Improvement of Traffic Signal Control Using Probe Data

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Originally, traffic control has been aimed at the safety and comfortableness of transportation. Recently, there has been a growing demand for reducing CO_2 emissions by intelligently controlling traffic signals depending on traffic conditions. However, this requires many detectors and high installation costs. To address this problem, we have focused on the probe data collected by vehicles through GPS or other devices. We have developed a signal control system that calculates consecutive spatial traffic information (spatial data), such as queue length, based on the probe data. In the simulation experiments conducted by the UTMS (Universal Traffic Management System) Society of Japan[*1], we demonstrated this system and presented the possibility of reducing the number of detectors.

Keywords: traffic signal control, probe

1. Introduction

In urban areas, traffic control has been used to ensure a safe and smooth flow of traffic. Reducing CO_2 emissions to prevent global warming is another issue to be addressed. To achieve these objectives, accurate information on traffic conditions is required as needed to provide relevant traffic information to allow signal control systems and vehicles to respond to traffic conditions. Fixed-point observation with devices, such as ultrasonic vehicle detectors, allows vehicles to be detected only discretely, and does not allow the measurement of changes in traffic conditions on the road as a whole. One possible solution to this issue is to install detectors on the road as densely as possible; however, the installation cost is high. Our solution to this issue is to collect continuous spatial traffic information (spatial data), such as queue length, using probe data. We have developed a probe data-based signal control system and evaluated it in simulation tests.

2. Probe Data

Probe data are data on vehicle behavior collected through a communication network. In Japan, infrared beacons are installed to provide VICS[*2] information. Since infrared beacons have intercommunication capabilities, systems have been developed to collect probe data via the beacons. Conventional infrared beacons have the drawback that they have limited communication capabilities and can collect information only from a limited number of sampling points. However, the new infrared beacon to replace the current infrared beacon has much greater communication capabilities and allows probe data to be collected from the sampling points at 6 second intervals. In our system, the timing of collecting vehicle position information is defined as an event (**Table 1**). Stop events and rapid deceleration events corresponding to a vehicle's stopping and rapid deceleration are defined to allow accurate detection of these events, which are important in the evaluation of traffic conditions. We have made it possible to collect data on vehicle behavior at 6-second intervals by defining a fixed-time travel event, which indicates that a vehicle has traveled for a fixed time period since the occurrence of the previous event. A stop event is defined to occur when the vehicle stops and starts. An increase in data collected is prevented by defining that the fixed-time travel event does not occur during stopping and deceleration.

Table 1. Description of probe data

Event	Collected data (Common)	Attribute information
Fixed-time travel	Time Latitude, longitude Road type (general road, highway)	—
Stop		—
Rapid deceleration		Deceleration

3. System Configuration

3-1 Overview

Figure 1 shows the configuration of our system. Probe data are transmitted by infrared communication from a vehicle with an on-board probe unit (hereinafter, a "probe vehicle") to the infrared beacon transmitter/receiver unit installed on the road, and then collected by the traffic control center. Information on passing vehicles is collected by the vehicle detection function of the beacon and the ultrasonic vehicle detector, and sent to the traffic control center. In the center, spatial data, such as queue length, are generated from the collected probe and detector data. A signal control command to provide the timing for changing traffic lights is generated by a signal control program based on the spatial data. The signal control command is sent from the traffic control center to each signal light on the road. The traffic light is changed by the command.

