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Field Tests of Signal Control Using Probe Data

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Abstract
The National Police Agency, responsible for traffic management on surface roads in Japan, conducted a research study from FY2020 to FY2023 on the future of traffic control systems. In 2023, the final year of this research study, field tests of the signal control system using probe data as an alternative to vehicle detectors were conducted in Hyogo Prefecture. As of FY2024, UTMS society of Japan, which was commissioned to carry out this research study, is currently developing national standard specifications and implementation guidelines for nationwide deployment based on the results of these tests. This paper addresses the findings of the field tests and the associated challenges.

Keywords:
Signal Control, Probe Data

Issues of Existing Signal Control in Japan

An adaptive signal control system (1), which updates signal control parameters in response to changing traffic conditions, is widely in operation in Japan. This system achieves consistent signal control from unsaturated to oversaturated traffic conditions by using the load factor given by the formula LF = (V+Q)/S, where LF is the load factor, V is the traffic volume (number of vehicles/cycle), Q is the number of vehicles in the queue and S is the saturated traffic volume (number of vehicles/cycle). The load factor is defined by adding the number of vehicles in queue to the saturation degree (traffic volume divided by saturated volume), which serves as the conventional traffic indicator. And green time is assigned to each signal phase according to LF of each signal phase.

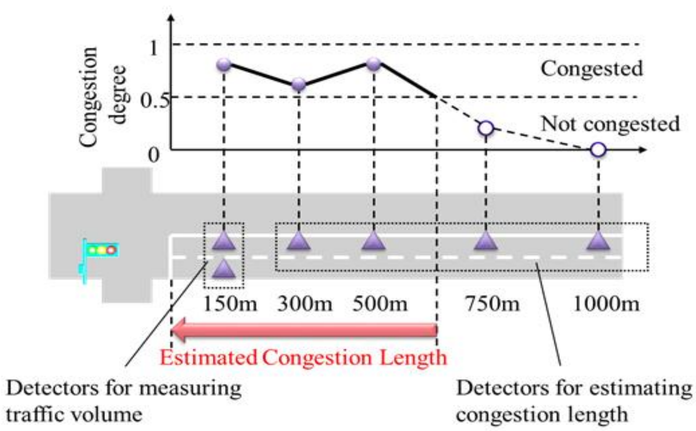

Figure 1 Standard detector layout

Regarding vehicle detectors that collect traffic information, ultrasonic vehicle detectors are commonly used. These detectors can accurately measure traffic volume and occupancy time for all vehicles traveling under them and can be utilized in real-time for signal control. However, for the queue measurement necessary to calculate LF, the queue cannot be detected unless it reaches the spot of vehicle detectors. Consequently, multiple vehicle detectors must be installed along the approach road, as illustrated in Figure 1. Additionally, it is essential to adjust threshold values, such as occupancy time, to judge whether the queue reaches the spot of vehicle detector. The ideal placement of vehicle detectors can also be challenging due to construction restrictions and other factors. Therefore, there are challenges related to installation, maintenance, operation, and overall management in queue measurement using vehicle detectors.

Aims of Using Probe Data

Probe data, which is traffic information derived from the trajectory (time and position) of a vehicle, has become increasingly available with the spread of connected vehicles in recent years, and can be used to collect vehicle delay times (signal waiting times), a basic evaluation indicator of signal control performance. It also has the advantages that there are no restrictions on the road sections to be collected. On the other hand, at present, probe data is limited to being collected only from specific vehicles, which arise issues in terms of availability, such as missing data and collection delays. In addition, it is easily affected by the behavior of individual vehicle, and is subject to restrictions on the aggregation method and aggregation unit (time, link) by the probe centers. In view of these characteristics, we set up the concept of the division of roles for signal control between probe data and vehicle detector data. The basic idea is to use vehicle detector data for traffic volume measurement and detection of the initial congestion, which is the transition from unsaturated to nearly saturated conditions. Specifically, vehicle detector data at the end of queue for one-cycle-signal waiting (corresponding to the 150 m position) is used. Probe data will be used to measure large-scale queue, such as during oversaturation. We also set the goal to reduce the total number of vehicle detectors by at least 50% and to reduce the burden of the overall management tasks associated with queue measurements by vehicle detectors.

