

Travel Time Prediction for Pre-trip Information Using Latest Traffic Conditions on Expressway

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This study evaluates a method of providing pre-trip information that predicts travel time by matching past accumulated traffic data with traffic data on the day of the trip while taking into account the time required to reach the Metropolitan Expressway. Since pre-trip information is available at the time of access to the information media, it is highly likely that the congestion conditions have changed by the time people actually drive on the Metropolitan Expressway. Predicted future travel time is also very useful for drivers to decide their trip departure times. Therefore, it is necessary to provide pre-trip information while predicting traffic fluctuations. The proposed method is verified using observed traffic data on two major radial routes and it is concluded that estimated travel time is accurate enough for the practical use.

Keywords: *Traffic information, Travel time prediction, Forecast method, pre-trip*

1. Introduction

Due to the increasing use of the Intelligent Transport Systems (ITS), a wide range of road traffic information, including information on congestion and travel time, is provided on the Metropolitan Expressway through diverse media, such as traffic information boards, Internet and mobile communication terminals. These types of information can be divided into three major categories based on how people use such information: long-term information used several days prior to departure when travel plans are drawn up; medium-term information used just before leaving and short-term information used while driving. Various studies are conducted based on these categories. For people who want to plan trips, the Metropolitan Expressway Public Corporation (MEPC) and the Japan Highway Public Corporation provide statistical data via the Internet [1]-[3]. People can access pre-trip information via the Internet and other media [4]. While people are driving, traffic information boards and other media provide current information on congestion and travel time, but

the accuracy of the information on the propagation of the congestion is a problem [5]. There have been several researches on traffic jam prediction methods [6]-[16].

Among the types of information mentioned above, pre-trip information on congestion and travel time is provided via the Internet, mobile phones and other media, but since the information provided is that available at the time of access, it is highly likely that the congestion conditions have changed by the time people actually drive on the Metropolitan Expressway. Therefore, it is necessary to provide pre-trip information that accounts for traffic fluctuations. However, although a broader range of information is being provided and the information providers and tools are becoming more diverse, the content of information remains unchanged. There is a need to improve the quality of information. In a survey conducted by MEPC [17], over 90% participants replied that they needed pre-trip information, demonstrating the high demand for such information.

This study evaluates a method of providing pre-trip information that predicts congestion and travel time under ordinary conditions by matching past accumulated

traffic data with traffic data on the day of the trip while taking into account of the time required to reach the Metropolitan Expressway.

2. Outline of the Prediction Method

2.1. Basic Concept

In order to predict travel time, the authors decided to use time-series fluctuations in travel time (hereafter referred to as “time-series prediction”). Various time-series prediction methods have been proposed, including Kalman filtering and other self learning techniques [9]; method for searching similar patterns based on data on cumulative traffic volume and occupancy obtained from vehicle sensors, ETC data, uplink data and others [10]-[13]; and method of estimating travel time using probe data and other kinds of data.

In this study, the method of searching for similar patterns was chosen because it is relatively easy, there is a lot of high-precision data for the Metropolitan Expressway, and the Expressway is chronically congested every day, offering a large volume of similar patterns. The authors thus studied a prediction method that can be used one to two hours before departure rather than short-term predictions that is more suitable when driving.

In the past, many versions of similar pattern method have been proposed. The differences between those versions and the method proposed in this article are as follows:

- The method proposed in this article is designed to provide pre-trip information. For this reason, it takes into consideration use of the Metropolitan Expressway two hours ahead of time, which means that it provides predictions for a longer period of time than other methods. Previous methods provided predictions for the period of time required to reach the Expressway.
- Our method covers the Metropolitan Expressway, where accidents, construction work and other irregularities occur frequently. (For this reason, the authors came up with better prediction methods, including referring to the top ten patterns.)
- Our method uses data accumulated over the past several years.
- Our method analyzes multiple routes while most of the previous methods analyzed only one route.
- Our method considers the possibility of providing practical information on travel time for the Metropolitan Expressway.

Figure 1 show the basic concept of the method, which takes into account fluctuations in travel time, for example. As the figure shows, the method takes into consideration the fact that fluctuations in traffic conditions in the

immediate past affect traffic conditions in the near future, and predicts traffic conditions by matching past traffic data with traffic data of the day for which the prediction is made.

