Development of Delay Estimation Method using Probe Data for Adaptive Signal Control Algorithm

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Abstract. This study describes a real time delay estimation method using probe data with adaptive signal control algorithm, "CARREN" (Control Algorithm Retuning paRameters with self performance EvaluatioN) [1]. So far, CARREN supposed the use of AVI (Automatic Vehicle Identifier) data to estimate the total delay on approaching each intersection. In this paper, the application of CARREN using probe data in place of AVI data is explained subsequently. After the explanation, the real time delay estimation method is validated using traffic simulation. In the conclusion section, the performance of the proposed method will be discussed with respect to the penetration rate of probe vehicles, as well as the issues to be tackled in the future.

Keywords: Adaptive Signal Control, Probe Data, Total Delay Estimation

1 Introduction

The purpose of this study is to develop a delay estimation method using probe data for a real time signal control algorithm. The conventional traffic signal control systems used in Japan design signal parameters based on the degree of saturation. In this case, the optimal signal parameters are selected from pre-determined sets to manipulate the current traffic conditions. However, the systems can only adapt to limited conditions because of the limited number of pre-determined sets of signal parameters. In addition, a signal control based on the degree of saturation does not guarantee a minimization of traffic congestion cost (=delay) as an original purpose. Therefore, It is important that the delay time is used for the adaptable signal control in real time. For examples, MODERATO (Management by Origin-Destination Related Adaptation for Traffic Optimization) calculates the signal parameters to minimize the estimated delay time using the traffic volume from detectors. However, the estimated delay time is not measured directory. SCOOT (Split, Cycle and Offset Optimising Technique) estimates the queue length using detector data and evaluates by calculating the degree of saturation. SCOOT also does not measure the delay time directory. In these methods, the evaluation indicators based on the degree of saturation are used to decide the signal parameters. To estimate the indicators, the parameters used in the calculation of the degree of saturation such as the saturation flow rate and the travel speed are assumed (not measured in real time).

The delay estimation method in this study is applied to the real time signal control algorithm CARREN for the validation in the traffic simulator AVENUE (an Advanced & Visual Evaluator for road Networks in Urban arEas). CARREN uses AVI systems and detectors to evaluate delay. AVI is the device to observe the plate number of the passing vehicles. This system can measure the travel time of the section between AVIs by the plate number matching process. However, the cost of the AVI system such as installation and maintenance is high. Therefore we discuss the possibility application of probe data in place of AVI system.

In recent years, various applications using probe data have been discussed such as the estimation of traffic congestion and vehicle behavior analysis for new technology and services in the field of road traffic. On the other hand, a variety of probe data has been collected and data processing techniques for probe data have been developed. It may be said that probe data is expected to be easily-available by the growing of automotive telematics services. For example, if the precision of probe data is relatively precise, the stop and go status of the vehicle can be discriminated. The method described by Horiguchi, et al.[2] The probe information we assume here has the link-wised linear trajectory data identified by the entry/exit times of each link. In this case, we should consider how to estimate the total delay in real time from the probe data according to the penetration of the probe vehicle.

2 Algorithm of CARREN

CARREN is the real-time signal control algorithm proposed by Koshi, et al. They described that CARREN is used on the premise of observing travel times of all passing vehicles and the traffic volume by AVI systems and detectors. The algorithm decides signal parameters (split, offset and cycle) using the total delay time for each stream. Fig.1 shows the image of the total delay evaluation of CARREN. AVI(A) and AVI(B) are located at upstream side and downstream side of the target intersection. The detector is located at the same position of AVI(B). From AVI system, travel times of the passing vehicle between AVI(A) and AVI(B) is observed. The exit time of the section can also be observed from AVI system. From the detector, traffic count with passing times of the vehicle is observed. Using the traffic count data, the cumulative departure curve can be drawn.

Following the observation, the cumulative arrival curve is drawn by the travel times, the exit times and the cumulative departure curve to calculate total delay time. First, the position of each vehicle on the cumulative departure curve (=departure position) is plotted by the exit time. After drawing the cumulative departure curve, the arrival time of each vehicle is calculated by the travel time. Then the cumulative arrival curve is drawn by the arrival positions excluded the free flow travel time. Therefore, the area enclosed by the cumulative arrival curves and the cumulative departure curve in Fig. 1 is the total delay time.

