Journal of the Eastern Asia Society for Transportation Studies, Vol. 6, pp. 1557 - 1569, 2005

TIME DEPENDENT CORRELATIONS BETWEEN TRAVEL TIME AND TRAFFIC VOLUME ON EXPRESSWAYS

Takamasa IRYO
Research Associate
Department of Architecture and Civil Engineering
Kobe University
1-1, Rokkodai-cho, Nada-ku, Kobe, 657-8501, Japan
Fax: +81-78-803-6360
E-mail: iryo@kobe-u.ac.jp

Kohji INOUE
Postgraduate student
Graduate School of Science and Engineering
Kobe University
1-1, Rokkodai-cho, Nada-ku, Kobe, 657-8501, Japan
Fax: +81-78-803-6360
E-mail: 045t102n@y04.kobe-u.ac.jp

Takahiro TOHYAMA
Postgraduate student
Graduate School of Science and Engineering
Kobe University
1-1, Rokkodai-cho, Nada-ku, Kobe, 657-8501, Japan
Fax: +81-78-803-6360
E-mail: 048t123n@y04.kobe-u.ac.jp

Yasuo ASAKURA
Professor
Graduate School of Science and Engineering
Kobe University
1-1, Rokkodai-cho, Nada-ku, Kobe, 657-8501, Japan
Fax: +81-78-803-6360
E-mail: Asakura@kobe-u.ac.jp

Abstract: This study analyzes time-dependent correlations between travel time and traffic volume in urban expressways. Traffic volume can be changed by many factors and is necessary to know what factors are important. Congestion can be one of the most important factors. It is natural to consider that drivers avoid congested roads and this can make negative correlations between travel time and traffic volume in neighbour hour. In addition, congestion may influence traffic volume in remote hours. It is important to check such "time-dependent" correlations to examine policies like dynamic congestion pricing and so on. This study analyzes the time-dependent correlation between travel time and traffic volume with data obtained with traffic detectors. As a result, negative correlations are observed in neighbour hours and positive correlations are observed between daytime travel time and night traffic volume. This indicates that congestion can have relationship to traffic volume in later hours.

Key Words: Traffic congestion, Traffic detectors, Urban expressways

1. INTRODUCTION

Urban expressways in Japan have well developed traffic monitoring systems. There are many types of technologies to monitor traffic conditions. Traffic detectors are one of most important instruments, which are installed quite densely. Most detectors collect traffic volumes, speeds, occupancies, and heavy traffic volumes on each site in every one to five minutes. The intensive development of computer technology allows road operators and researchers to analyze huge historical traffic data collected over many years. Such improvement makes new types of researches in transport sciences and some applications have been already developed. For example, a new system of travel time forecast system has been developed (Bajwa et al., 2003a, 2003b) with utilizing huge amount of historical traffic data for several months.

Traffic data can be also utilized for estimating relationships between traffic volumes and congestion. Traffic volume can be changed by many factors and it is important for road operators to estimate which factors are important for more effective and advanced traffic control systems, such as information systems, dynamic channelling changes, and dynamic toll scheme. However, there can be many factors in the changes and it should be difficult to determine all factors precisely. This study assumes that "congestion" must be one of most important factors and revealing relationships between congestion and traffic volume can be helpful to understand the mechanism of traffic volume changing. Congestions on urban expressways are very popular in Japan and can make drivers to detour to alternative routes or surface roads. Some relationship between traffic volume and travel time measured in the neighbour hours have been measured (see Kim et al. (2004)).

In addition to the relationship in the neighbour hours, the relationship between traffic volume and travel time in different hours should be also examined. Traffic congestion is known as a dynamic phenomenon and considering time axis is essential. The bottleneck model indicates that the increase of traffic volume makes travel time longer throughout the duration where congestion exists. This means that the relationship between traffic and travel time has "externality of time". Besides the bottleneck model, such externality should be considered in driver's behaviour. For example, drivers can change their departure times to avoid congestion. Travelling in off-peak hours is attractive for the drivers whose schedule constraints are not strict. Checking the externality of time is also important to estimate characteristics of change of traffic volumes against congestion.