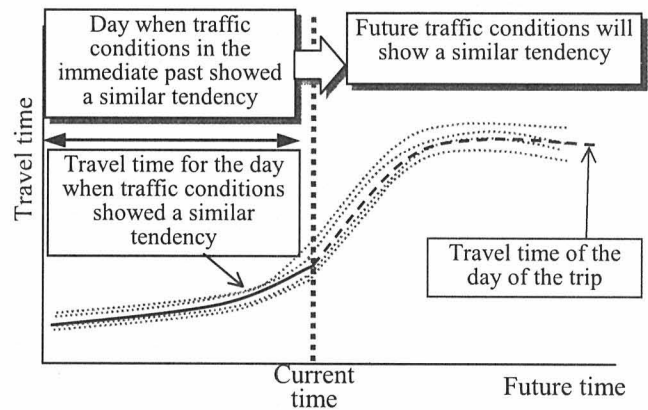


Figure 1: Basic Concept of the Prediction Method

2.2. Timing for Providing Predictive Values.

In the monitor survey [17], nearly half the respondents stated that they would like to have pre-trip information one hour before they used the Metropolitan Expressway. The Origin Destination Surveys [18] of the Metropolitan Expressway show, meanwhile, that the average distance covered to reach the Metropolitan Expressway (distance between the nearest ramp and the center of a given zone) is 21 km. If it is assumed that half of this represents the distance to the ramp and users drive on surface streets at an average speed of 20 km/h, the time required for driving on surface streets is about 30 minutes. Based on these findings, it is assumed that drivers can easily reach the nearest entrance to the Metropolitan Expressway if they have one hour. The authors decided to add an additional hour, to account for a possible change in departure time, and provide pre-trip information from two hours before.

2.3. Location Studied and Data Used

In examining the prediction method, the inbound Yoga-Tanimachi section of Route No. 3 Shibuya Line was used (see Figure 2). The following data was used:

- Period: April 1, 2000 to March 31, 2002 (two years)
- Content of data: Five-minute data for each 500- to 1,000-meter section (survey data: traffic volume, vehicle speed, occupancy, calculated data: travel time)

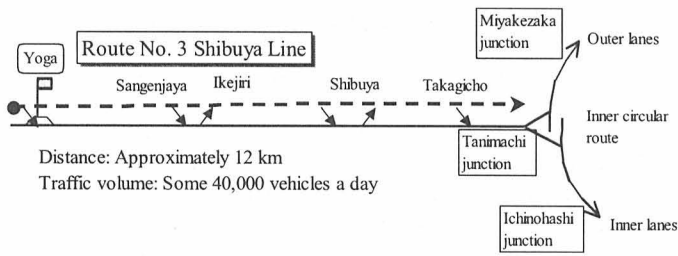


Figure 2: Route Covered in the Study (Route No. 3)

2.4. Evaluation of prediction methods

In order to determine a prediction method, it is necessary to consider the data used for matching, matching methods and the method of calculating predictive values using the matching results. The following section shows the results of such evaluation.

2.4.1. Data used for matching. In order to determine the most suitable data when matching past accumulated data with data for the day of the prediction, the authors compared the travel time for the Yoga-Tanimachi section, as well as the travel time, occupancy and vehicle speed for each section. As a result, since it is assumed that information on both congestion and travel time will be provided, matching using section data is more appropriate. Occupancy takes into consideration too many detailed fluctuations, such as the density or sparsity of traffic as well as the existence of large vehicles in traffic, and travel time enables more appropriate matching than vehicle speed because the former involves the concept of distance. For these reasons, the authors decided to use section travel time.

2.4.2. Matching. Matching involves calculating cumulative squared errors for the time required for traveling the same section at the same time of each day using past accumulated data and data for the day of the prediction. Days showing smaller errors are considered to show a similar tendency.

Accumulated data for a long period make it possible to perform searches using a large volume of data, but such data tend to respond slowly to changes in traffic conditions due to new routes and other factors. For this reason, two-year data are used in this study. There is, however, room for further research on the relationship between accumulated data periods and data accuracy levels.

