ABSTRACT

The amendment of the Road Transportation Law effective February 2002, along with increased ridership and frequency of bus services along extended highways, has resulted in a greater need for required travel time information service for users. At the same time, the traffic engineering technology of traffic counter or probe-car can more accurately read real-time traffic volume and speed in the real world. From this background, a required time prediction system using legacy traffic counters and emerging probe technology for expressway bus is being studied to put a system in service operation in 2005. The method that is put forward in this paper is based on the traffic conditions of subject route sections and
facility availability.

**STUDY BACKGROUND AND OBJECTIVE**

The amendment of the Road Transportation Law effective in February 2002 has deregulated transit bus operators’ business. They are taking the initiative to extend their business remit and operation routes, and to revise the fare system. Start-up companies are also coming into the market. Additionally, the extension of expressway networks entices transit operators to increase the operational frequency or to extend operation courses. These efforts, together with a lower fare when compared to rail travel, are attracting more passengers recently. A current issue that has caused a concern for their operations is unexpected delays due to traffic congestion. A time-sensitive traveler is definitely reluctant to travel by bus. On this score, an accurate and timely information service on travel required time at primary traffic node points such as bus terminals will be beneficial for travelers, enhancing the transit serviceability and reliability of bus operations.

The expressways extending throughout Japan are generally equipped with traffic counters at shorter intervals by each jurisdictional administrator, enabling the systems to sense traffic volume and speed in real time. Moreover, the emerging probe-car allows a vehicle to identify its own positioning and to transmit the data. The key to the future system development is the effective and efficient use of these technologies. The paper introduces the study on a required time prediction system based on the data from traffic counter and probe-car and predicts travel time to inform travelers of the forecast promptly.

**SUBJECT ROUTE SELECTION**

Scheduled facility openings in Nagoya are the Central Japan International Airport (CJIA) in February 2005, followed by Expo 2005 Aichi Japan during March to September 2005 successively. Anticipating the new facility and events, expressway bus operation linking the new international airport and the metropolitan

![Figure 1: Subject route](image)
Nagoya is scheduled to be operational by that time. Aiming to further transport service enhancement, a case study on travel required time has been conducted, and an information dissemination system has been studied, using the expressway bus route section between CJIA and Sakae terminal in the central Nagoya (Figure 1).

**APPROACH FOR REQUIRED TIME PREDICTION**

**RATIONALE**

The currently available required time information along expressways is based on data from traffic counters, which have been installed at expressways across the nation. The offered time information is derived by calculating travel time over sections by the time of day, and then adding each sectional time to determine the time prediction over the required sections (an approach referred to as an ‘instant value’). This approach of an instant value reflects barely any change in the closer future traffic conditions in the calculations. As a result, the occasional error range in prediction, with respect to the elapsed travel time in real travel, is too large to be neglected. In order to enhance reliability of travel time predictions, the travel time over each section has to be extrapolated and predicted for a destination based on the anticipated future conditions (referred to as ‘a time slice value’).

![Figure 2: Instance value and time slice value](image)

**OUTLINE ON APPROACH FOR TIME PREDICTION**

**MACRO SIMULATION APPROACH (I/O METHOD)**

The approach using macro simulation uses traffic flow simulation to extrapolate futuristic traffic volume and gather required travel time to the given destinations. In simulating each link, the expected futuristic traffic volume data is input and the correlation of traffic volume and density (QK pattern) is used to extrapolate required travel prediction time. This approach necessitates more precise real time data (traffic volume every five minutes) from traffic counters. The real-time data is additionally input to modify the simulated conditions. This
approach enables the simulation to replicate with high precision the ever-changing conditions, particularly the onset of tie-up formation and dispersion. Compared to congestion conditions to other locations, a section between Otaka ramp and Marunouchi ramp along Nagoya Expressways has been selected for a simulation case study.