This study makes a simple empirical analysis of time dependent correlation to examine the existence of externality on congested urban expressways. Two urban expressway sections in Tokyo and Osaka, which connects suburbs and city centres are chosen as study sites. They have bottlenecks and congestion frequently occurs in every morning and evening on weekdays. Traffic volume at the upstream end and travel time through the section are obtained from detector data and correlation coefficients between traffic volume and travel time in different hours are calculated to examine time dependent correlations.

2. DETAILS OF STUDY SITES AND ANALYSIS

Two study sites are chosen to examine the time dependent correlation. One is "Hanshin Expressway Ikeda Line" in Osaka and the other is "Metropolitan Expressway Ikebukuro Line" in Tokyo. Metropolitan Expressways and Hanshin Expressways are urban express networks, which cover city and urban areas of Tokyo and Osaka respectively. Both Ikeda line and Ikebukuro line are radial lines and connect suburban areas and city centres. Inbound direction, where severe congestion frequently occurs, is chosen on each section. Figures 1 and 2 show the maps of these sections. To avoid confusion, this paper calls these roads as "Ikebukuro line in Tokyo" and "Ikeda line in Osaka", or "Tokyo" and "Osaka" as abbreviations.

Traffic detectors are installed on the roads by road operators and collect traffic volume and speed in every one (Tokyo) or five (Osaka) minutes. This study uses the data taken from January 2000 to December 2000 in Tokyo and the data taken from April 2003 to December 2003. in Osaka. The numbers of study days are 217 days (Tokyo) and 153 days (Osaka). These days do not include any Saturdays, Sundays and holidays. Travel times through the study sections are calculated with the speed data. Traffic volume counted at the end of the upper stream of the study section is also obtained. The days when the queue occurs at the upstream end are eliminated from study days to count the traffic volume correctly.