Features of Probe data Used in the Field Tests

In Japan, VICS (Vehicle Information and Communication System) [2] has been in operation since the 1990s, providing traffic information, such as traffic congestion and traffic regulations, to car navigation systems using FM multiplex broadcasts and beacons. Currently, an experiment has been conducted by VICS center to collect average travel time information as probe data from traffic service providers, mainly car manufacturers in Japan, and to provide this aggregated traffic congestion information to general users via FM multiplex broadcasts. In our field tests, with a view to future operation, it was decided to use this probe travel time information (in units of links defined by VICS, in units of 5 minutes) generated by VICS center, which is already online with the traffic control centers and exchanging information in a secure and stable manner. However, the precondition of the field tests was to use historical probe data (past probe travel time information), which is assumed to be one of the initial forms of probe data use.

Field Test Overview

The field tests were conducted in August 2023 and January 2024 at seven intersections with different traffic conditions selected from urban and suburban areas in Hyogo Prefecture. In the field tests, the number of vehicle detectors was reduced from 122 heads to 53 heads overall (a reduction rate of 56.6%). Table 1 shows reduction rate of the number of vehicle detectors at each test intersection.

Table 1 Test intersections name and detectors reduction rate

Intersection Name	Kano-cho 3	Isogami-dori 1	Zeikan-mae	Hirano	Tarumi Keisatusyo mae	Hiyodori-goe	Chimori	Total
Num. of detectors	16 ↓ 8	12 ↓ 11	21 ↓ 7	21 ↓ 7	27 ↓ 9	12 ↓ 5	13 ↓ 6	122 ↓ 53
Reduction rate (%)	50.0	8.3	66.7	66.7	66.7	58.3	53.8	56.6

Preliminary Test Results

Detector data and probe data

During the preliminary survey of the test intersections, there were cases where the vehicle detector data and probe data differed significantly. As a typical example, the traffic situation (visual survey results, detector-measured queue length and probe travel time) during the morning peak hour (29/11/2023, 7:00-9:00) at the inflow-1 of Hiyodorigoe intersection is shown in Figure 2. Traffic congestion in the visual survey and the probe travel time were well synchronized, with both showing severe congestion from 07:00 to just before 09:00. The probe travel time is considered to have a certain degree of reliability, as a relatively large number of probe vehicles can be expected to be mixed in on the road, where traffic volumes are high and congestion occurs, which is the target of the signal control using prob data.

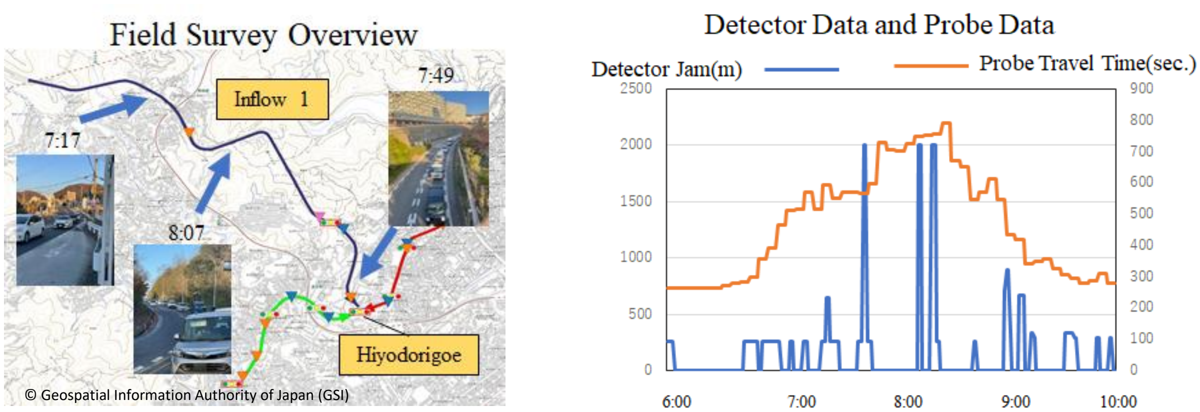

Figure 2 Comparison of field survey, probe data and detector data

On the other hand, vehicle detectors did not detect traffic congestion around the peak hour of 8:00 am. An example of vehicle detectors queue measurement for during peak hours is shown in Figure 3. Traffic congestion were frequently not detected by the vehicle detector at the 110 m position near the intersection. This is due to the fact that the vehicle detector is on a downhill slope, where travelling speed tends to be high, and that there tends to be a large departure delay at green lights (large vehicle headway time) caused by drivers' inattention due to driving in traffic congestion for long periods of time. From this, it is considered that the occupancy time measured by the detector dropped and that it was judged that there was no traffic congestion at the spot. The signal control system, on the other hand, is designed to control traffic arriving at the intersection. In the setting of the signal control system at this test site, the length of the queue is treated as 0 m if the queue start position is observed more than 400 m upstream from the intersection, as shown in Figure 3. Thus, it is confirmed that queue measurement with vehicle detectors is significantly affected by the adjustment of threshold values according to the location of the vehicle detectors and the surrounding environment. Therefore, probe data is expected to be one of the alternatives for queue measurement.

