Traffic Flow Control Using Probe Vehicle Data

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ABSTRACT

UTMS (Universal Traffic Management Society of Japan) is researching on the technologies and specifications for traffic flow control using probe data for CO_2 emission reduction. First, we defined the services which realized advanced traffic flow control and examined the technological requirements of each service in 2008. In 2009, we conducted some simulation experiments to verify the requirements of probe data and key technologies for the realization of the services. We report the outline of the services and the results of the simulation experiments in this paper.

BACKGROUND

So far the urban traffic control has been addressing to realize the safety and smoothness of traffic flow. From now on, there is a new need to reduce total amount of CO_2 emission by signal control toward prevention of global warming. It is important to detect accurate traffic condition promptly in order to execute suitable signal control corresponding to traffic condition and to provide suitable traffic information. But, a spot detector such as an ultrasonic vehicle detector only detects vehicle existence discretely and then can't measure change of traffic condition in all parts of the road. And it is a problem that it takes costs to install spot detectors densely in all parts of the road. To solve these problems, we decided to use probe data to extract consecutive spatial traffic information (spatial data) such as queue length. Then we have defined the services to enhance traffic flow control, clarified technological requirements to realize the services and verified the key technologies and effectiveness of the services.

USE OF PROBE DATA

Probe data is travelling information of vehicles collected through a wireless network directly by running vehicles. It is information of the samplings for some vehicles with the functions to generate probe data and we can collect the travelling situation of vehicles such as the time, the position and the speed in every place that the vehicles ran. It has the characteristic that the density and time delay of probe data depend on the contents of processing by vehicles and the period of communication to the infrastructure collecting probe data. The available devices for collection of probe data at present are mainly a cellular phone and an infrared beacon in Japan. It is comparatively easy to use an infrared beacon for the traffic control such as signal control because it is the device on the road which has the function of the communication between the road and vehicles and used for delivery of the VICS(Vehicle Information and Communication System) information and is connected with traffic control center. More than 48,000 infrared beacons have been already installed in major roads all over Japan. So, we examined about the use for probe data collected by an infrared beacon.

EXAMINATION OF ADVANCED TRAFFIC CONTROL

At first, we defined services for advanced traffic flow control to reduce CO_2 emission. Next, we clarified the necessary input data items to realize each service. And, for generation of those input data, we defined the requirements in terms of probe data collection such as the position and timing of collection and the requirements of probe data specification such as the data items to collect, the data precision and the storage timing, with considering the characteristics such as installation positions or transmission capacity of an infrared beacon. Furthermore, we defined the criteria for judging the locations, the time, and so on where some kinds of events including vehicle stop occurred, because the stop location of the vehicles, the change of direction of the vehicles and the run of constant distance of the vehicles are important to satisfy the requirements of advanced traffic flow control. Moreover, the specifications of the central systems which process probe data and realize advanced traffic flow control services are under development.
Because the vehicles with the in-vehicle unit are in a part of all the vehicles, we can't grasp the exact volume of the whole traffic which run under the infrared beacon now. So we examined services which can be realized even if deployment rate of the in-vehicle unit is at present level. One of them is a service which used probe data comparatively in real time and others used it statistically. We defined three services with incentive for the driver. Table.1 shows the requirements of probe data and the main issues about each service.

Table 1. The Service Menu and The Requirements

No.	Service	Requirements	Main issues
1	Traffic flow analysis	Input data: stop location, stop time Delay of data: none(use in offline) Deployment rate of in-vehicle unit: greater than low	Judging method of bottleneck Precision of bottleneck position Number of probe data
2	Improvement of the signal control performance	Input data: queue length, saturation flow rate etc. Delay of data: from one second to one cycle Deployment rate of in-vehicle unit: greater than medium	Collection delay Precision of position information Uniting to detector information in-vehicle unit deployment rate
3	Priority control of bypass	Input data: traveling time, selection rate of travel route Delay of data: none(use as statistics data) Deployment rate of in-vehicle unit: greater than medium	Conditions of priority control execution Content of information provided to driver