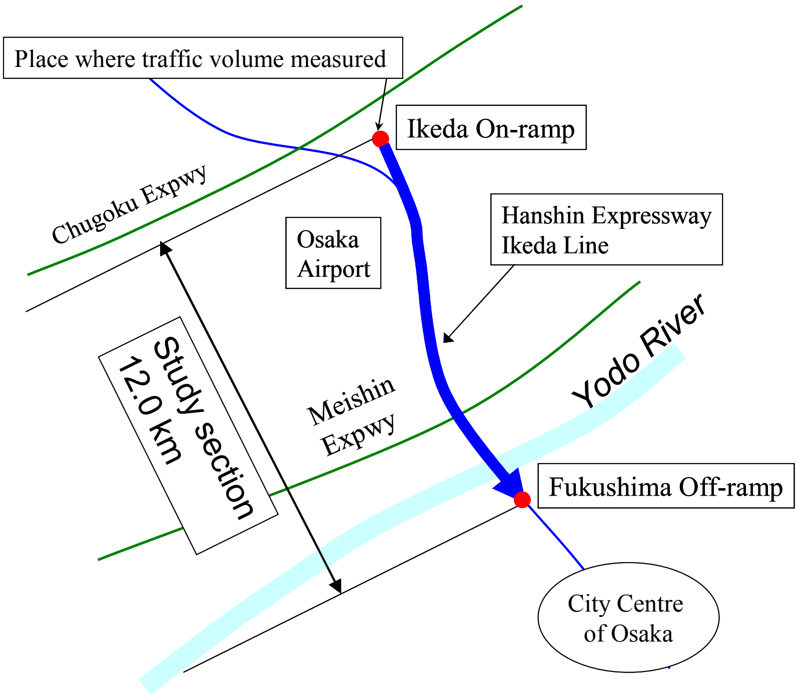

Figure 1. Map of Ikeda Line in Osaka

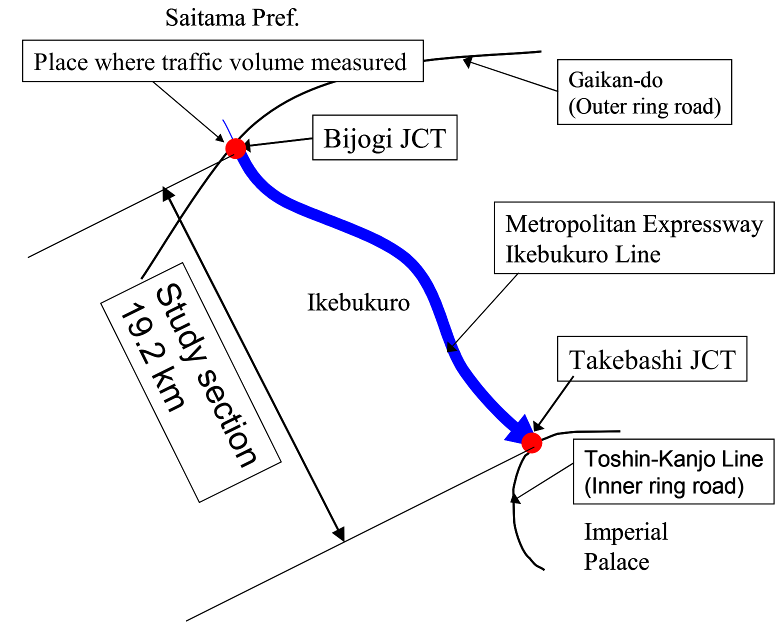

Figure 2. Map of Ikebukuro Line in Tokyo

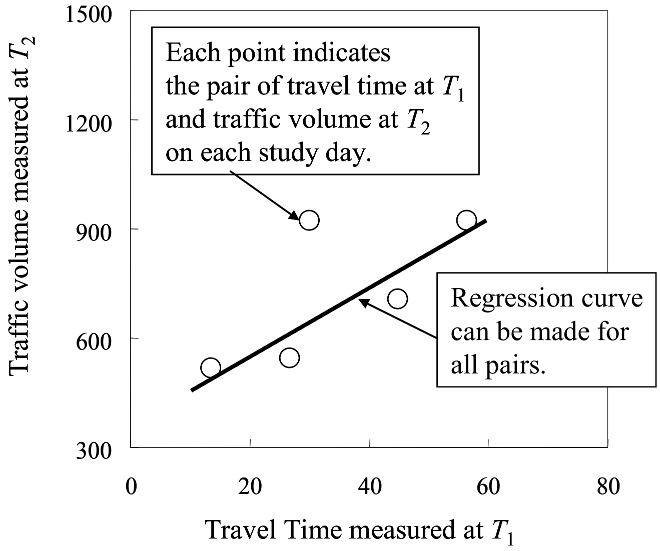

Figure 3. Schematic Picture of Scattered Plot

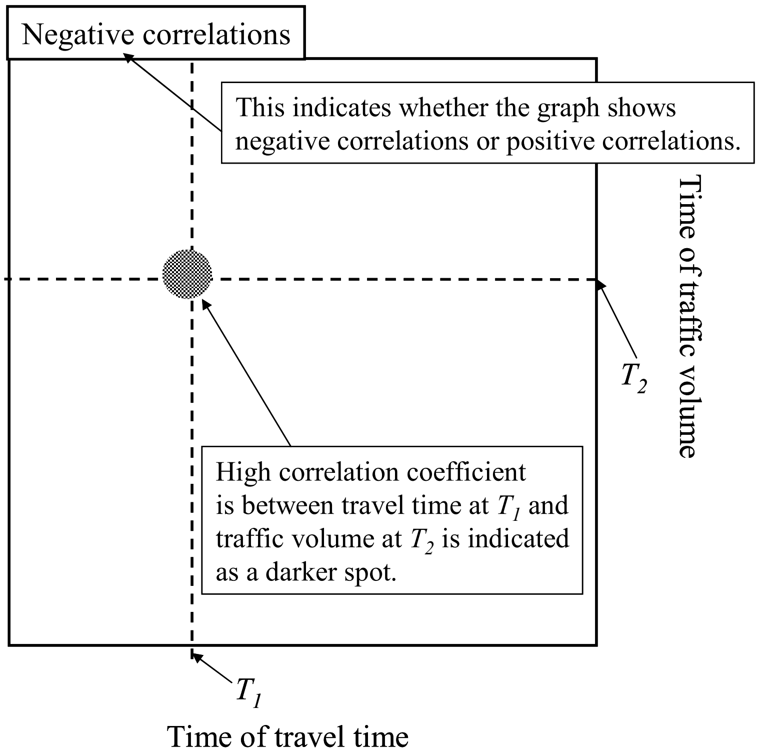

Figure 4. Schematic Picture of Correlation Graph

The relationship between travel time at a certain time and traffic volume at another certain time can be shown with scattered plots. An example of the scattered plots is shown in figure 3. The horizontal axis of the graph shows travel time of vehicles which pass through upstream end at T_1 and the vertical axis shows traffic volume at the upstream end at T_2. The analysis of linear regression is made on these plots and correlation coefficients $r(T_1, T_2)$ are calculated to check the relationship between travel time and traffic volume. All combinations of T_1 and T_2 are examined and the number of this combinations is quite large.

To show the overview of the correlation coefficients of all combinations, “Correlation graph”, shown in figure 4, is introduced. This graph has two axis, one shows the time when travel time is measured (T_1) and the other shows the