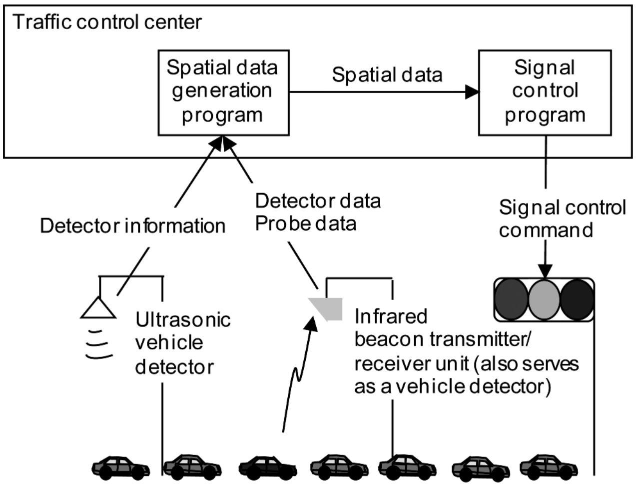

Fig. 1. System configuration

3-2 Infrared beacon

An infrared beacon is a key device of this system. The infrared beacon head interactively communicates with a probe vehicle using a near-infrared (850 ± 50 nm) transmitter installed above the lane (**Fig. 2**). Probe data are collected through an uplink from the vehicle, and, at the same time, the traffic information (congestion, travel time, etc.) generated from the probe data and other data by the traffic control center is sent to the vehicle through a downlink. The infrared beacon head also serves as a near-infrared vehicle detector to provide information on passing non-probe vehicles.

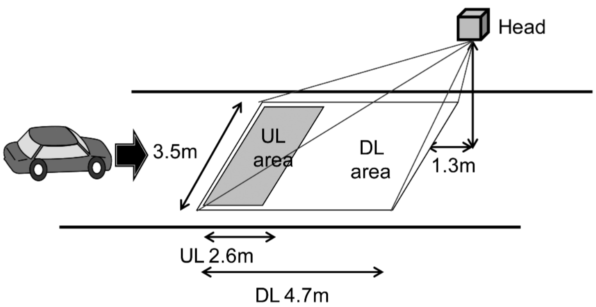

Fig. 2. Infrared Beacon

4. Signal Control Based on Probe Data

4-1 Signal control system

In Japan, MODERATO (Management by Origin-Destination Related Adaptation for Traffic Optimization)[1] is commonly used as a signal control system and is used in our system. MODERATO determines the cycle length and the split based on a quantity called the load factor, which is calculated from the volume of traffic entering the intersection and the length of a traffic light queue. Our system takes into account the queue length and therefore allows the green light to stay on longer for vehicles on a congested road that enter the intersection. Consequently, a traffic light queue caused by an increase in the volume of traffic entering the intersection can be prevented from getting longer or eliminated promptly. Our system uses probe data to increase the accuracy of an estimate of the length of a traffic light queue and to improve the signal control performance of MODERATO.

4-2 Estimate of traffic light queue length

Since the behavior of a probe vehicle can be obtained, information on where and when the vehicle has stopped becomes available. This information shows that a traffic light queue has reached the position where the vehicle is at a stop. However, the length of a traffic light queue extending beyond the vehicle cannot be detected from probe data. Therefore, the length of a queue extending beyond the probe vehicle is estimated by combining the probe data with detector data (**Fig. 3**). Vehicles at a stop behind the probe vehicle are considered to follow the probe vehicle. Our system uses this relationship to estimate the behavior of the vehicles following the probe vehicle based on the probe and detector data as well as the length of the traffic light queue extending beyond the probe vehicle. The probe data provide spatial information on the behavior of the probe vehicle, but not of other vehicles. The detector data provide information on all passing vehicles, but only pinpoint information at the location where the detector is installed. Our method combines these advantages and disadvantages of the probe and detector data in a complementary way.

