus by carrying out the weighting in the delay time of the bus, when the objective function is calculated. When α is the ratio of the number of bus passenger to that of car, the object function means total passenger delay. It is possible to carry out the optimum control according to the importance of bus by changing the weighting parameter α.

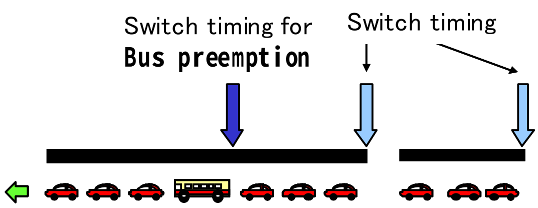

Fig.10 Method of bus preemption control

Objective function =Dcar+ α ×Dbus,

where

Dcar = the delay time of passenger cars,
Dbus = the delay time of the buses,
α = the weighting parameter of the buses.

3. 2 Calculation results

This bus priority signal was controlled by the heuristic programming approach. The evaluation time was one hundred seconds, and the traffic volume was 600 vph. The speed of the passenger vehicle was 50 km/h, and that of the bus was 40 km/h. The total delay was obtained from calculation of one hundred kinds of vehicle arrival patterns.

The results by the two bus priority signal control techniques are shown in Table.4, where case (a) is the technique that does not care the immediate time after the bus passage, and case (b) is the proposed new technique. The values in each delay time are the sum total of one hundred kinds of arrival patterns. This proposed technique has predominated in respect of the weighted total delay, and the differences between the two increase as the values of α increase. When α is 50, total delay without weight factor of this new technique (b) becomes bigger than that of case (a) by 191 seconds. That's because the total passenger vehicles delay of case (b) increases, and this technique is more effective in the respect of bus delay.

Fig.11 shows the average delay of buses and passenger vehicles as weight parameter α changes. The shortening effect in the delay time of the bus increases as the weight parameter α increases, and it is confirmed that the increasing rate in delay time of passenger vehicle is smaller than it.

Table. 4 Result of bus preemption control

α	Total delay [sec] (include weight)			Total delay [sec]			Vehicle delay [sec]			Bus delay [sec]		
	(a)	(b)	(b)-(a)	(a)	(b)	(b)-(a)	(a)	(b)	(b)-(a)	(a)	(b)	(b)-(a)
1	33,442	33,416	-26	33,442	33,416	-26	32,125	32,113	-12	1,317	1,303	-14
2	34,588	34,518	-70	33,550	33,512	-38	32,512	32,506	-6	1,038	1,006	-32
5	37,302	37,080	-222	34,414	34,368	-46	33,692	33,690	-2	722	678	-44
10	40,276	39,800	-476	35,848	35,786	-62	35,356	35,340	-16	492	446	-46
20	44,355	43,389	-966	37,800	37,746	-54	37,455	37,449	-6	345	297	-48
50	52,463	49,469	-2,994	41,683	41,874	191	41,463	41,719	256	220	155	-65
100	62,531	56,275	-6,256	43,424	43,405	-19	43,231	43,275	44	193	130	-63

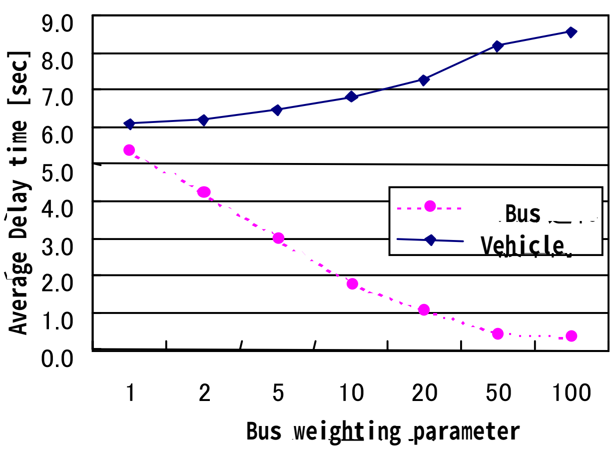

Fig.11 Transformation of delay by bus weighting parameter

4. CONCLUSIONS AND FURTHUR RESEARCH ISSUES

This study has developed the heuristic programming approach and the dynamic bus priority signal control system that can get the approximate solution within feasible calculation time. The heuristic programming approach can reduce the calculation time by 36-95% without conspicuous deterioration of solutions. Bus priority signal control can obtain the delay time shortening effect of the bus without affecting the delay time of other general vehicles.

For future problems for this research, it is necessary to improve approximate solution and to bring it close to the optimum solution. We have to examine the case that optimum solutions are not obtained and improve it. Furthermore, development of the method for reducing the search period according to the traffic situation is also necessary for the calculation time shortening. In this paper, just one lane in each leg is considered. Therefore, no lane-changing or passing is allowed and platoon naturally forms. We have to make efforts to approach a model frame of realistic traffic condition.

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