"Traffic flow analysis" improves traffic control by detecting the bottleneck of the traffic flow on the road network containing the intersection without vehicle detectors. If this service is introduced, the effect is expected that the dissatisfaction of drivers is broken off by transmitting probe data including "running delay" in travelling path to the traffic control center, using it in traffic flow analysis and improving the signal control performance. "Improvement of the signal control performance" calculates what is called "spatial data" such as the queue length and saturation flow rate, and improves the control performance of MODERATO(1) which is the current popular signal control method in Japan by grasping more accurate traffic condition from probe data. It is hoped that the precision of the evaluation index of MODERATO improves as deployment rate of the in-vehicle unit rises and ideal signal control without waste is realized and there is the advantage that drivers can run smoothly. "Priority control of bypass" provides the bypass information and executes priority control for the bypass based on the information of road network usage. The advantage that a driver accords with a traffic condition and can arrive at the destination in a short time is anticipated by this service.

SIMULATION EXPERIMENT

We conducted evaluation by the simulation experiments to inspect requirements and matters in use of probe data for “Traffic flow analysis” and “Improvement of the signal control performance” service.

“TRAFFIC FLOW ANALYSIS”

It is important to establish a method to detect a bottleneck of traffic flow from probe data and clarify requirement of the number of the up-link data which are necessary for the bottleneck detection in “Traffic flow analysis”. Therefore we conducted the simulation that used probe data generated from a traffic simulator artificially and inspected correlation of detection precision and deployment rate of the in-vehicle unit for detection of bottleneck intersections from probe data. And we analyzed the correlation of deployment rate of the in-vehicle unit and the accumulation days of probe data when we detected a bottleneck in offline statistically. We performed 100 times of simulation that changed deployment rate of the in-vehicle unit into every deployment rate of the in-vehicle unit for the same traffic condition. Figure 1 shows the relations of deployment rate of the in-vehicle unit and rate of correct detection when we performed the bottleneck crossing detection by the right turn traffic jam in real time.

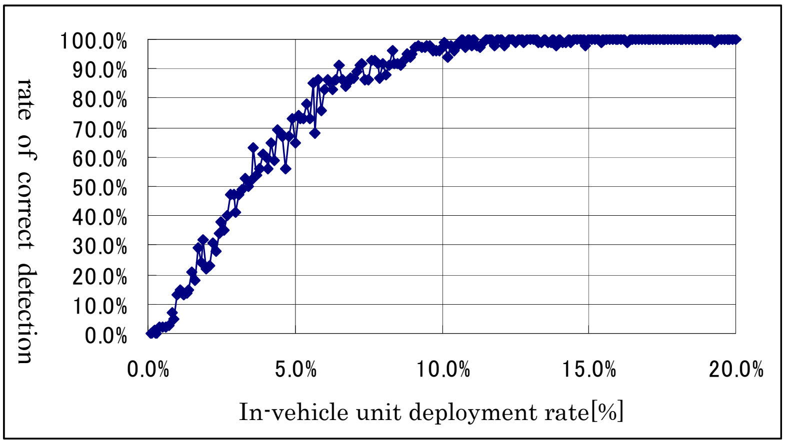

Figure.1 Relations of deployment rate of the in-vehicle unit and rate of correct detection

Figure 1 shows that deployment rate of the in-vehicle unit must be more than 10% to detect the bottleneck crossing with precision more than 95% in real time. From this result, we estemate that the accumulation days is 10 days in the case of deployment rate of the in-vehicle unit 1% and is 100 days in the case of deployment rate of the in-vehicle unit 0.1%. The result shows that deployment rate of the in-vehicle unit is not a critical condition in the service when we use probe data statistically even though the condition might differ by road shape and the traffic condition.

“IMPROVEMENT OF THE SIGNAL CONTROL PERFORMANCE”

We thought that it is necessary to clarify the precision of spatial data to improve signal control performance and necessary deployment rate of in-vehicle unit and precision of location data in probe data to generate the spatial data precise enough to use in "Improvement of the signal control performance". Therefore, with simulations shown in Figure 2, we verified the requirements of spatial data and probe data.