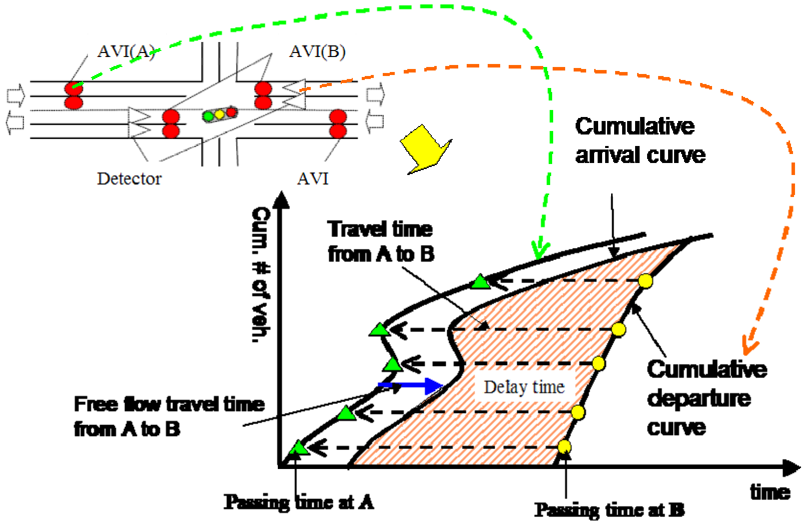

Fig.1 Estimation of total delay by signal

CARREN finds the best combination of split, offset and cycle to minimize the total delay time. Fig. 2 shows the evaluation image of the signal parameter change. To evaluate the parameter change, CARREN estimates the new cumulative curve when the split and the offset are increased or decreased by increments. After the estimation, the relationship between the original total delay time and the estimated total delay time is organized to the matrix of Table 1. *f* in Table 1 is total delay when the split and the offset are changed (-Δ or +Δ). For example, if the split is decreased, the arrival cumulative curve is extended and the cumulative departure curve is translated for Δ seconds. On the other hand, if the split is increased, the cumulative arrival curve is shorter than the original one and the cumulative departure curve is translated for –Δ seconds. Therefore, the area of total delay is decreased.

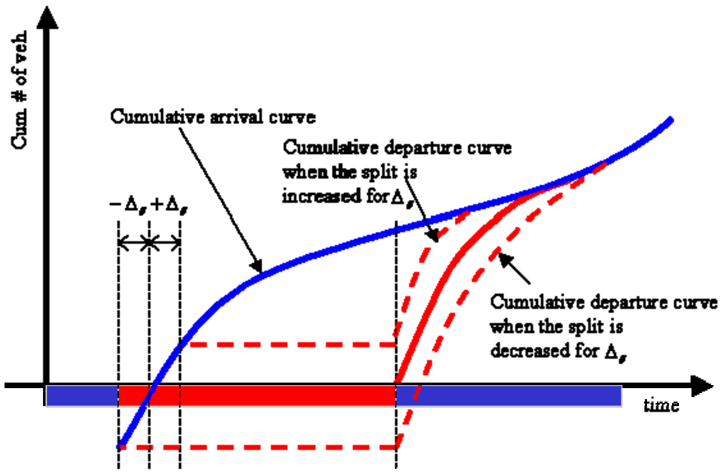

Fig. 2 Evaluation image of signal parameter change using the cumulative curves

Table 1. Matrix of the total delay time by changing the signal timing

		Offset		
		−Δ	0	+Δ
Split	−Δ	f_{--}	f_{-0}	f_{-+}
	0	f_{0-}	$f_{00}=0$	f_{0+}
	+Δ	f_{-+}	f_{+0}	f_{++}

In CARREN, the matrices of the total delay time are calculated for all directions of the inflow of each intersection. Fig.3 shows the image of the split adjustment. Basically, signal controller has some signal phases to control the traffic flow from the different directions. In addition, signal controller has to consider the cooperation with the neighbor intersections. Therefore, the total delay times of each signal in the target section are compared to each other, and searched the better combination to meet the requirements. The best combination of signal timing parameters can be determined when the all of *f* are evaluated. The application method of CARREN for practical use described by Asano, et al. [3] [4]