STATISTICAL APPROACH
A statistical approach is used to extrapolate future travel time based on statistic of historical data. The probe-bus is used to collate and store the required data. The probe-bus has an available sensor to detect conditions in sections where a traffic counter is not installed. Since the statistical approach uses historical data for travel time predictions, it is all but impossible to extrapolate the required travel time over the sections where any gap in traffic conditions is large day by day. In view of this, the approach is used for the sections where congestion scarcely occurs (Central Japan International Airport Link Road, Chita-o-dan Road, Chita-hanto Expressway, Ordinary roads), not along Nagoya Expressways.

SYSTEM CONFIGURATION
Figure 4 illustrates a predicted travel time information service system.

DATA COLLATION
The legacy traffic counter enables the collation of traffic data on operational volume and speed at five minute intervals. A transit bus with a probe system can transfer the data of its position and the time. Other required data on road works, accidents and
expressway closures is provided by each jurisdictional operator.

**REQUIRED TIME CALCULATION**
The data in real time is transferred online to a traffic center and is issued in both simulation and statistical approaches to extrapolate the required travel time.

**INFORMATION SERVICE**
The extrapolated figures for the required time are supposed to be relayed to message boards at airport, bus terminal or other public places to enhance transport serviceability to bus passengers.

**STUDY ON SIMULATION APPROACH**

**OUTLINE OF I/O METHOD**
The parameter which needs to be input to I/O simulation modeling is illustrated in Figure 5. They are QK pattern, traffic capacity, inflow volume and demerging ratio. The QK pattern sets up a relation of traffic volume (Q) with density (K) and decides traffic capacity at each link. Thus, the extrapolation figure is determined through an interrelation among traffic volume, density and speed. Fundamental shift patterns are created using stored data on the inflow traffic volume and demerging ratio as time lapses. When simulating, a modification is made using the real time data for these patterns.

**STUDY ON MACRO SIMULATION**

**SETTING OF QK PATTERN AND TRAFFIC CAPACITY**
The historical data from the traffic counters (data collated for 91 days, at five minute intervals during a period between September 1st, 2001 to November 11th, 2001) has provided a basis for the creation of a QK pattern and quantity figure of traffic volume for each link. The pattern and volume data are input to road networks. In order to evaluate and verify both sets of figures for QK pattern and traffic volume data, the precision is reviewed through the replications of the current conditions.
CREATING FUNDAMENTAL PATTERNS FOR INFLOW VOLUME AND DEMERGING RATIO
The historical data on traffic volume from the traffic counters (data collated for 91 days, at five minute intervals during a period between September 1st, 2001 to November 11th, 2001) has been statistically processed to provide a basis for the creation of a fundamental shift pattern for inflow traffic volume and demerging ratio as time lapses. These inflow volume and demerging ratio represent figures at sections of ramp and link-ends. The traffic features in the subject sections are reviewed to break down into fundamental patterns.

MODIFICATION METHOD USING TRAFFIC COUNTER DATA
The inflow traffic volume and demerging ratio based on the fundamental patterns are used as predicted figures and input into simulations. The traffic condition in the real world varying with day of week never matches with the prepared fundamental patterns. This is a reason to use real-time data from traffic counters to modify the fundamental patterns to input parameters into simulations.

REVIEW ON PRECISION IN PREDICTION
The simulation outcome and the measured travel time in the real world have been juxtaposed, with a variance indicating an error rate in the 95 percentile, or less than five minutes. In simulation, the input parameters based on the descriptions in the above item (1), (2) and (3) were used. Furthermore, compared both to the average figures sought by statistical approach and currently available required time information as the instant value, the validity of simulation approach has been carefully examined.

STUDY OUTCOME
SETTING OF QK PATTERN AND TRAFFIC CAPACITY
In order to verify the QK pattern and traffic capacity to be set for simulations, a trial calculation was conducted using inflow traffic volumes and demerging ratios in the real world. The outcome of the trial calculation shows that the average error range in travel time is about one minute, and all samples fall within five minutes. The outcome has proved the validity of the data.