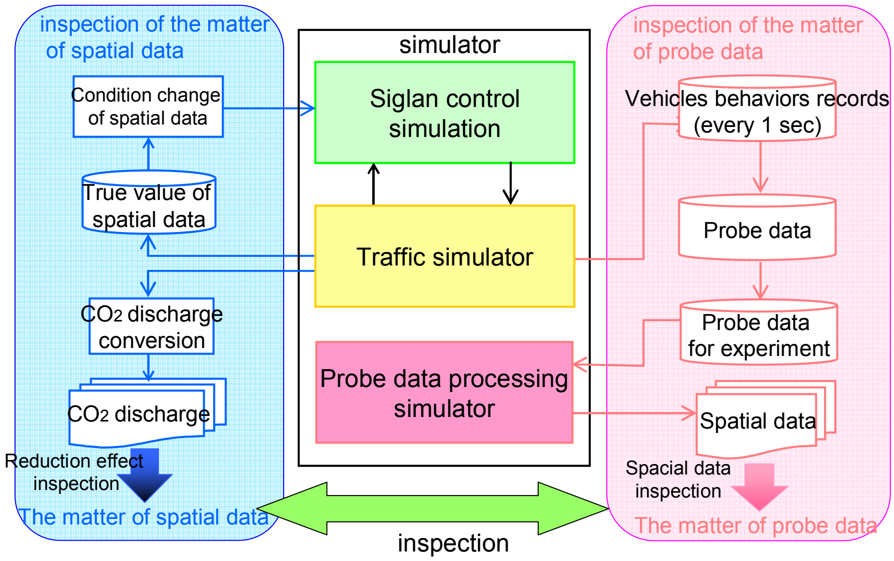

Figure.2 The constitution of the simulation experiment

At first we conducted simulation to inspect CO_2 emission reduction effect and verified requirements of the spatial data (queue length) in the road network model of Figure 3 that the roads of main and sub direction intersected in one crossing under the near-saturated traffic condition. We compared the CO_2 emission when we used the queue length measured with the vehicle detector installed in crossing upper reaches 150m and when we used the queue length generated by using probe data and as input information of MODERATO by the simulation.

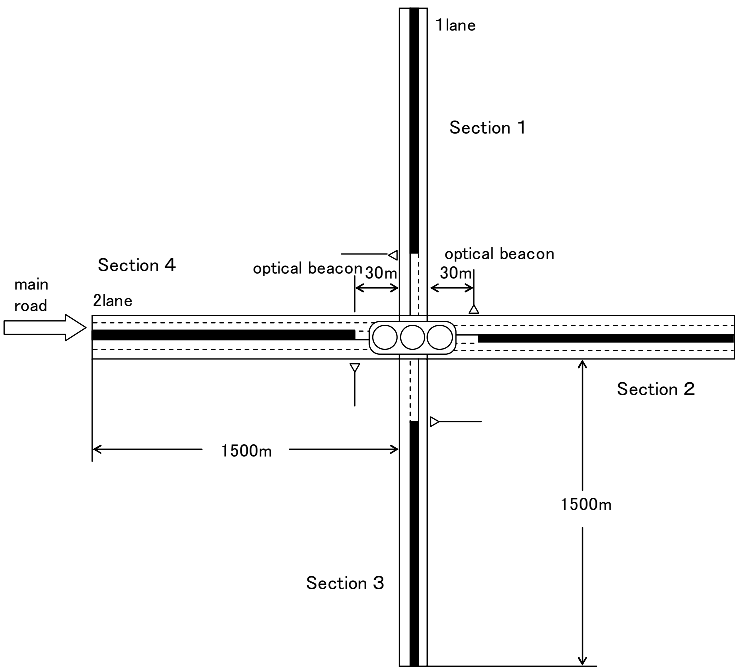

Figure.3 The road network

We adopted the equation(3) to calculate the CO_2 emission.

$$E = a \cdot T + b \cdot L + c \cdot (V_f^{\,2} \cdot S + V_j^{\,2} \cdot S_j) \qquad \cdots \text{Equation(1)}$$

$a = 0.68$, $b = 0.064$, $c = 0.13$, $V_f = 13.9$m/sec, $V_j = 5.6$m/sec

T : Travel time

L : Distance

S : Stop number of times with the signal

S_j : Departure numbers of times in the traffic jam

We added error to the spatial data generated from a traffic simulator and changed error degree and executed MODERATO signal control with the spatial data while changing the traffic demand ratio of main and sub direction. Figure 4 shows the simulation result.