With respect to the spatial range of matching, since Route No. 3 is affected by congestion ahead on the Inner Circular Route, the effects of such congestion were taken into account in comparing the range of the adjacent Inner Circular Route to be covered in the study (plus one or two junctions) in addition to the 17 sections of the Yoga-Tanimachi section. As a result, if the two junctions on

the Inner Circular Route are included, the Yoga-Tanimachi section data are overly affected by traffic fluctuation data on the loop, resulting in extraction of days that do not show a similar tendency to Route No. 3, the prediction target in this study. Therefore, the authors decided to cover only one junction on the Inner Circular Route: the Ichinohashi junction for the inner lanes (two sections) and the Miyakezaka junction for the outer lanes (two sections) (see Figure 3).

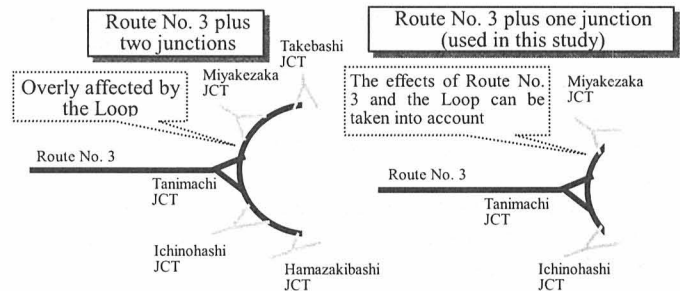


Figure 3: Spatial Range of Matching

With respect to temporal matching, data for 30 minutes, one hour, two hours and three hours before were compared. As a result, there were discrepancies in the days extracted as data for 30 minutes before cannot reflect subsequent fluctuations in traffic because they only provide information on the immediate past, and data for three hours before tend to reflect fluctuations that have nothing to do with traffic changes after the time of prediction. There was no large difference between the results of extraction for one hour and two hours before, but data for two hours before were used because traffic conditions generally change in cycles of around two hours (see Figure 4). With respect to the temporal range of matching, however, it is necessary to verify discrepancies in the prediction results again.

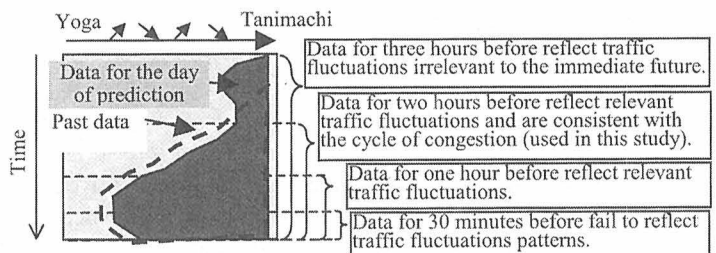


Figure 4: Temporal Range of Matching

2.4.3. Method for Calculating Predictive Values. Based on the results obtained in section 2.4.2, the authors extracted the section travel times for the top 10 days that showed similar tendencies. The main reasons we use the median for the top 10 days rather than for the most similar day are: the data for the top 10 days may include accidents and other unique data; data for the top

20 days would be leveled too much; and there is variation even in the actually extracted data for the top 10 days. Figure 5 compares the accuracy levels for predicted travel time due to differences in the number of days used. As the figure shows, the data for the top 10 days indicate a stable accuracy level.

Then, for the top 10 days obtained after outlier were eliminated, the median for five-minute travel times for each section and time period was calculated as predicted section travel time, and the total predicted travel time for the Yoga-Tanimachi section was calculated by applying and adding up predicted section travel times according to the passage of time (time slice). Five-minute travel time is used here because that is the minimum unit for preparing information on travel time on the Metropolitan Expressway.

In addition, predicted section travel times and the length of the sections were used to calculate section vehicle speed, which was assumed to be the predictive value for congestion maps.

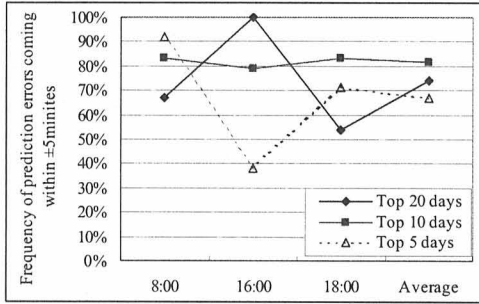


Figure 5 Differences in Prediction Accuracy Levels Due to Differences in Number of Days Used

2.5. Prediction Procedures

Figure 6 gives an overview of prediction procedures. This analysis is an extension of previous travel time study by Shamas [11] [12] in which the provision of travel time was mainly for drivers already en-route. This study however considers travelers who are about to depart from their origin.