time when traffic volume is measured (T_2). Each section of the graph is painted according to the correlation coefficients. If the absolute number of a correlation coefficient $r(T_1, T_2)$ is larger, the section indicated by T_1 and T_2 is painted with darker colour. Two graphs are used to distinguish positive correlations and negative correlations.

3. RESULTS

3.1 Overview of congestion

The degree of congestion is different between these study sites. Congestion occurs throughout the day on the Ikebukuro line in Tokyo, whereas congestion occurs only in the morning and evening on the Ikeda line in Osaka. Figure 5 shows average travel time of two lines over all study days. In the Ikeda line in Osaka, free flow travel time is maintained during daytime.

3.2 Relationship between travel time and traffic volume

The correlation graphs are drawn to check the time dependent correlations between travel time and traffic volume. Figure 6 is a correlation graph of the Ikebukuro Line in Tokyo, and figure 7 is a correlation graph of the Ikeda Line in Osaka. Both positive and negative correlations are indicated in these figures.

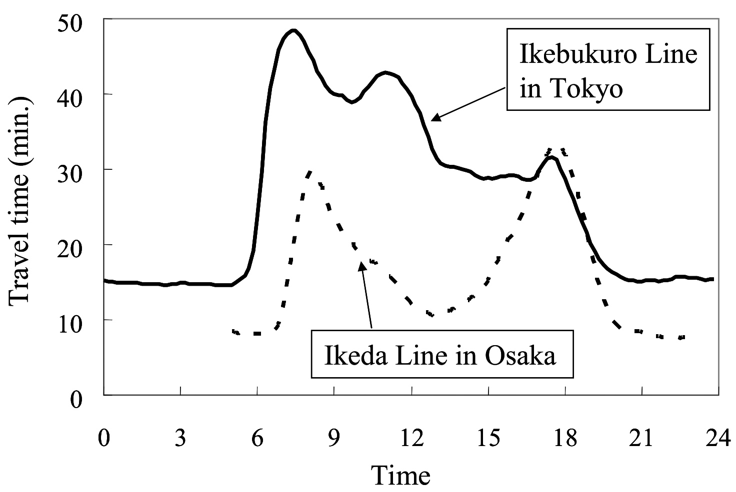

Figure 5. Mean Travel Time of Both Lines.