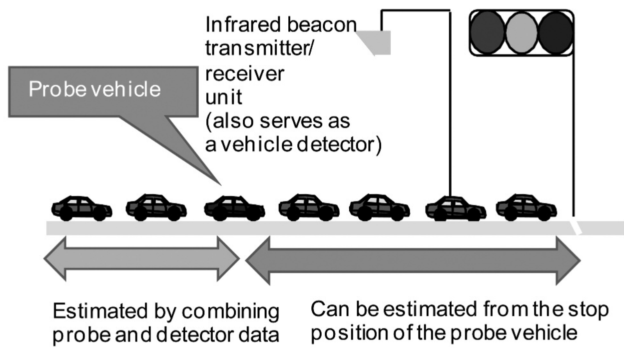

Fig. 3. Estimate of queue length

5. Simulation

A simulation experiment was conducted to evaluate the effectiveness of the system. VISSIM[2] was used as a traffic flow simulator. **Figure 4** shows the configuration of the simulation system. The information on the behavior of all vehicles output from the traffic flow simulator is used to determine the probe vehicle, and artificial probe data are generated from the vehicle behavior by a probe data generation simulator. The probe and detector data are input into the traffic flow control system to calculate a signal control command. The traffic lights in the simulator are controlled by the calculated signal control demand.

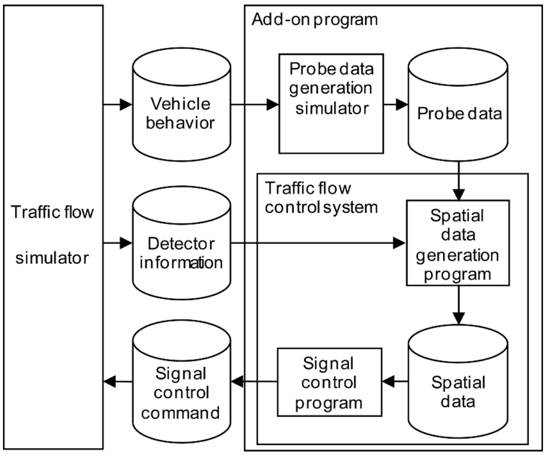

Fig. 4. Configuration of the simulation system

6. Evaluation Conditions

Intersections with frequent congestion were selected for simulation. Two detector installation configurations were considered: a multiple-detector configuration, which is the actual detector configuration, and a single-detector configuration where one detector is located on each road into the intersection (**Fig. 5**). The multiple-detector configuration is intended to evaluate the possibility of improving the effectiveness of signal control using probe data.

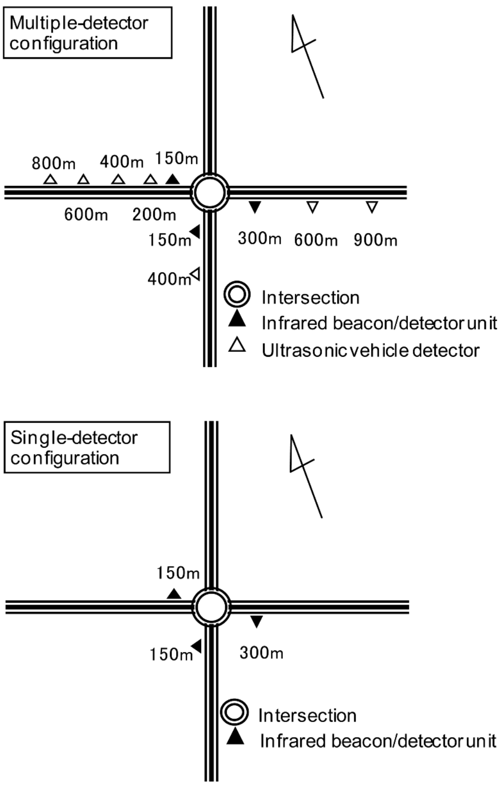

Fig. 5. Intersection detector configuration

The single-detector configuration is intended to evaluate the possibility of using probe data as an alternative means to a detector. Since probe data can be collected only from vehicles with an on-board probe unit, the percentage of vehicles with an on-board probe unit (hereinafter, the "probe vehicle ratio") is considered to have a significant effect on the signal control performance. The effect was evaluated for a probe vehicle ratio of 0 to 20% under each detector configuration. CO_2 emissions were used as an evaluation indicator, considering the issues mentioned in the introduction. A probe vehicle ratio of 0% under the actual detector configuration (with multiple detectors installed on each road into the intersection) at the selected intersections (which is the same as the actual condition) was used as the baseline for the evaluation of the effectiveness of signal control.