- 1) The squared error is calculated from the section travel times for the same time and same time period, which are obtained from accumulated traffic data and traffic data for a given day. The E_k employed here has been proposed by Shama [11] [12].

$$E_k = \sum_{i=1}^n \sum_{j=1}^m (TP_{ijk} - TT_{ij})^2$$

TP_{ijk} : Section travel time for section i , time j and date k , which is obtained from accumulated traffic data

TT_{ij} : Section travel time for section i and time j , which is obtained from traffic data for a given day

n : Total number of sections for which data matching is performed

m : Number of times (24) (five-minute pitch; two hours)

k : Data accumulation period (730) (two years)

- 2) Squared errors (E_k) are sorted and arranged on a daily basis with the smallest coming first.
- 3) Section travel times (S_{ijk}) for the time periods (two hours), which are used for prediction for the top 10 days, are extracted.
- 4) The median of the section travel time for each section and each five-minute period is used to calculate the predicted section travel time (YS_{ij}).
- 5) The section travel time (YS_{ij}) is predicted for the next 2 hours at five minutes interval. By estimating the piecewise linear trajectory based on the section travel time, the total travel time is predicted.
- 6) The predicted section speed (YV_{ij}) for each five-minute period is calculated by dividing the section length (L_j) by the predicted section travel time (YS_{ij}). Predictive values for the congestion chart are created by color-coding speed levels as follows:
 - 0-20 km/h - Red (Congestion)
 - 20-40 km/h - Blue (Slight congestion)
 - 40 km/h or higher - White (Free flow)

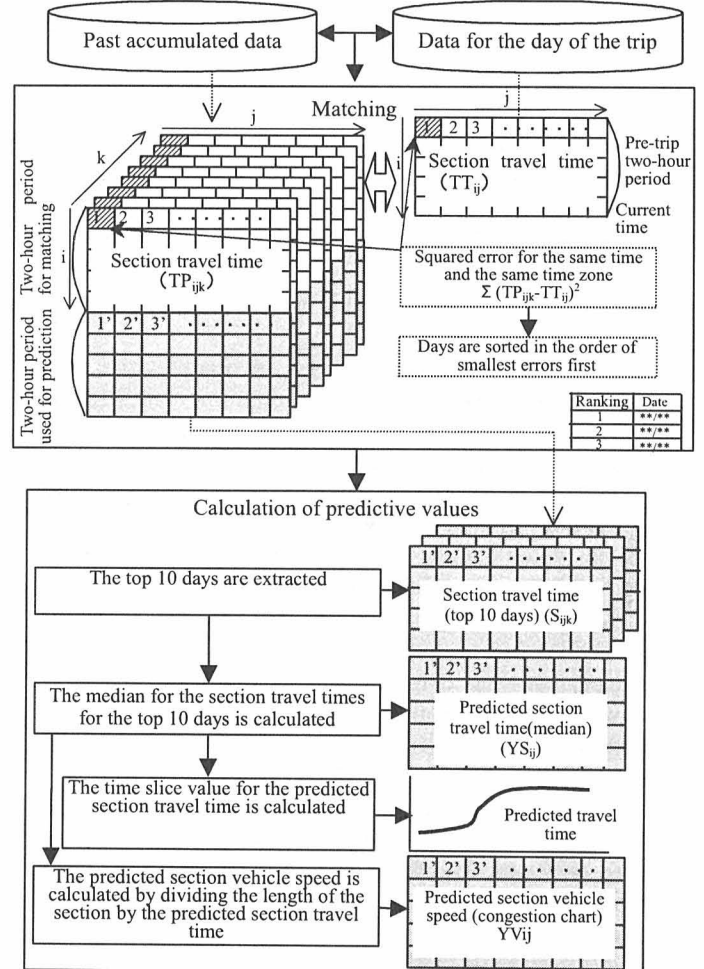


Figure 6: Prediction Procedures

3. Verification of the Prediction Method

3.1. Verification Method

The prediction method was verified using two routes: the Yoga-Tanimachi section of Route No. 3 (see Figure 2) and the Takaido-Miyakezaka section of Route No. 4 (see Figure 7). Verification was performed by randomly choosing three time periods (morning, afternoon and evening) on three weekdays in the months that have a high, average and low traffic volume. On these days, Route No. 3 was not particularly affected by accidents and other irregularities, but Route No. 4 was affected by accidents on October 16 and July 24, and therefore, the time periods when the accidents occurred were avoided when the verification was performed.