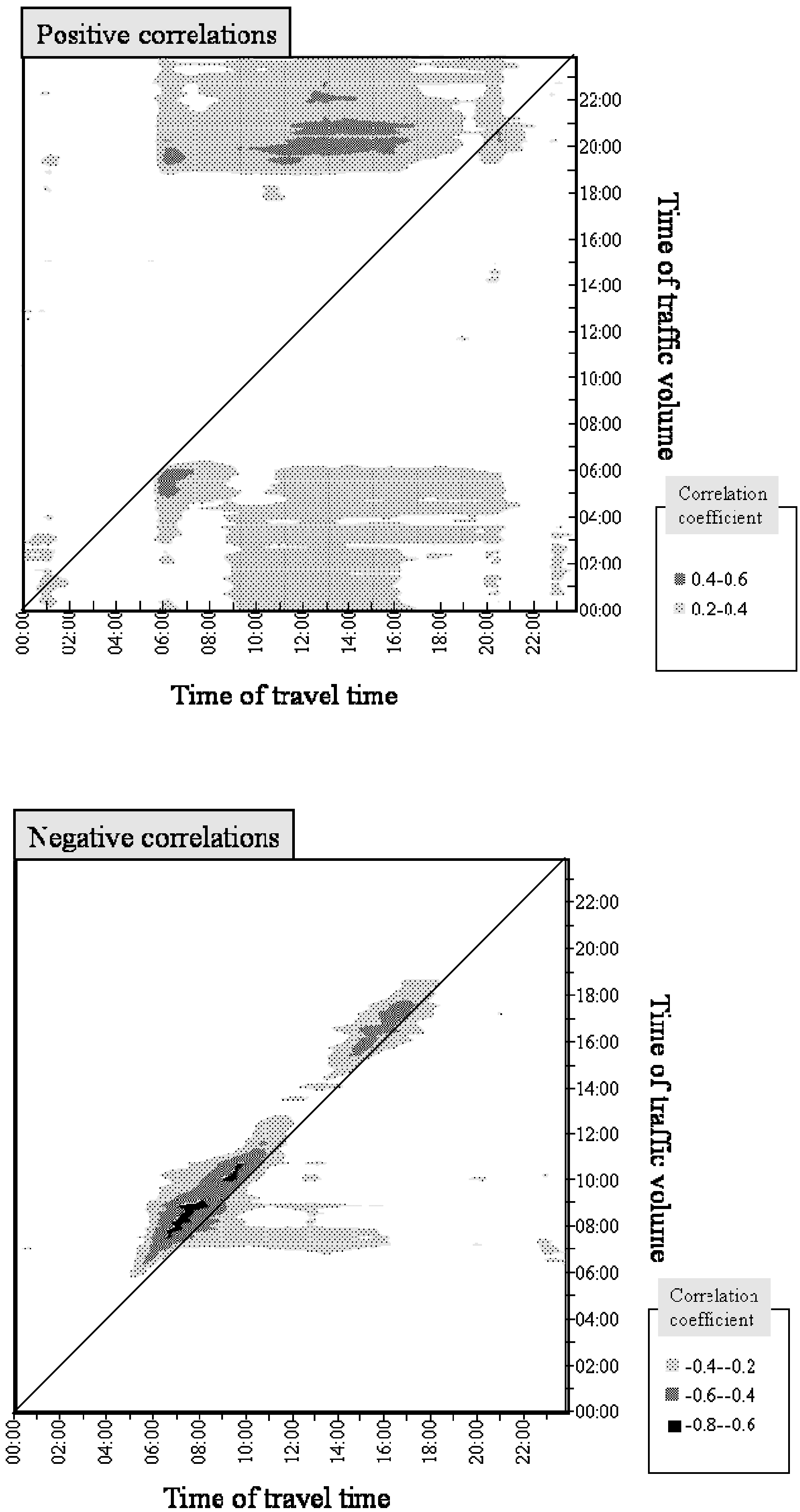

Figure 6. Correlation Graph of Ikebukuro Line in Tokyo

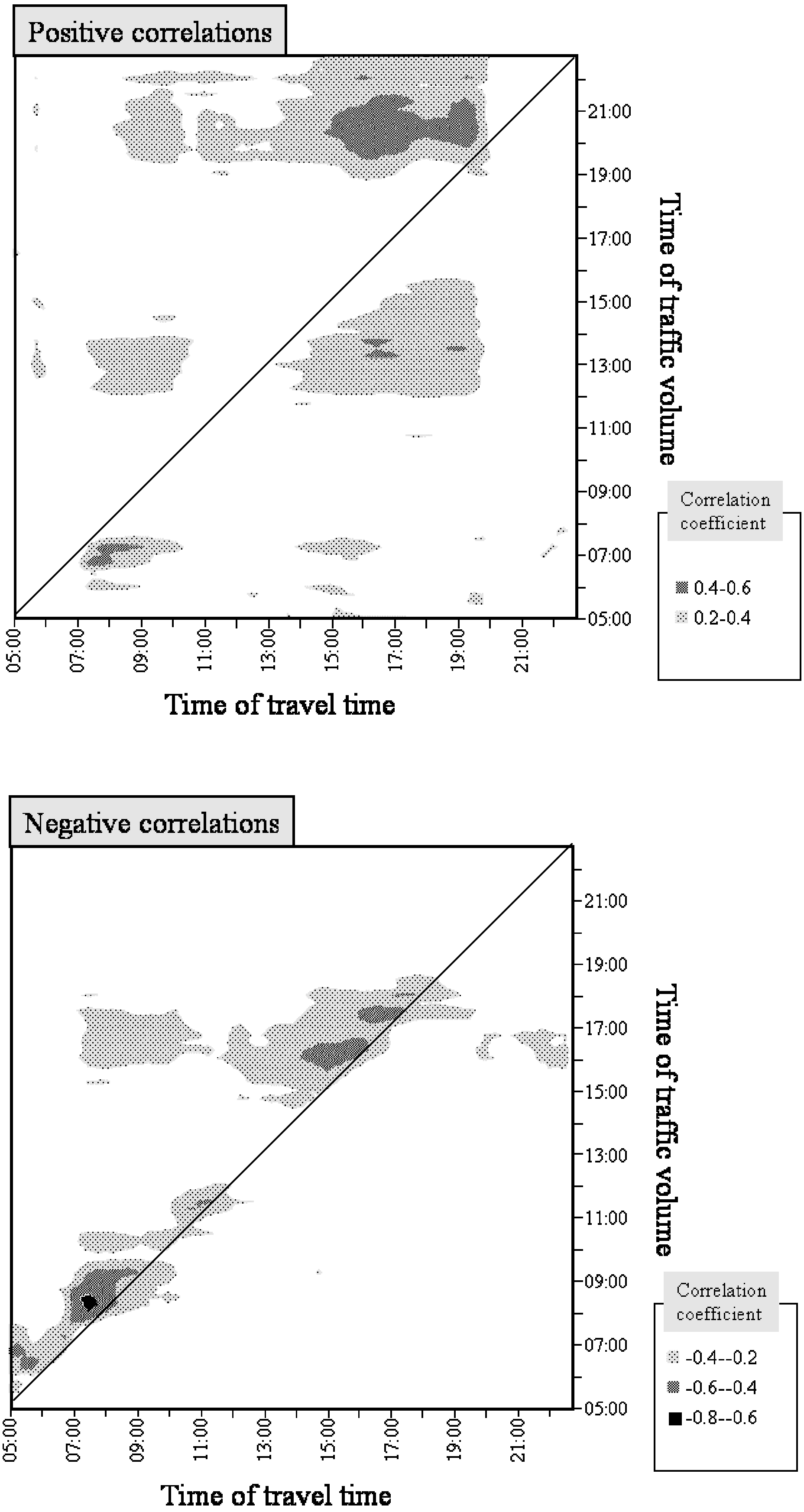

Figure 7. Correlation Graph of Ikeda Line in Osaka

Negative correlations are observed near the diagonals of the graphs. The diagonal line on the correlation graph corresponds to the relationship between neighbour hours and therefore this result indicates negative correlations between travel time and traffic volume in neighbour hours. In the case of Tokyo, moderate correlations ($0.6 \le \left| r\left(T_1, T_2\right) \right| \le 0.8$) are found between travel time and traffic volume in the morning, and weaker correlations ($0.4 \le \left| r\left(T_1, T_2\right) \right| \le 0.6$) exist in evening. In the case of Osaka, moderate correlations are shown in the morning and weaker correlations are also shown in evening. These negative correlations are named "diagonal negative correlations". The negative correlations are not strictly on the diagonal. The spots where stronger correlations appear are slightly above the diagonal. This means that the travel time has stronger correlation with traffic volumes of following time, not at the same time. This duration is around an hour.