Figure 6: Simulation figures compared to traffic counter figures
FUNDAMENTAL PATTERNS FOR INFLOW TRAFFIC VOLUME AND DEMERGING RATIO

The time sequential traffic volume shift is classified into several fundamental patterns: shifts in day of week, seasonal shifts (monthly), shifts due to weather conditions, impacts in monthly accounting day limits of the 5th and 10th of every month, and busy periods (extended holiday seasons ‘the beginning of May, middle of August, New Year’s break). As well, the impact of each period has also been analyzed.

The outcome of the analysis shows traffic volume for day of week and hour of day varies with weekday, weekend and Sunday or holiday. The rudimentary patterns to cope with these have been generated.

Furthermore, analysis has been conducted on traffic ‘busy periods.’ The traffic volume for hour of day in a rudimentary pattern of ‘busy periods’ shows a difference from one weekday, but the volume itself was almost the same as weekdays and particularly, no tie-ups were observed. The ‘busy days’ defined here fall on a different day of week each year, and also the chance to gather relevant data is limited to once a year. Again, road developments and network extension are progressing year by year. These inconsistencies invalidate the data collected in previous years. For the reasons listed above, the ‘busy days’ have not actually formed a pattern, but each day of that relevant period falls into relevant rudimentary patterns.

In the research of this study, the particular differences resulting from traffic volume in season, weather, or days of monthly accounting activities have not been clearly identified. For this reason, the relevant pattern has not been created either.

MODIFICATION METHOD BY TRAFFIC COUNTER DATA

A certain ratio of the measured data by traffic counter and the created rudimentary pattern has been set up as a modification coefficient, and is used for prediction input figures. The 11 types of the prediction input figures, with respect to modification coefficient, range from 0.0 to 1.0, with increments of 0.1 degree. The prediction input figure is compared to the measured data of five minute intervals to set up a modification coefficient with a minimum error range (Figure 8 and Figure 9).
REVIEW ON PREDICTION PRECISION

Table 1 and Figure 10 list the test results on precise predictions in macro simulations. In the case of predictions ranging in advance from five minutes to 30 minutes ahead of the present time, the identified error range produced a 95 percentile within five minutes. When the prediction was extended to 60 minutes ahead of the present time, a 95 percentile exceeded five minutes. Both trends in predicted travel time and measured time are nearly consistent.

Next, the predicted required time by simulation is compared to the average figure of the measured historical data determined from statistics. Alternatively, the required time is calculated using an instance value method, followed by some simulations to determine the precision of the results.
Since the average figure cannot accurately reflect the traffic conditions of a particular day, the gap from the average value may increase the error range. Meanwhile, an instant value is available with higher precision, particularly when predicting 5 to 15 minutes ahead of the present time. However, when predicting 30 to 60 minutes ahead of the present time, the results lag considerably behind the real occurrence, particularly when tie-ups form or disperse. A predicted figure with the minimum error range is the simulation result of 5 to 30 minutes ahead of the present time. The observed error range becomes larger when predicting 60 minutes ahead, but peak hours still converge with actual results.

With consideration of the abovementioned results, the simulation approach, as compared to the other two methods, (1) can include traffic conditions of the subject day; (2) has a shorter time lag even during peak hours, and can be verified.

### STUDY ON STATISTIC METHOD

**OUTLINE OF PROBE-CAR**

A probe-car is a car transformed into a mobile sensor device to monitor traffic conditions. The individual vehicle positioning or operational behaviors are monitored by the system on board. The data provided by a probe-car is uninterrupted in terms of time and space, and allows operational traffic speed, travel time on each section and presence/absence of tie-ups to be identified in real time along roads.

![Figure 11: Conceptual image of probe-car](image)

### RATIONALE OF STATISTICAL METHOD USING PROBE-CAR

The probe data gathered for each section provides input for calculating the travel time for each section. Such accumulated data is used to form a fundamental shift pattern in travel time. Further, probe data gathered on the subject day for prediction simulations is utilized for the
pattern modification when required to achieve futuristic travel prediction accurately.