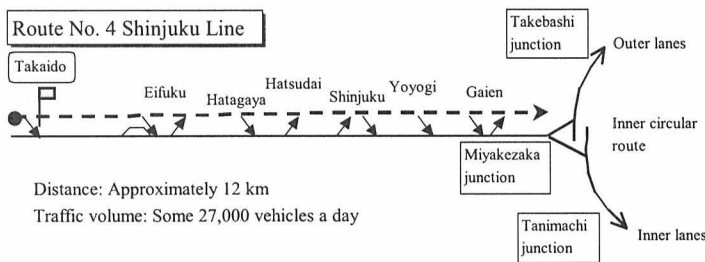


Figure 7: Route on Which Verification Was Performed (Route No. 4)

Travel time was used to quantitatively evaluate the verification results, and since the results of a survey[17] indicate that the largest percentage of users, over 40%, demand an accuracy level within ± 10 minutes, irrespective of the time when the traffic information is provided, this was considered the standard value. The accuracy of errors within the range of ± 5 minutes, and the accuracy of errors within the range of $\pm 33\%$ were used as reference values. The reason for using the latter is that the permissible level of errors for the travel time of 30 minutes is ± 10 minutes.

Table 1: Days and Time Periods When Verification Was Performed

Route	Date	Time period			Accidents and other irregularities
		Morn ing	Afterno on	Even ing	
Route No. 3	2001/7/24 (Tue)	8:00	12:00	16:00	
	2001/10/16 (Tue)	8:00	12:00	16:00	
	2002/2/12 (Tue)	8:00	12:00	16:00	
Route No. 4	2001/7/24 (Tue)	8:00	12:00	18:00	An accident occurred around 14:00
	2001/10/16 (Tue)	8:00	10:00	18:00	An accident occurred around 12:00 and 14:00
	2002/2/12 (Tue)	8:00	12:00	16:00	

3.2. Results of Verification

Figures 8 and 9 compare the prediction results with actual measurements of congestion and fluctuations in travel time for Route No. 3 Shibuya Line on Tuesday, October 16 and for Route No. 4 Shinjuku Line on Tuesday, July 24. These figures indicate that except for 8 a.m. in Figure 9, actual measurements are almost consistent with predictions in terms of propagation of congestion and increased travel time. The accuracy level for Route No. 4 Shinjuku Line at 8 a.m. is low because, although precise matching was achieved for the period up to 8 a.m., congestion started to quickly spread from 8:30 a.m. due to the congestion on the Inner Circular Route ahead. This type of congestion rarely occurs on days when traffic is heavy and therefore what probably cannot be extracted. In the following sections, this result is excluded.

Table 2 shows the congestion and accuracy for predicted travel time in all cases. About 90% of predicted travel times achieved an accuracy of errors being within the range of ± 10 minutes, and about 85% within the range of $\pm 33\%$, suggesting that the predictions are almost consistent with actual measurements.

By time period, there is no large difference, and almost all time periods achieved an accuracy level of 80% or higher in terms of errors being within ± 10 minutes and $\pm 33\%$ for travel time, indicating that for all time periods, the predictions are accurate. Particularly, the accuracy levels for the morning peak time on Route No. 3 Shibuya Line and for the afternoon on Route No. 4 Shinjuku Line are high, at 93% for travel time errors within ± 5 minutes and 86% for travel time errors within ± 5 minutes, respectively. The accuracy level for the morning peak time is high, probably because many of the users leave home at certain fixed times on weekday mornings. The high accuracy level for the afternoon on Route No. 4 Shinjuku Line is probably because the average travel time is about 20 minutes, indicating that the section is not so heavily congested.

By day, the accuracy level for Tuesday, July 24, when the average travel time was long, is lower than that for other days. It is inferred that this is because the other two days had an average traffic volume, enabling extraction of days that had a traffic volume similar to that for the time period in the immediate past, while July 24 had heavy traffic volume and there are few days that had similar traffic conditions. Under these circumstances, it is likely that the calculation of the median for the top 10 days results in average values, predicting less heavy congestion. This led the authors to predict congestion for the afternoon of July 24, when the largest error was observed for Route No. 3 Shibuya Line, using the median for the top five days, which resulted in accuracy level being raised from 63% to 88% in terms of travel time errors within the range of ± 10 minutes.

