Evaluation of a Field Operation Test for an Expressway Bus Location System Utilizing DSRC

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1. Overview
A bus location system performs real time collection of the positions of buses by GPS put in the bus, and bus system operators use this information to manage its operations and provide customers with the positions of buses, expected arrival times and other information. This field operation test was undertaken to construct a new express bus location system that utilizes a 5.8GHz DSRC (Dedicated Short Range Communication) system linking roadside wireless devices installed on expressways with ITS on-board units installed on express buses. It was confirmed that the use of this system contributes to the improvement of road management, traffic control and the reduction of costs for collecting information. This report describes the progress of a field operation test in Kyushu in Japan and plans for future development of this system.

2. Overview of the express bus location system utilizing DSRC
(1) Whole image of the system
Bus location systems in use throughout Japan mainly adopt packet communication of cellular phones to collect information of each bus. The bus location system that has been constructed through this field operation test has adopted 5.8GHz-DSRC instead of packet communication as the road-vehicle communication system that collects information of express buses. The system uses DSRC communications between on-board ITS devices on the express buses and the roadside wireless devices installed on express bus routes at intervals of about 5 to 10 kilometers to collect the records of the movement of buses and transmits this information to a center. The bus center system transmits information such as present location of buses and their expected arrival time to display boards at bus stops, to personal computers, to cellular phones and so forth. through the
Internet. The information that is collected by the bus center system is used by the bus system operator to manage the operation of buses. The use of DSRC that is a free communication tool can lower overall running costs and because it can gather bus operation records (locations and times) on one second or every 15 meters, it can be used to obtain more detailed information of the road traffic.

(2) DSRC Communication with buses

Each roadside wireless device can use and control two frequencies: the ITS probe frequency (F3:5,785MHz, F4:5,775MHz) and ETC frequency (F1:5,805MHz, F2:5,795MHz).

Figure 2 shows the estimated travel time distribution of an approximately ten-kilometer expressway section. Floating vehicle data are aggregated in every fifteen minutes. The left figure is the travel time distribution just before traffic congestion occurs and the second figure from the left is the distribution during traffic congestion. The third figure from the left is the distribution when congestion is decreasing. And, the rightmost figure is the distribution after the congestion was relieved. Except the second
3. Installation of a bus location system in Kyushu

The Ministry of Land, Infrastructure and Transport of Japan has begun a full-scale introduction of express bus location systems as part of the Bus Traffic Revitalization Project since 2005. Systems using packet communications of cellular phones are now in use in six areas of Japan. Among these, systems adopting 5.8GHz-DSRC road-vehicle communication have been introduced on some routes in Kanto and Kyushu areas. Packet communication systems are going to be replaced by the 5.8GHz-DSRC communication tool after its effectiveness is verified by field operation tests.

In the Kyushu area, the test is underway on the Fukuoka - Kumamoto route where densely scheduled buses carry a large number of passengers (traveling time of about 2 hours, 100 round trips per day at approximately 10 minute intervals). Roadside wireless devices are installed at 27 locations on the inbound and outbound lanes of the expressway with length of 110km, and at 3 a bus terminal in the urban areas. All 71 busses traveling on this route are equipped with on-board devices.

Figure 4: Areas where Express Bus Location Systems have been installed
4. Verification of effectiveness and future development of systems utilizing DSRC

Through the field operation test in actual transport in the Kyushu area, verification of the following items was carried out with regard to the effectiveness of the location system for expressway route buses based on the probe data on cruising records gathered during traffic congestion and on a regular basis, the data on the calculated results for travel time based on this, data on the detection of abnormal cruising, and so forth.

(1) Accuracy of calculations on the travel time between beacons

Objective) An evaluation of the accuracy of average travel times between beacons is carried out with vehicles equipped with ETC on-board units, and issues for the application of practical operation are identified.

(2) Accuracy of the detection of traffic congestion and abnormal cruising

Objective) An evaluation is carried out on the practical use of the specification of the locations of the starting and ending points of traffic congestion and locations where there are swerving vehicles.

(3) Accuracy of expected arrival time

Objective) Measures to improve the accuracy of expected arrival times with the effective utilization of not only bus stop passage information using the existing packet communications units but also information on travel times between beacons and so forth is examined.

(4) Effectiveness in reducing costs, etc.

Objective) The effectiveness in reducing packet communications costs is verified.

In particular, of the things mentioned above, this paper covers an evaluation of the logic of detection and the results obtained with regard to the detection of traffic congestion (behavior of the starting and ending points) and abnormal cruising (behavior of vehicles and abnormalities in tracks).