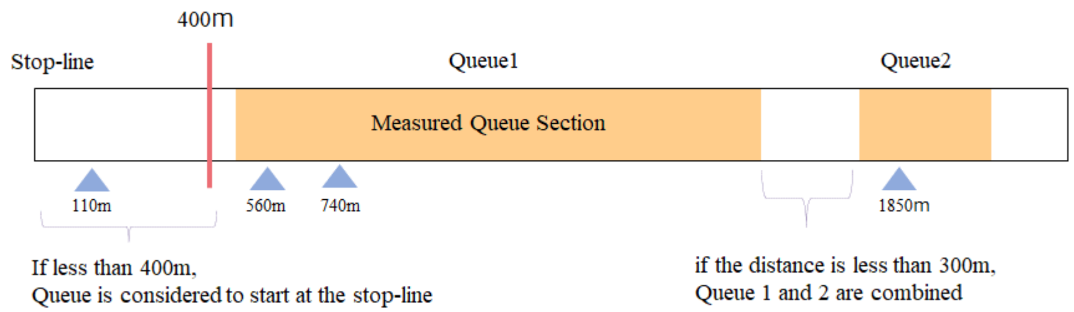

Figure 3 Example of detector measurement result

Challenges and solutions in using probe data

For effective signal control, it is essential to collect changes in traffic conditions continually. When replacing vehicle detectors with probe data, several issues arise, including missing data and collection delays. Additionally, as in this field test, there is a precondition to utilize past probe data. Here, the missing rate of probe data at the intersections in the test site ranged from 1% to 66% for each approach road, while the average collection delay was about 10 to 15 minutes—longer than the delay associated with vehicle detector data, which was approximately 5 minutes. In this field test, with the aim of verifying a technology designed to address the challenges of missing probe data and collection delays, a learning model (3) trained by past probe data (average travel time) and past vehicle detector data (traffic volume and occupancy time) was utilized. By inputting the current vehicle detector data into the learning model installed in the signal control system, the learning model outputs the current estimated travel time. This can be converted into the number vehicles in queue to calculate the load factor. An overview of the process is shown in Figure 4.

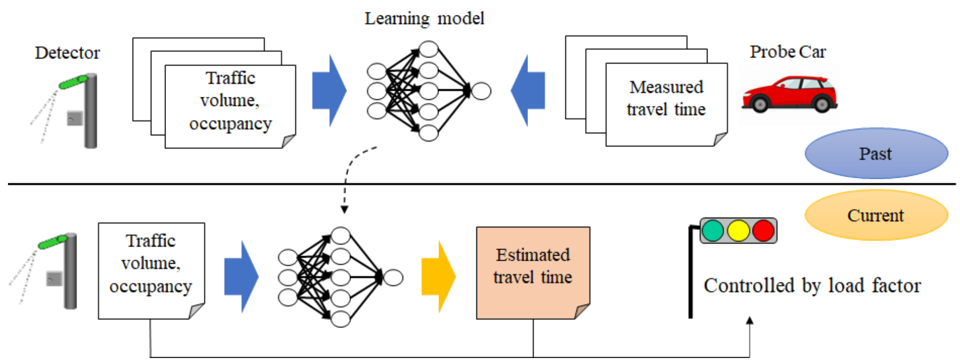

Figure 4 Overview of learning model method

Next, the estimated travel time accuracy is evaluated using the measured probe travel time acquired later as the true value. Figure 5 shows RMSE (root mean square error) at the time points over time (after 3, 6 and 9 months) after trained with one month of data. In the evaluation of the test intersections, the accuracy did not change over time and RMSE was generally ≤ 60 s, except for inflow-1 of Chimori. Here, it was assumed that the difference in estimated travel time is caused by the signal waiting time and that the signal waiting time can be calculated from the formula (probe travel time - (link length / regulated speed)). From the work of T. Ito and K. Tani [(4)], the vehicle delay time due to signal waiting can be approximately calculated by dividing the number of vehicles in queue by traffic flow rate. When traffic flow rate is 900 vehicles/hour (the maximum traffic volume at the test intersections) and the average error in delay time is assumed to be 60 s, the calculated average error in terms of the number of vehicles in the queue is 15 vehicles and the average error in terms of the length of the queue is approximately 105 m (when the average headway is 7 m). It is considered that the learning model can estimate the number of vehicles in the queue with an accuracy equivalent to the standard vehicle detector installation interval (200 to 250 meters) shown in Figure 1. Here, the average error in queue measurements by vehicle detectors is considered to correspond to the median of the detector installation interval, while the maximum error corresponds to the detector installation interval.