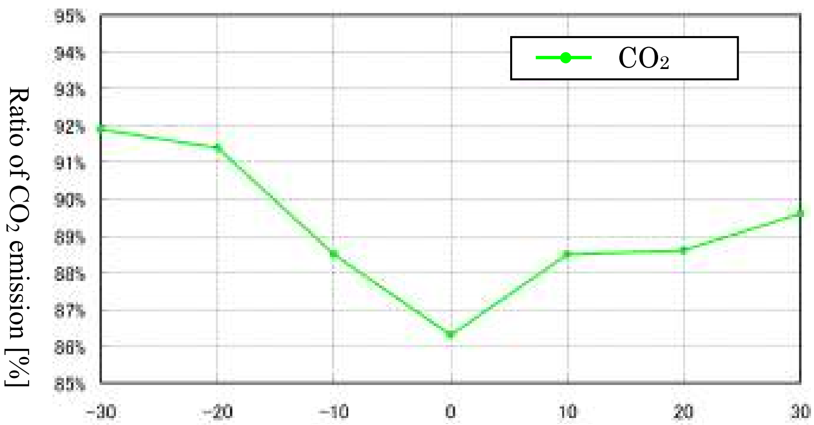

Figure.4 Result of Simulation

Hereby, we confirmed the total amount of CO_2 emission could be reduced from 8% to 14% if error of queue length was from -30m to 30m compared with the case of MODERATO control with spot detectors at 150m upstream from stop lines.

Next, we changed deployment rate of the in-vehicle unit and a condition of the location precision of probe data in order to clarify requirements of probe data to generate a queue length with an error within 30 meters and evaluated the queue length generated by using only probe data. We evaluated the precision of the queue length in section 4. Road network model and the input traffic density were same in the experiment for inspecting the matter of spatial data. We changed deployment rate of the in-vehicle unit from 1% to 100% and evaluated in the case of -15meters and +15meters that the vehicle position error condition was equivalent to the city area and in the case of 0 meters that the vehicle position error condition was equivalent to the opening place.

Figure 5 shows the relation between the measurement error and the ratio of such cycles for all cycles where the queue length could be generated within the error, in each deployment rate of the in-vehicle unit when there is no location error in probe data.

In addition, Figure 6 shows the ratio of the case in which the queue length more than 150m can be measured by probe data for all cases in which the queue length is longer than 150m that are the measurement range of the spot detector.