(1) Logic and evaluation of the detection of the starting and ending points of traffic congestion

For the detection of traffic congestion using probe data on cruising records, the road is divided into links in units of 100 m as shown in Figure 6. The average speed of passing vehicles is estimated from the speed information recorded with the on-board units in each link, and the determination of traffic congestion is carried out with the following procedure.

[Method for determining traffic congestion]

The average speed of passing vehicles over one minute $V_1$ (Formula (1)) is sought, and traffic congestion (starting and ending points) is detected with the link speed that is generated by the weighted average speed over the past five minutes $V_5$ (Formula (2)).

$$
\bar{V}_1 = \frac{n}{\sum_{i=1}^{n} V_i} \quad \text{*** Formula (1)}
$$

$V_i$ is the average speed for the link, and $n$ is the number of vehicles

$$
\bar{V}_5 = \frac{\sum_{i=1}^{Q(i)} V(i)}{\sum_{i=1}^{Q(i)}} \quad \text{*** Formula (2)}
$$

$V(i)$ is the average speed for the link over one minute, and $Q(i)$ is the number of vehicles.

Actual road traffic information (January 3, 2007, 3 p.m.~5 p.m., 112.5 KP, peak length of traffic congestion: 25.5 km) and traffic congestion information detected with the above formulates are compared, and the detection of traffic congestion with probe data on cruising records is assessed. Graphs of the average link speeds of two buses cruising during traffic congestion are shown for the time of the peak of the traffic congestion (Figure 7) and for the time when the traffic congestion is easing (Figure 8). When the average speed is 60 km/h or below, it is determined to be “crowded” and when the average speed is 40 km/h or below it is determined to be “traffic congestion.”

In terms of an evaluation of the detection of traffic congestion using probe data on cruising records, since the average speeds for link units can be obtained, there are advantages such as “the fact that changes in
the status of the occurrence and elimination of traffic congestion can be grasped in detail,” and “the fact that the locations of the starting and ending points of traffic congestion and the traffic congestion distance are clarified.” Furthermore, it is possible to specify traffic congestion over short distances and the locations of the ending point and starting point of traffic congestion, which were difficult to detect with existing sensors, and it is judged that a contribution to the appropriate provision of information to users will be possible.

![Average speed at time of peak of traffic](image1)

**Figure 7** Average speed at time of peak of traffic

![Average speed at time of easing of traffic](image2)

**Figure 8** Average speed at time of easing of traffic

(2) Logic and evaluation of the detection of abnormal cruising

In order to grasp the status of the discovery of accident vehicles stopped on the road and obstacles on the road and construction accompanied by traffic regulations in real time, the detection of the circumstances of the abnormal cruising of passing vehicles is effective. Evaluation was carried out with the following three methods for the detection of abnormal cruising using the cruising tracks of the probe data on cruising records in this system.

1) Logic of detection of abnormalities in the tracks of vehicles

The current cruising positions (transverse direction) and past vehicle cruising positions (transverse direction) are calculated for the duration of several hours, and the sections where differences between them are changes at or above certain figures (set as threshold amounts) are determined to be abnormalities in tracks.

![Abnormality in cruising track](image3)

**Figure 9** Abnormality in cruising track
The average figure for the amount of deviation in the track over one minute \( W_i \) (Formula (1)) and the average figure for the amount of deviation in the track over the past 60 minutes (standard amount of deviation) \( W_{60} \) (Formula (2)) are calculated for the road link units being measured, the difference between the standard amount of deviation and the amount of deviation in the track \( K \) (Formula (3)) is sought, and in the case of difference value \( K \) being at or above the threshold amount, it is determined to be an abnormality in track.

\[
W_i = \frac{\sum w_i}{Q} \quad \text{*** Formula (1) } w_i \text{ is the average deviation amount in the link, and } Q \text{ and } n \text{ are the number of vehicles.}
\]

\[
W_{60} = \frac{\sum_{i=1}^{Q_{(i)}} w_{i(i)}}{\sum_{i=1}^{Q_{(i)}}} \quad \text{*** Formula (2) } W_{i(i)} \text{ is the average deviation amount in the link and } Q_{(i)} \text{ is the number of vehicles.}
\]

\[
K = |W_i - W_{60}| \quad \text{*** Formula (3)}
\]

2) Logic of detection of abnormalities in the distribution of vehicles

The cruising position distribution and past cruising position distribution averaged for the road link unit are compared, and when the differences are at or above certain figures (set as threshold amounts), a bias in the cruising position (abnormality in the track distribution) is determined to have occurred.