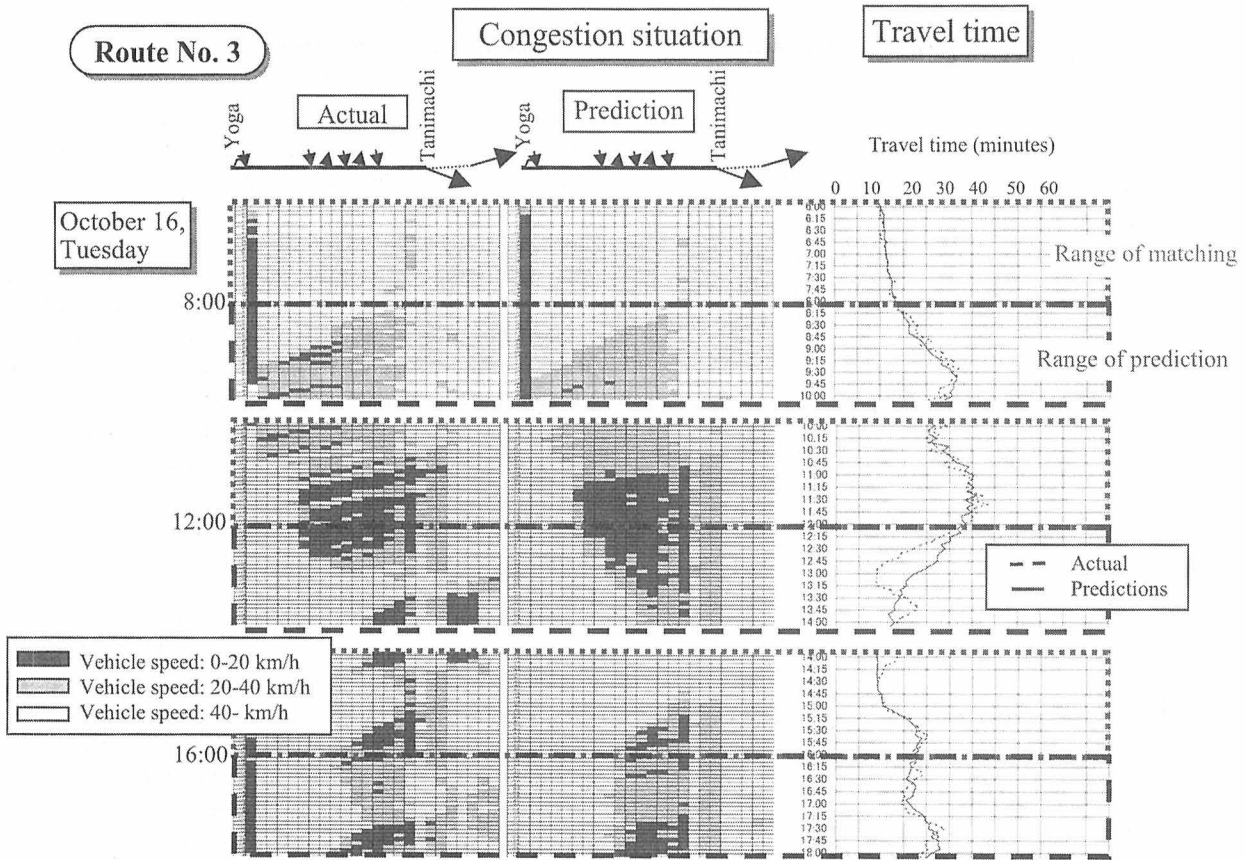


Figure 8: Comparison of Congestion and Fluctuations in Travel Time for Route No. 3 Shibuya Line on Tuesday, October 16, a Day with Average Traffic Volume