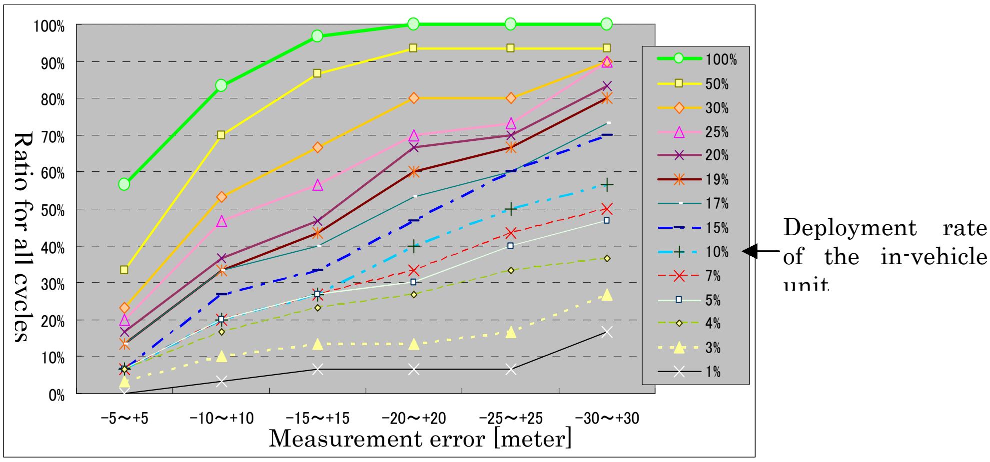

Figure.5 The distribution of the measurement error of the queue length

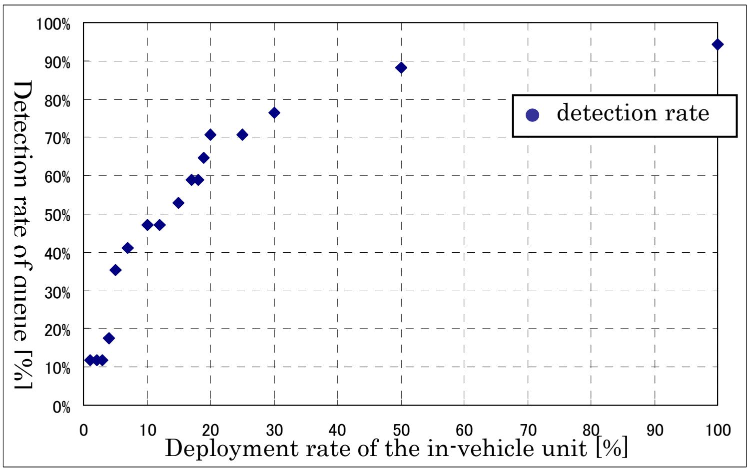

Figure.6 A measurement result of the queues length more than 150m

It is shown that the measurement error of spatial data is equal to or less than 30meters for about 70% signal cycles, when probe data did not have a position error and in-vehicle unit deployment rate was 15% and about 50% signal cycles, when probe data did not have a position error and deployment rate of the in-vehicle unit was 10%.
In addition, Figure 6 shows that we can detect the queue length beyond 150 meters that the spot detector equipped at 150m upstream from stop line can not detect at about 50% frequency if in-vehicle unit deployment rate is 15%.
Figure 7 and Figure 8 show the distribution of the measurement error of the queue length in each in-vehicle unit deployment rate in such condition that probe data might have error by 15m constantly which may be maximum error in the city area.
Figure 7 shows that precision in the appearance is improved when the error of location is given toward the rear direction.
Figure 8 shows that deployment rate of the in-vehicle unit must be more than 20%, so that the measurement error could be within the range between -30 meters and 30 meters in more than 50% signal cycles for all cycles when the location error is given toward the front direction.
We confirmed that CO_2 emission could be reduced by using the spatial data measured by probe data when deployment rate of the in-vehicle unit was higher than 20% even if position precision of probe data was lower than the above-mentioned experiment result. But we used only probe data in the spatial data generation by this experiment and did not use spot detector information. We think that we can generate spatial data precise enough to meet the requirement to use in “Improvement of the signal control” service by fusing in probe data and

spot detector information even in the case when deployment rate of the in-vehicle unit is much lower.