Weaker positive correlations are also observed on both roads. In the case of Tokyo, weaker positive correlations ($0.4 \le \left| r\left(T_1, T_2\right) \right| \le 0.6$) are observed mainly between travel time from morning to evening and the traffic volume at night. In addition, some insignificant correlations ($0.2 \le \left| r\left(T_1, T_2\right) \right| \le 0.4$) are widely observed on the lower and upper areas of the correlation graph. Small spots of weaker correlations are also found in these areas. In the case of Osaka, weaker positive correlations are observed mainly between travel time in evening and the traffic volume at night. Unlike Tokyo's case, there is no correlation between travel time in morning and the traffic volume at night. Insignificant correlations can be observed on the upper areas of the correlation graph and is similar to Tokyo's case. However, the correlations is also found between travel time in evening and traffic volume before evening and is not similar to Tokyo's case. A small spot of weaker correlation is found between travel time in morning and traffic volume in earlier morning and is also similar to Tokyo's case.

Figure 8 shows schematic view of correlations. The spots where moderate and weaker correlations exist are marked. The diagonal negative correlations are indicated by "Nt1", "Nt2" in Tokyo's case and indicated by "No1" and "No2" in Osaka's case. The positive correlations are indicated by "Pt1" and "Pt2" in Tokyo's case and "Po1", "Po2" and "Po3" in Osaka's case. Both Tokyo's case and Osaka's case have similar correlations, but is slightly different from each other. In the Osaka's case, the correlations concerning to morning and daytime travel time tend to be weaker than in the Tokyo' case.

Scattered plots of selected spots are drawn to check the details of the correlations. Figures 9 to 12 show the scattered plots of "Nt1", "No1", "Pt1", and "Po1", respectively. T-values are calculated on all plots and it is confirmed that all correlation is significant at the 95% confidence.