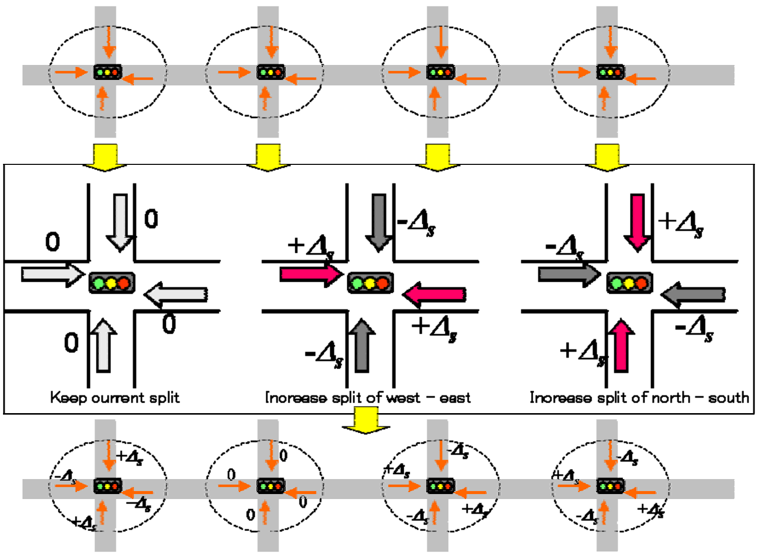

Fig. 3 Split adjustment

3 Delay Estimation using Probe Data

In the first section on this chapter summarizes the issues for the delay estimation using probe data. The subsequent section explains the assumptions and the procedure of the delay estimation method which we propose.

There would be three issues when we develop the delay estimation method using probe data for CARREN. The first issue is how to draw the cumulative departure curve from the detector data. The cumulative departure curve is very important to identify the order of the departure of probe data. The second issue is how to draw the cumulative arrival curve with the imperfect link traverse data from the probe vehicles. The AVI data used in the original CARREN may provide the perfect information of all vehicles. However, the probe data only provides some samples of link traverses. It is obvious that we may draw the cumulative arrival curve with fairly reasonable accuracy when the penetration rate of probe vehicles is high enough. Therefore, the main issue is how to make the drawing method that is feasible when the probe penetration is low. The third issue is the time lag in the data transmission from probe vehicles to the signal control system. In general, the time lag may lose the accuracy of delay estimation when the traffic conditions are varying time by time. The time lag in data transmission should be considered for the practical examination.

Fig.4 shows the image of the delay estimation method. To estimate the total delay time, the cumulative arrival curve and the cumulative departure curve should be drawn. The cumulative departure curve is drawn by detector data located at downstream side of the intersection. When we assume that a certain percentage of passing vehicles are probe vehicles, the passing time at intersection and the arrival time estimated by travel time consist of a part of cumulative arrival curve arrival curve and cumulative departure curve. At this point, cumulative arrival curve is not drawn.

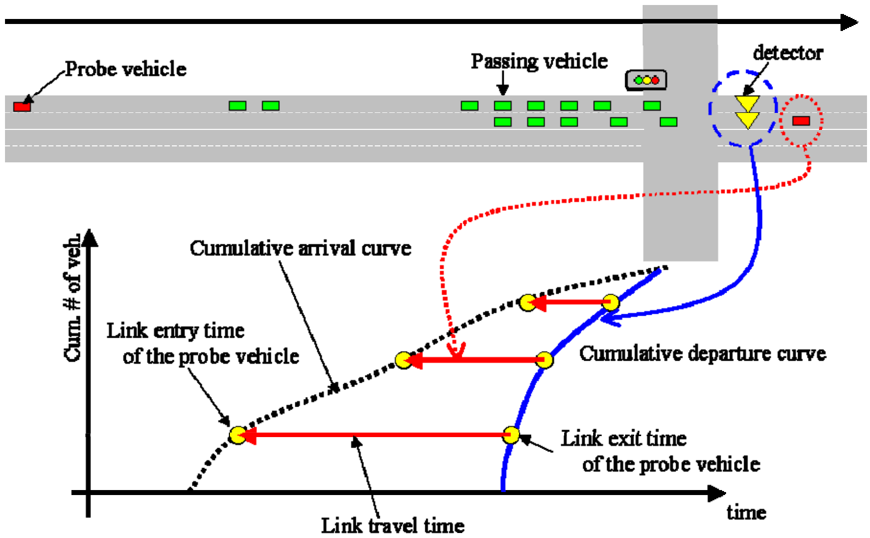

Fig. 4 System for total delay estimation

If probe vehicles are evaluated, the total delay of all passing vehicle is underestimated. Therefore, passing time of all vehicle at intersection is observed using detector (pulse data) to draw departure curve correctly. On the other hand, a part of arrival curve can be drawn by the passing time at intersection and link travel time. This method consists of probe data fusion process and arrival curve estimation process. Since the probe data provides link entry time and link travel time, the cumulative arrival curve can be approximated by interpolating the points of the probe entry times on the cumulative flow diagram. Fig. 5 shows the image of the probe data fusion process and the arrival curve estimation process in total delay estimation method. The following steps describe the process of the total delay estimation.