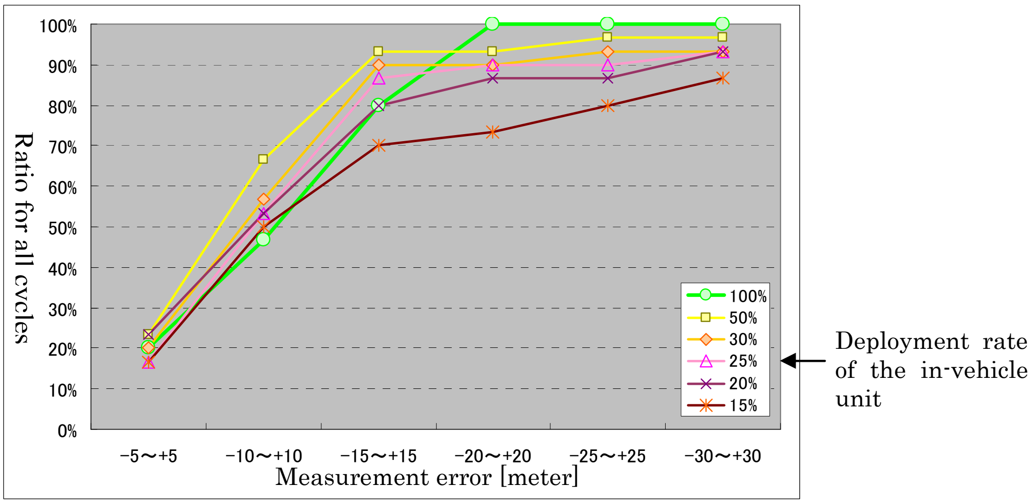

Figure.7 Measurement error of queue length

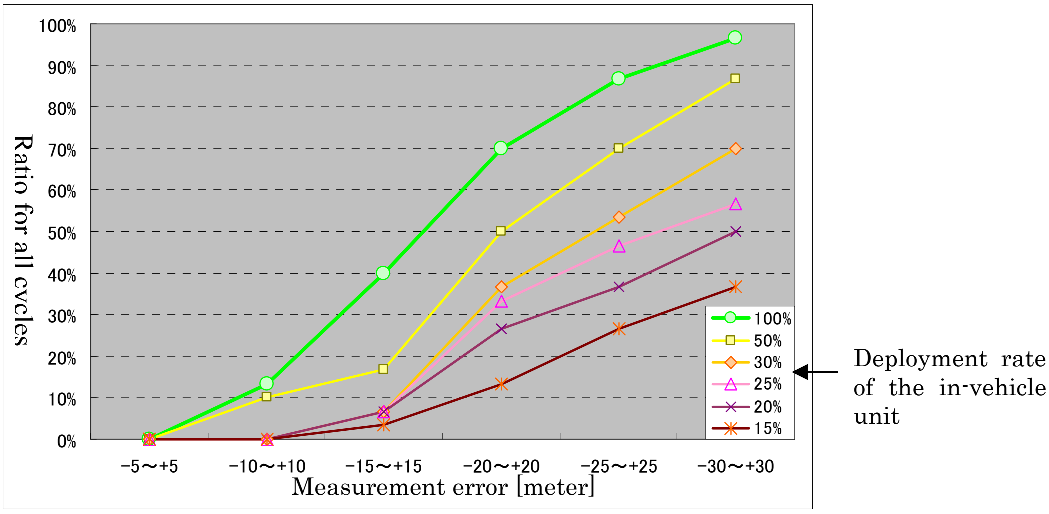

Figure.8 Measurement error of queue length

FIELD EXPERIMENT

In 2010, we are conducting the field verification test to collect probe data form vehicles equipped with the in-vehicle unit by the event extraction method. The purpose of the test is to verify the performance of the event extraction method in collecting and processing of probe data and verify feasibility of traffic flow analysis service. In the performance verification of the event extraction method, we will compare the logged driving data in the in-vehicle unit and the driving route data with events processed in central systems. And in the verification of traffic analysis service, we will inspect the algorithm to detect the bottleneck intersections by comparing the detection result in offline, and the traffic congestion information measured by spot detectors.

CONCLUSION

We defined three services to enhance traffic flow control which used probe data for the purpose of CO_2 emission reduction. Then, we confirmed that we could detect a bottleneck without depending on deployment rate of the in-vehicle unit by using probe data statistically in “Traffic flow analysis”. If deployment rate of the in-vehicle unit was more than 10% when position precision of probe data was high, it was confirmed that there was a remarkable effect to reduce CO_2 emission by ” Improvement of the signal control performance”. On the other hand, it was confirmed that deployment rate of the in-vehicle unit of 20% was necessary to reduce CO_2 emission when position precision of probe data is low. But this result was provided with the case in which an evaluation index of the signal control was calculated with only probe data. We will examine fusion of probe data and spot detector information to reduce the required condition of development rate of the in-vehicle unit in the next step. In addition, we plans to examine a problem and the matter of “Priority control of bypass” that uses probe data and promotes dispersion of the traffic demand.

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