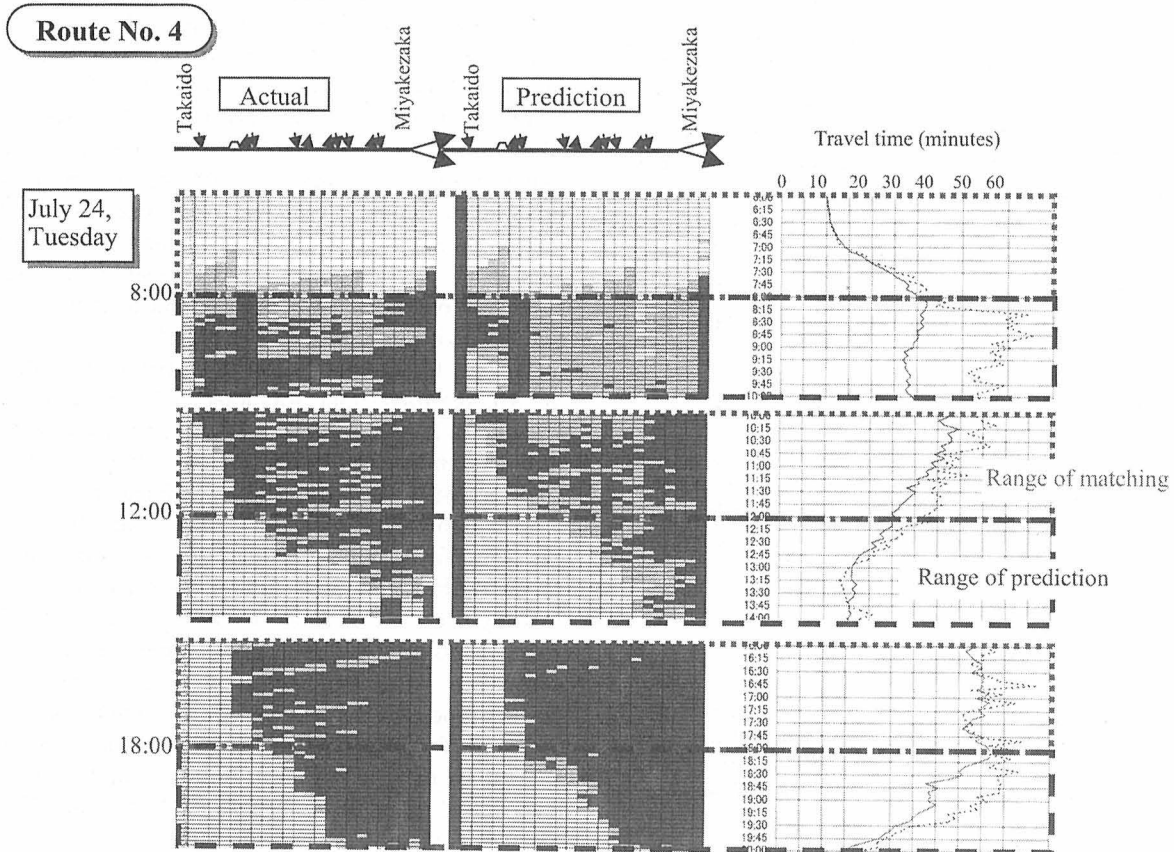


Figure 9: Comparison of Congestion and Fluctuations in Travel Time for Route No. 4 Shinjuku Line on Tuesday, July 24, a Day with Heavy Traffic Volume

This method is effective for situations where traffic volume is high, and in the future, it is necessary to analyze a method of setting a threshold for squared sums and using those below the threshold.

Based on the above findings, it can be said that although some problems remain to be addressed in the future, the overall accuracy levels are high and the applicability of the prediction method to inbound Route No. 3 Shibuya Line and Route No. 4 Shinjuku Line to Tokyo has been confirmed.

Table 2: Accuracy Level for Predicted Travel Time

◆Route No. 3

Item	Day	Morning	Afternoon	Evening	Average
Within ±10 minutes	2001/7/24(Tue)	88%	63%	75%	75%
	2001/10/16(Tue)	100%	88%	100%	96%
	2002/2/12(Tue)	100%	100%	100%	100%
	Average	96%	83%	92%	90%
(Reference) Within ±5 minutes	2001/7/24(Tue)	79%	29%	25%	44%
	2001/10/16(Tue)	100%	54%	100%	85%
	2002/2/12(Tue)	100%	33%	83%	72%
	Average	93%	39%	69%	67%
(Reference) ±33%	2001/7/24(Tue)	88%	100%	92%	93%
	2001/10/16(Tue)	100%	58%	100%	86%
	2002/2/12(Tue)	100%	50%	100%	83%
	Average	96%	69%	97%	88%
(Reference) Average travel time	2001/7/24(Tue)	30.2	37.4	43.3	37.0
	2001/10/16(Tue)	20.6	15.7	18.1	18.2
	2002/2/12(Tue)	17.5	21.6	34.6	24.6
	Average				