1) Plot arrival point of probe and departure point of probe on departure curve (departure curve is drawn by passing time of detector) every cycle. Arrival time on arrival curve is excluded free flow travel time.
2) Repeat the step of 1) for specified cycles (parameter of the method) and integrate past arrival curves and past departure curves over the specified cycles. (probe data fusion process)
3) Approximate arrival curve by two lines. (arrival curve estimation process)
4) Estimate total delay by cycle using the approximated arrival curve.
5) Repeat from step 1) to step 4) for every cycle.

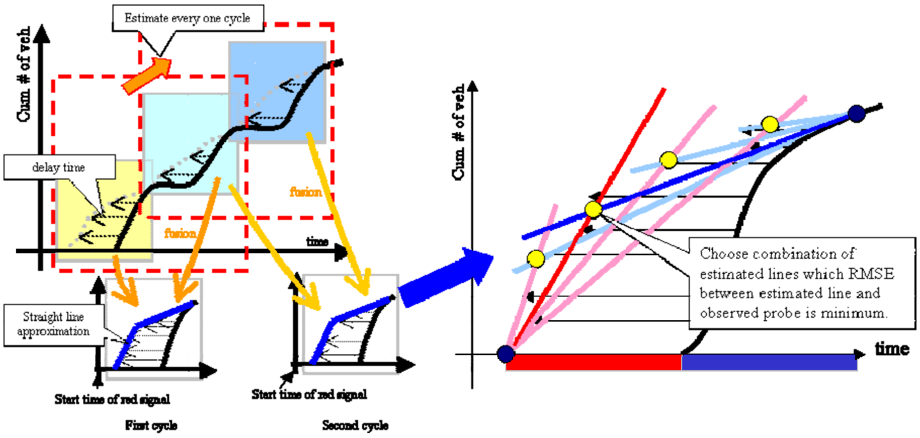

Fig. 5 Fusion of cumulative curve

Here, we simplify the arrival curve with two approximated lines. The reason is that we assume that cumulative arrival curve has two characteristics when traffic is controlled by systematic signal control. The first one is that the first arrival pattern from the upstream intersection can be in saturation flow for a few second to several tens of seconds. The second one is that the second arrival pattern can be in free flow traffic with demand flow rate after the saturated flow (the first arrival pattern). In the situation of saturated flow, the angle of the first approximate line should be equal to saturation flow rate. On the other hand, the angle of the second approximate line depends on the flow rate of demand and it should be smaller than the angle of the first approximate line. Adding to this, the total delay consists of one approximate line is simultaneously evaluated. Then we can have a variety of combination of approximate lines and select the best lines. To select the best approximate lines, RMSE (Root Mean Square Error) between the approximated lines and the arrival points using observed link travel times from probe data is calculated for each lines. Finally, the combination of lines that minimizes the RMSE is selected and is used for the delay estimation.

4 Implementation of the delay estimation method

In this study, we use the traffic simulation model for the validation of the delay estimation method. Therefore the method should be installed as a part of CARREN. Fig. 6 shows the basic procedure of CARREN. *N* is the number of cycle for the data collection (obtain probe data and detector data). The method is installed between the data collection process and the signal timing update process. This procedure is executed every simulation scan (1 second) for each intersection.