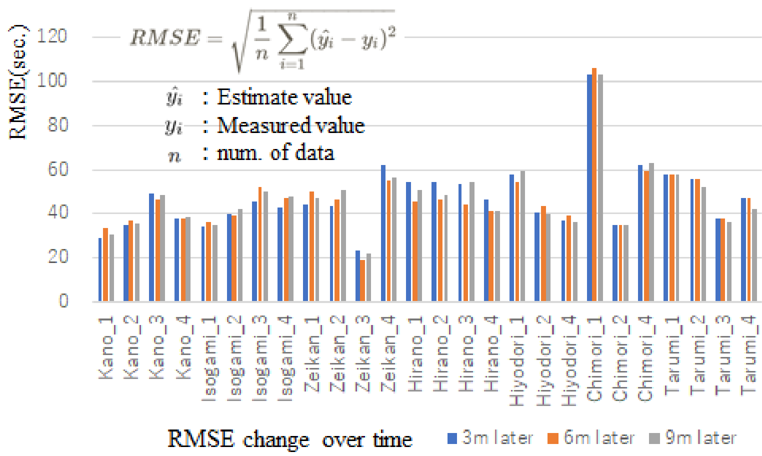

Figure 5 RMSE change over time

On the other hand, there is a strong positive correlation between RMSE of the estimated travel time and the standard deviation of the measured travel time, as shown on Figure 6.

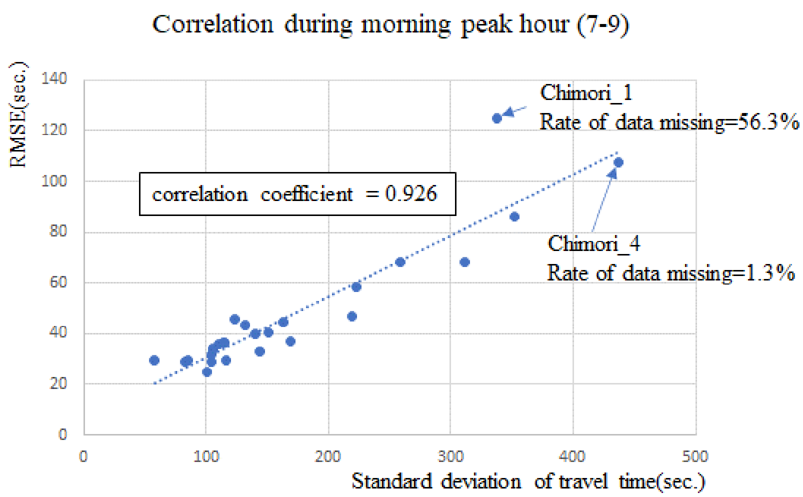

Figure 6 Correlation between RMSE and standard deviation of travel time during morning peak hour

The case of inflow-1 of Chimori, where RMSE exceeds 120 s, is assumed to be influenced by the large daily variation in travel time and the small amount of probe data available for training. There are also challenges in applying the learning model. Figure 7 shows the travel time on August 22, 2023, at the Inflow-2 of Isogamidori intersection, where an unexpected traffic congestion occurred due to spillback from the adjacent intersection. During around 11:00, the actual measured travel times (blue) were significantly different from the statistics travel time used for the learning data (green). And the estimated travel time (orange) could not reflect this increase in travel time. This shows the difficulty of accurately estimating traffic events that deviate from normal traffic conditions.