The following three modification methods are reviewed: 1) A fundamental shift pattern for required time is identified as the prediction figure itself (Draft 1); 2) a gap between the required time of the fundamental shift pattern and travel time of the leading bus in real operation is used for a modification on predictions (Draft 2); 3) not only a gap between the fundamental shift pattern and travel time of the leading bus in real operation, but also a certain ratio (modification coefficient) between the leading bus operation data and the data of the bus before the leading bus is used for a prediction in future required time (Draft 3).

![Diagram of required time and fundamental shift pattern](image)

**Figure 12: Rationale of statistical method using probe-car**

**STUDY ON PRECISION USING BUS-PROBE**

**SUBJECT COURSE SELECTION**

Since probe-car is currently not available in sections between CJIA and Sakae bus terminal, probe-data on a bus course between Tokyo and Tsukuba is selected due to equivalent traffic and vicinity conditions and is provided to determine the precision of the approach.

<table>
<thead>
<tr>
<th>Classification</th>
<th>Route</th>
<th>No. of lane</th>
<th>Daily traffic</th>
<th>Operation speed in peak hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject Route (Section in statistic approach)</td>
<td>Chita-hanto Expressway (Handa-Tokoname Junction - Otaka Interchange)</td>
<td>4</td>
<td>39,651 vehicles /day (9,912 /lane)</td>
<td>81.5 km/h</td>
</tr>
<tr>
<td>Equivalent Route (Section verified by probe-data)</td>
<td>Joban Expressway (Sakura-Tsuchiura Interchange - Misato Junction)</td>
<td>6</td>
<td>78,052 vehicles /day (13,008 /lane)</td>
<td>96.9 km/h</td>
</tr>
</tbody>
</table>

Source: 1999 Road Traffic Census
FUNDAMENTAL PATTERN SETTING
The average hourly travel time between the specified points (interchange or cross-section) is determined using stored probe-data and made into a fundamental pattern.

STUDY OUTCOME
Table 4 lists the precision study outcome. Generally, since Joban Expressway is free of congestion, the predicted travel time advancing 60 minutes ahead of the present time only includes a small error range of 2 minutes. The statistical approach based on probe-data is valid for time predictions. Again, an error range using a modification coefficient is small. A fundamental pattern itself is also valid in terms of prediction precision.

<table>
<thead>
<tr>
<th></th>
<th>Joban Expressway (Sakura-tsuchiura Interchange – Misato Junc.)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 minutes ahead</td>
</tr>
<tr>
<td>Draft 1</td>
<td>2.44</td>
</tr>
<tr>
<td>Draft 2</td>
<td>2.64</td>
</tr>
<tr>
<td>Draft 3</td>
<td></td>
</tr>
<tr>
<td>r = 0.1</td>
<td>2.50</td>
</tr>
<tr>
<td>r = 0.2</td>
<td>2.64</td>
</tr>
<tr>
<td>r = 0.3</td>
<td>2.61</td>
</tr>
<tr>
<td>r = 0.4</td>
<td>2.68</td>
</tr>
<tr>
<td>r = 0.5</td>
<td>2.81</td>
</tr>
<tr>
<td>r = 0.6</td>
<td>2.95</td>
</tr>
<tr>
<td>r = 0.7</td>
<td>3.16</td>
</tr>
<tr>
<td>r = 0.8</td>
<td>3.13</td>
</tr>
<tr>
<td>r = 0.9</td>
<td>3.07</td>
</tr>
</tbody>
</table>

CONCLUSION
The study has been conducted on an information system for predicted arrival time for bus using the existing traffic counter and probe-data technology. A careful review and analysis has been carried out on traffic conditions and facility availability over the subject sections and proposes that a combined approach of macro simulation and statistical methods is suitable for travel time prediction for bus operations. The preciseness of the prediction was examined using history data. Looking to a system being operational in 2005, further precise information services are being addressed through the system development.