\[
S_{15} = \sqrt{\frac{\sum_{i=1}^{n} (W_{i(i)} - W_1)^2}{n-1}} \quad \text{*** Formula (1) } W_{1(i)} \text{ is the average deviation amount in the link over one minute, and } n \text{ is the number of vehicles.}
\]

\[
S_{60} = \sqrt{\frac{\sum_{i=1}^{n} (W_{i(i)} - W_{60})^2}{n-1}} \quad \text{*** Formula (2) } W_{1(i)} \text{ is the average deviation amount in the link over one minute, and } n \text{ is the number of vehicles.}
\]

\[
D = |S_{15} - S_{60}| \quad \text{*** Formula (3)}
\]

3) Logic of detection of abnormalities in the behavior of vehicles

The amount of change in speed, degree of acceleration, and angular velocity are sought from the ITS on-board devices and are calculated for the road link units. In the case that a situation occurs in which these are above certain figures (set as threshold amounts), it is determined to be an abnormality.
<table>
<thead>
<tr>
<th>No.</th>
<th>Item for determination of behavior</th>
<th>Overview</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>Abnormality in deceleration</td>
<td>Detection of abnormality in decrease of speed (deceleration direction) in the road link</td>
</tr>
<tr>
<td>(2)</td>
<td>Abnormality in acceleration</td>
<td>Detection of abnormality in increase of speed (acceleration direction) in the road link</td>
</tr>
<tr>
<td>(3)</td>
<td>Abnormality in change in acceleration</td>
<td>Detection of abnormality in rapid acceleration / deceleration from the change in acceleration in the road link</td>
</tr>
<tr>
<td>(4)</td>
<td>Abnormality in change in angular velocity</td>
<td>Detection of abnormality from the change in angular velocity in the road link</td>
</tr>
<tr>
<td>(5)</td>
<td>Abnormality in maximum value in the distribution of cruising positions</td>
<td>Detection of abnormality in the position change in the transverse direction in the road link</td>
</tr>
<tr>
<td>(6)</td>
<td>Abnormality in change in speed between links</td>
<td>Detection of abnormality in significant change in speed between road links</td>
</tr>
</tbody>
</table>

(1) Determination of abnormality in deceleration  
For abnormalities in deceleration, an abnormality is determined in the case that the maximum value $V_{gapMAX}$ (Formula (1)) of the difference between the speed when entering $v_{IN}$ and the speed when exiting $v_{OUT}$ the link on the cruising track passing through the road link which has been measured for the past five minutes is at or above the threshold amount.

$$- V_{gapMAX} = v_{OUT} - v_{IN} \quad \cdots \text{Formula (1)}$$

(2) Determination of abnormality in acceleration  
For abnormalities in acceleration, an abnormality is determined in the case that the maximum value $V_{gapMAX}$ (Formula (2)) of the difference between the speed when entering $v_{IN}$ and the speed when exiting $v_{OUT}$ the link on the cruising track passing through the road link which has been measured for the past five minutes is at or above the threshold amount.

$$V_{gapMAX} = v_{OUT} - v_{IN} \quad \cdots \text{Formula (2)}$$

(3) Determination of abnormality in change in acceleration  
For abnormalities in change in acceleration, an abnormality is determined in the case that the maximum value $G_{gapMAX}$ (Formula (3)) of the difference between the maximum acceleration $g_{MAX}$ and minimum acceleration $g_{MIN}$ inside the link on the cruising track passing through the road link which has been measured for the past five minutes is at or above the threshold amount.

$$G_{gapMAX} = g_{MAX} - g_{MIN} \quad \cdots \text{Formula (3)}$$

(4) Determination of abnormality in change in angular velocity  
For abnormalities in change in angular velocity, an abnormality is determined in the case that the maximum value $\omega_{gapMAX}$ (Formula (4)) of the difference between the maximum angular velocity $\omega_{MAX}$ and minimum angular velocity $\omega_{MIN}$ inside the link on the cruising track passing through the road link which has been measured for the past five minutes is at or above the threshold amount.

$$\omega_{gapMAX} = \omega_{MAX} - \omega_{MIN} \quad \cdots \text{Formula (4)}$$

(5) Determination of abnormality in maximum value in the distribution of cruising positions  
For abnormalities in maximum value in the distribution of cruising positions, an abnormality is determined in the case that the maximum value $S_{SMAX}$ (Formula (5)) of the standard deviation of the amount of deviation from the track over the past five minutes is at or above the threshold amount.

$$INOUTgapMAX vvV \quad \cdots \text{Formula (5)}$$
\[ S_{\text{MAX}} = \sqrt{\frac{\sum_{i=1}^{n} (W_{\text{t}i} - \bar{W})^2}{n-1}} \]  

**Formula (5)**  
- \( W_{\text{t}i} \) is the average deviation amount in the link over one minute, and \( n \) is the number of vehicles.