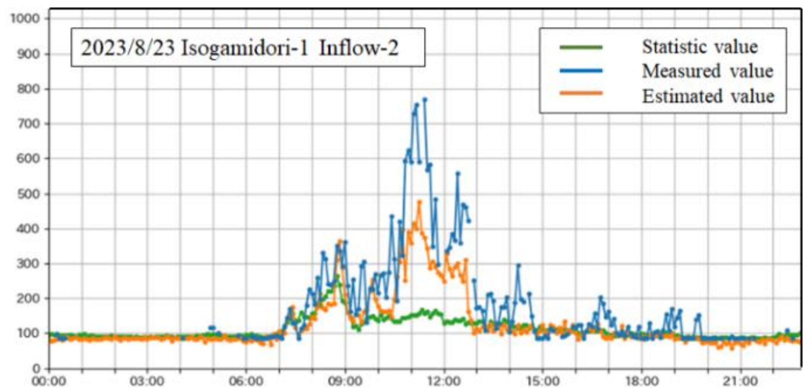

Figure 7 Comparison of static, measured and estimated travel time

Field Test Results

The performance of the signal control using probe data was evaluated by the total vehicle delay time given by the formula Σ(vehicle delay time × traffic volume), where vehicle delay time is given by the formula (probe travel time - (link length / regulated speed)), as shown in Figure 8.

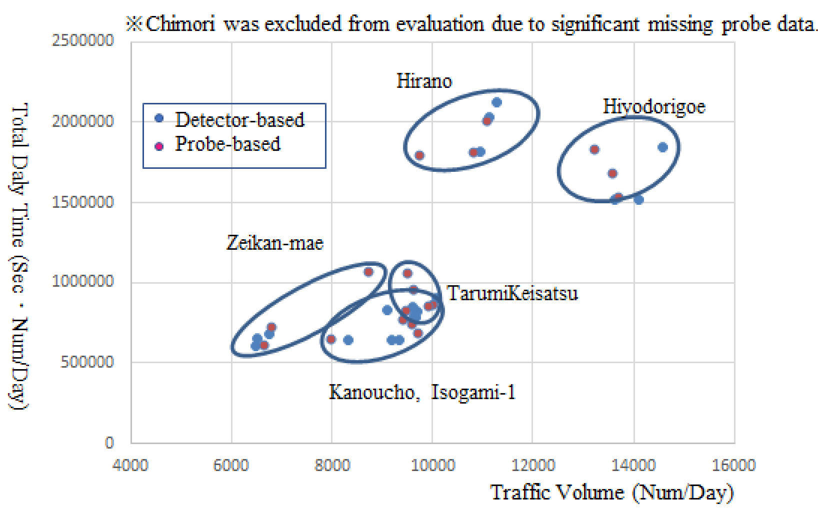

Figure 8 Total Delay Time of representative inflows of the main and sub directions

There was no congestion in the field tests caused by the use of probe data, and a comparison of total vehicle delay times showed a consistent correlation between traffic volume and total vehicle delay times in both the pre-test (detector-based: 9-11 January 2024) and post-test (probe-based: 16-18 January 2024), suggesting that comparable control performance was achieved.

Findings and Issues

The usefulness and challenges of signal control using probe data have become clear through the preliminary tests and the field tests. UTMS society of Japan is developing national standard specifications based on these results, as well as guidelines for nationwide deployment. The guidelines are addressing important considerations for system implementation and operation. Typical contents are as follows:

- When the probe data collection link is long such as exceeds 1 km, Vehicle delay times in the upstream section may be excessively added as vehicle delay times at the intersection subject to signal control.
- Probe data collected from VICS center has a larger collection delay compared to vehicle detector data. In addition, missing probe data may occur on roads with few probe vehicles.
- Signal control systems must ensure availability at all times. This requires supplementing missing probe data and mitigating the effects of collection delays using methods such as learning models verified in the field tests, statistical models and other techniques.
- Travel time estimation technologies such as learning models may not be able to respond effectively to unexpected congestion that differs from normal conditions. When considering the applicability of these technologies, it is important to take into account the importance of the intersection in traffic management.
- Probe data is becoming more widespread, and it is expected that the quality of probe data will improve as the rate of missing data and collection delays are reduced. In addition, by connecting traffic control systems and probe centers and collecting probe data in real time, it will be possible to respond to traffic situations when unforeseen events occur, thereby expanding the potential for probe data use.

Conclusions

This paper presents the results of field tests on signal control using probe data and the challenges for actual operation. In Japan, budgetary constraints on traffic management require more efficient traffic control systems. Probe data is expected to be a new source of traffic information for this purpose. UTMS society of Japan is working on the development of national standard specifications and guidelines for the nationwide development of a signal control system using probe data. Furthermore, UTMS society of Japan will continue to address various issues in traffic management and promote research and development of advanced traffic management solutions.

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