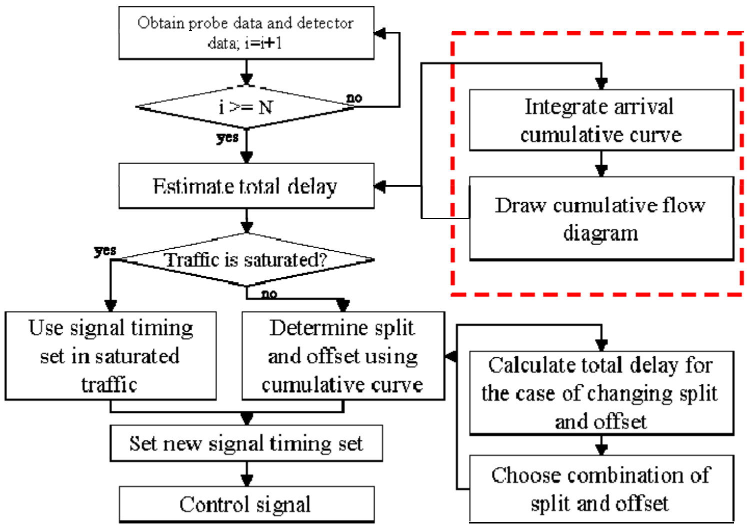

Fig 6. Procedure of CARREN and the estimation method

5 Test Bed for Validation

As a test bed of this study, we have built a simulation dataset for Yasukuni-dori in Tokyo. Table 2 shows the overview of the test bed (Yasukuni-dori test bed). We surveyed traffic volume and signal timing for each intersection to develop Yasukuni-dori test bed. The travel times of the target section was also observed. This data is used as the input data for the traffic simulator and the validation data for the reproduced traffic situation. The OD traffic volume (Origin-Destination traffic volume) is estimated by the traffic volume data.

Table 2. Outline of the Yasukuni-dori test bed.

Network size	1.8km * 0.5km (61 links, 32 nodes)
Simulation time	From 7:00 to 19:00 (12 hours)
Total number of demand	127029 vehicles
Schedule of OD traffic volume	Every 10 min.
Type of vehicle	Small vehicle and large vehicle

The traffic simulator used here is AVENUE. AVENUE employs the ‘Hybrid Block Density Method (HBDM)’ (Horiguchi et al. 1994). In the HBDM, each link is divided into several blocks. The in/out–flow and the density of each block are revised at every scanning interval base on the flow-conservation law and the Q-K (Capacity and Density) relationships. Fig. 7 shows the display of Yasukuni-dori test bed and AVENUE.

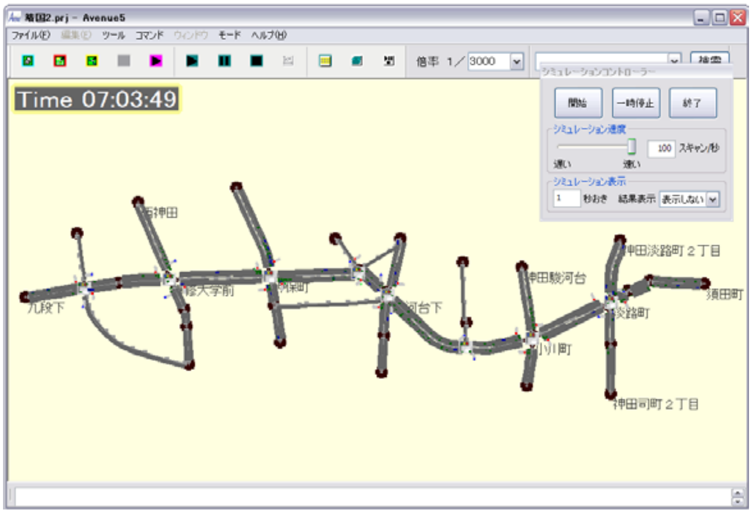

Fig 7. Test bed on AVENUE

6 Validation of Delay Estimation

For the validation of the delay estimation method, one link section between the intersection A and the intersection B is chosen (the direction is from A to B). Fig. 8 shows the validation section. The link has 3 lanes with right turn lane. We set a detector on the downstream side of intersection B. As the probe data, the link entry time and the link exit time of probe vehicle are observed.

Fig. 9 shows the comparison result between the total delay estimation method and the total delay time of all vehicles. We simulated for 12 hours (from 7:00 to 19:00) and compared the estimated total delay times from the probe data with the measured total delay times (the total delay time from all vehicles as the true value) in every cycle. We examined 12 simulation cases changing the parameter combinations depending on the probe penetration and the number of cycles for the probe data collection.

The three figures in Fig. 9 describe that the accuracy of the estimated delay times tend to be high when the probe penetration or the number of cycles is high. When the probe penetration was relatively higher as much as 50-70%, the estimated delay times seem to correlate with the measured delay times. On the other hand, the estimated delay times were underestimated when probe penetration was relatively lower as much as 5-10%.