7. Results

Figures 6 and 7 are graphs of CO_2 emissions in a simulation with different probe vehicle ratios under the multiple-detector configuration and under the single-detector configuration, respectively. The horizontal axis is the probe vehicle ratio and the vertical axis is CO_2 emissions. CO_2 emissions are expressed as a ratio to the baseline value (the multiple-detector configuration, probe vehicle ratio of

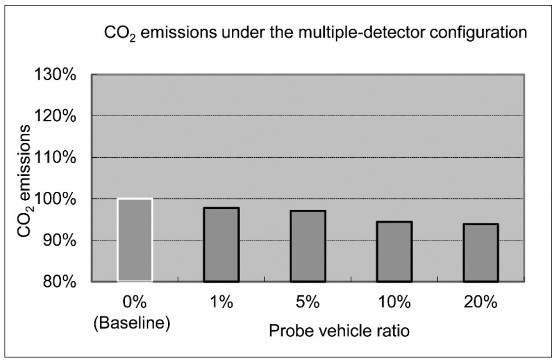

Fig. 6. Results of simulation under the multiple-detector configuration

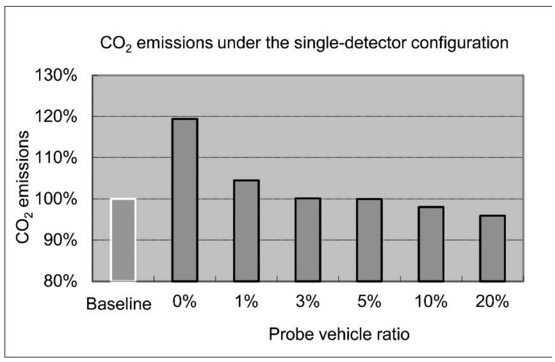

Fig. 7. Results of simulation under the single-detector configuration

0%). Under the multiple-detector configuration, CO_2 emissions decrease gradually but steadily with an increasing probe vehicle ratio. Under the single-detector configuration, CO_2 emissions significantly increase from the baseline value for a probe vehicle ratio of 0%, and rapidly decrease to the baseline value or less for a probe vehicle ratio of 3% or more as the probe vehicle ratio increases.

8. Discussion

Under the multiple-detector configuration, CO_2 emissions decrease with an increasing probe vehicle ratio. This indicates that the queue length at existing intersections with densely installed detectors can be measured more accurately using probe data, and the effectiveness of signal control can be improved. Under the single-detector configuration, an extended queue cannot be detected for a probe vehicle ratio of 0% due to a decrease in the number of detectors, resulting in a significant increase in CO_2 emissions. However, as the probe vehicle ratio increases to about 3%, the signal control becomes more effective due to the estimate of the queue length based on the probe data, resulting in the same level of CO_2 emissions as the baseline. The above indicates that with a certain number of probe vehicles on the road, the level of signal control currently achieved with multiple detectors can be achieved with one infrared beacon with detection capabilities.

9. Conclusions

A simulation showed that higher-performance signal control could be achieved with a smaller number of detectors using probe data. If this is achieved, we can solve the two apparently contradictory issues of reducing infrastructure installation cost and CO_2 emissions. In the next step, we will conduct not only a simulation but also a field evaluation to bring the system into practical use.

10. Acknowledgments

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Technical Terms

*1 UTMS Society of Japan: A general incorporated association that conducts study, research and development of universal traffic management systems (UTMS) based on advanced information and communication technology and disseminates their results.

*2 VICS (Vehicle Information and Communication System): An information and communication system that transmits traffic information in real time, such as queue and traffic control information provided by the Vehicle Information and Communication System Center, and displays the information on on-board devices, such as automotive navigation systems, with text and graphics.

References

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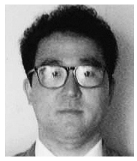

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