◆Route No. 4

Item	Day	Morning	Afternoon	Evening	Average
Within ±10 minutes	2001/7/24(Tue)	(13%)	100%	67%	83%
	2001/10/16(Tue)	100%	100%	75%	92%
	2002/2/12(Tue)	96%	100%	100%	99%
	Average	98%	100%	81%	93%
(Reference) Within ±5 minutes	2001/7/24(Tue)	(13%)	92%	33%	63%
	2001/10/16(Tue)	50%	96%	38%	61%
	2002/2/12(Tue)	54%	71%	79%	68%
	Average	52%	86%	50%	63%
(Reference) ±33%	2001/7/24(Tue)	(21%)	100%	96%	98%
	2001/10/16(Tue)	100%	100%	71%	90%
	2002/2/12(Tue)	67%	50%	88%	68%
	Average	83%	83%	85%	84%
(Reference) Average travel time	2001/7/24(Tue)	46.2	20.1	41.2	35.8
	2001/10/16(Tue)	30.0	24.5	22.7	25.7
	2002/2/12(Tue)	21.9	14.3	13.4	16.5
	Average				

* The accuracy level represents the probability at which errors come within the range of ±10 minutes or ±5 minutes during the two-hour prediction period. Errors were calculated by deducting actual measurements from predictive values.

* Data for Expressway No. 4 Shinjuku Line on the morning of July 24 were excluded when the average was taken.

3.3. Matching, Including Upstream Sections

In the preceding studies, the predicted route and its downstream section (near the center of Tokyo) were included, but in this section, the authors studied including the Tomei Expressway in the range of data matching, which constitutes the upstream section of the Yoga-Tanimachi section of Route No. 3.

The correlation between traffic volume for the upstream section and that for Route No. 3 near Yoga was analyzed. For example, a comparison of the correlations between the traffic volume near Yoga and the traffic volume near the Yokohama-Machida interchange located 20 km upstream from Yoga 15 minutes earlier indicated that there was a high level of correlation between the two, at 0.8 to 0.99. This led the authors to include Tomei Expressway around 20 km upstream from Yoga in the range of matching.

Table 3 compares the results obtained using the above method on Thursday, June 26, 2003 including and excluding the upstream section (ie. Tomei Expressway) and using the inbound lane on Expressway No. 3 (Shibuya Line) as the prediction target. The table indicates that overall, the prediction accuracy level has improved. In this way, the authors were able to confirm that the prediction accuracy level (Route No. 3 Shibuya Line inbound) for traffic conditions on the section covered by this study may improve if the Tomei Expressway is included in the range of matching. In the future, it will be necessary to verify the scalability of this method.

Table 3: Results of Prediction Including the Tomei Expressway

◆Route No. 3 Shibuya Line

Item	Upstream sections	6:00	8:00	10:00	12:00	16:00	18:00	Average	
		Within ±10 minutes	Excluding	100%	100%	92%	100%		96%
		Including	100%	100%	79%	100%	100%	100%	97%
(Reference)	Excluding	100%	83%	29%	100%	88%	83%	81%	
Within ±5 minutes	Including	100%	92%	29%	67%	75%	58%	70%	

4. Conclusion

This study proposes a prediction method of travel time for pre-trip information provision on the Metropolitan expressway using the pattern matching technique. The method is verified using observed data on Routes 3 and 4, and it is confirmed that the accuracy of the predicted congestion and travel time is adequate to provide useful pre-trip information. The predicted travel time is also quite useful for departure time choices and other trip arrangements.

In the future, in order to put the prediction method explained in this article to practical use and improve prediction accuracy for days when congestion occurs downstream or traffic is heavy or for other conditions, the authors plan to expand the scope of application, including weekends and other routes, expand the scope of data matching to include upstream sections, consider the most suitable data accumulation periods and classifications of data into patterns by taking into account new routes and the characteristics of the day of the week.

Acknowledgment

The authors would like to express their gratitude to the Japan Highway Public Corporation and Mr. Yoriyuki Sunaga of the Metropolitan Expressway Public Corporation, who provided valuable data for the analyses. Finally, our study group would like to express sincere thanks to Mr. Shamas ul Islam Bajwa, University of Tokyo for his valuable suggestions.

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Received: 7 May 2004

Revised: 20 August 2004

Accepted: 3 September 2004

Editor: Fumitaka Kurauchi