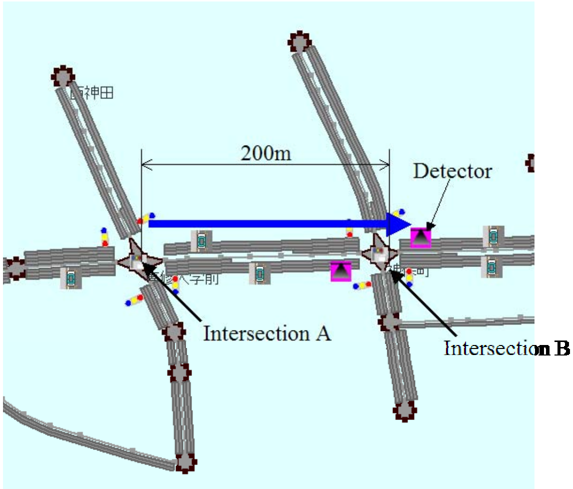

Fig. 8 Section for validation

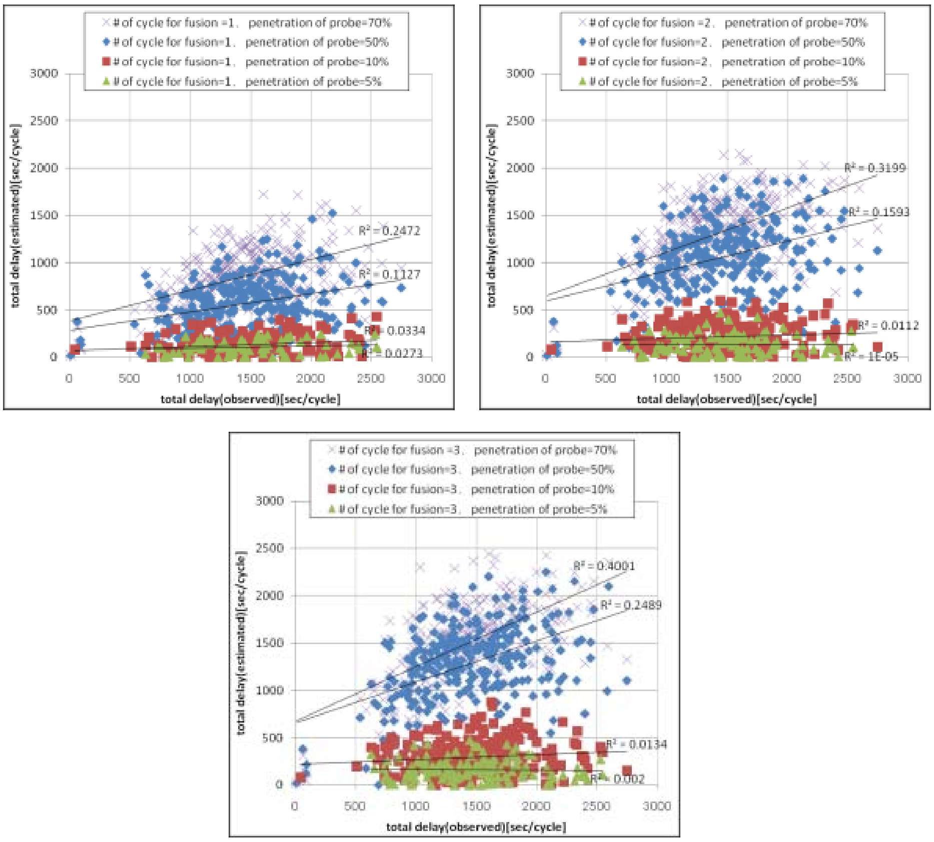

Fig. 9 Estimation result

The reason of the underestimate includes that the estimation method tends to choose the approximated arrival curve consisted of one line when the probe penetration is low. If the one-line approximated arrival curve is chosen, the delay time of the first some vehicles in the saturated flow are shortened to the point on the arrival curve (the delay time includes the stop time by signal and the waiting time of the queue). Therefore, the real delay times in saturated flow might not be considered. In addition, the validation result was greatly varied in each case. The reason includes that the estimation method uses all probe information that is collected in few cycles for the total delay estimation. To solute the problem, we think that the data cleansing to exclude the unsuitable samples for the total delay estimation should be installed.

In this study, we simulate the Yasukuni-dori test bed with CARREN and the delay estimation method by AVENUE. The calculation time is less than 1 second per one scan (The scan interval of AVENUE is 1sec). Therefore, we expect the estimation method is adaptable for the real time signal control.

6 Future Works

In this paper, we explained a delay estimation method by using probe, and we developed a test bed of traffic simulation for the validation. Then the validation result of the method is showed in a part of the simulation network by AVENUE. As for the immediate future works, we are going to install some data processes, for example, cleansing process to exclude unsuitableness data. On the other hand, the method will be improved by considering the Kinematic Wave theory that describes the fundamental characteristics of traffic flows. Using the test bed and CARREN, the capability of the application of probe information will be validated considering effect of penetration of probe car and difference from signal timing in real.

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