(6) Determination of abnormality in change in speed between links

For abnormalities in change in speed between links, an abnormality is determined in the case that the maximum value \( V_{\text{link}} \) (Formula (6)) of the difference in average speeds in adjacent road links being measured is at or above the threshold amount.

\[ V_{\text{link}} = V_{\text{link}(i)} - V_{\text{link}(i-1)} \]  

**Formula (6)**

The detection of abnormal cruising with the probe data on cruising records is evaluated, comparing the actual road traffic events (January 6, 2007; 16 cases: all lane regulation, lane regulation) and the results of the detection of abnormal cruising with the three methods indicated above. The results of the comparison with the road traffic events are shown in Chart 1.

**Number of cases detected:** Number of cases of abnormal cruising detected as a cruising abnormality by the system

**Decreases in position accuracy:** Number of cases of detection due to an abnormality in the probe data on cruising records (GPS) due to covering objects and so forth.

**Bus stop position:** Number of cases detected as a bus stopping at a bus stop

**Number of event concordances:** Number of cases of concordance with the road traffic event

**Difference in number of cases:** Difference with the number of event concordances excluding decreases in position accuracy and bus stop position

<table>
<thead>
<tr>
<th>No.</th>
<th>Item for determination of behavior</th>
<th>Number of cases detected (number of links)</th>
<th>Decreases in position accuracy</th>
<th>Bus stop position</th>
<th>Event concordances</th>
<th>Difference in number of cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Abnormality in vehicle track</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>Abnormality in the distribution of vehicles</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3-1</td>
<td>Abnormality in deceleration</td>
<td>48</td>
<td>0</td>
<td>48</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3-2</td>
<td>Abnormality in acceleration</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3-3</td>
<td>Abnormality in change in acceleration</td>
<td>25</td>
<td>3</td>
<td>2</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>3-4</td>
<td>Abnormality in change in angular velocity</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3-5</td>
<td>Abnormality in maximum value in the distribution of cruising positions</td>
<td>4,777</td>
<td>1936</td>
<td>671</td>
<td>12</td>
<td>2,158</td>
</tr>
<tr>
<td>3-6</td>
<td>Abnormality in change in speed between links</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The detection of abnormal cruising uses the vehicle movement track and vehicle speed pulse generated from vehicle position information measured with GPS and the measures of gyro sensors. The number of cases actually measured differed from the 16 cases for the number of cases of actual road traffic events, and the difference was bigger than initially expected, taking into consideration the current measurement accuracy of GPS.

The detection of abnormalities was zero cases for both abnormalities in vehicle track and abnormalities
in the distribution of vehicles, and there is a possibility that the specificity of the target vehicles being buses and the traffic volume of buses of around one bus every 10 minutes had an effect on detection. As the detection method itself is statistical processing, assessment cannot be expected to be valid unless there is vehicle information of three or more vehicles per minute. Thus, it seems that there is a need to implement the detection based on an appropriate traffic volume.

For abnormalities in vehicle behavior, even excluding mistaken detection due to decreases in position accuracy and bus stop position, for each item there was a significant difference with the number of events at 16 cases. In particular, with regard to abnormalities in maximum value in the distribution of cruising positions, there is a concentration of mistaken detections at spots where there are decreases in the position accuracy of GPS (urban areas where there are many covering objects, mountain areas with poor visibility, etc.). The threshold amount for carrying out the determination of abnormalities is set at a theoretical assumed value, so based on the current results, going forward there is a need to review the threshold amounts and enable the setting of thresholds for road link units in accordance with the characteristics of road formats. Also, when there is little vehicle information, it necessary to carry out detection taking measures such as utilizing past statistical results.

(3) Future development

Based on the results of the evaluation with a view toward practical use, there are plans to promote examination regarding the expansion of the introduction of bus location systems and the development of technology for the provision of road traffic information utilizing 5.8GHz-DSRC.

Furthermore, the expansion of roads and the provision of information to bus companies will be added to existing information on passing times and travel times between bus stops, and traffic information will be newly provided.

Acknowledgment

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