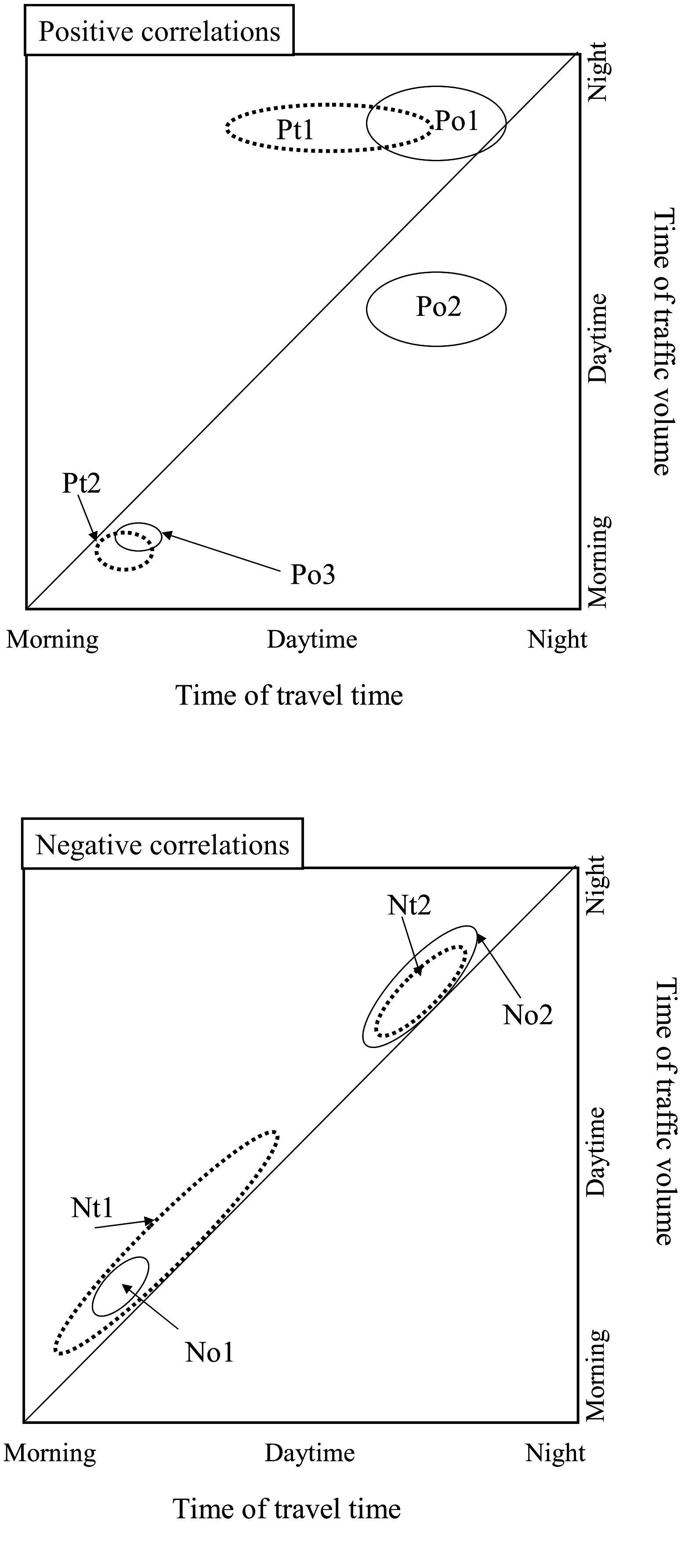

Figure 8. Schematic Pictures of Correlation Graphs of Both Tokyo and Osaka.

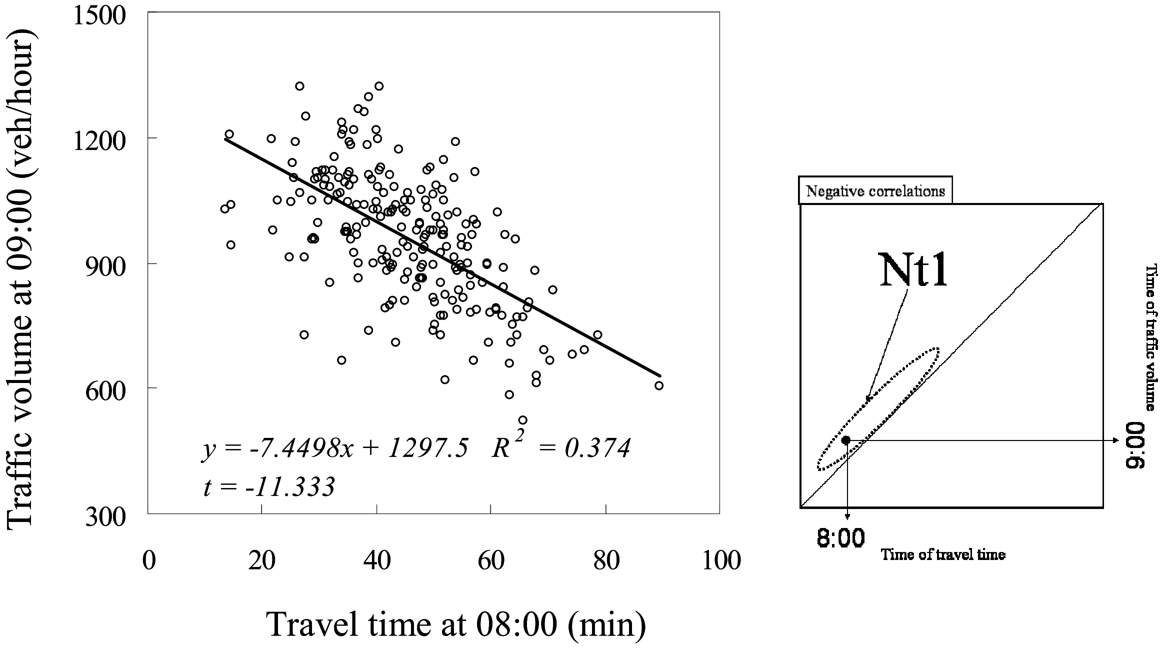

Figure 9. Scattered Plot of Travel Time at 8:00 and Traffic Volume at 9:00 in Tokyo, Corresponding to Nt1 in the Correlation Graph.

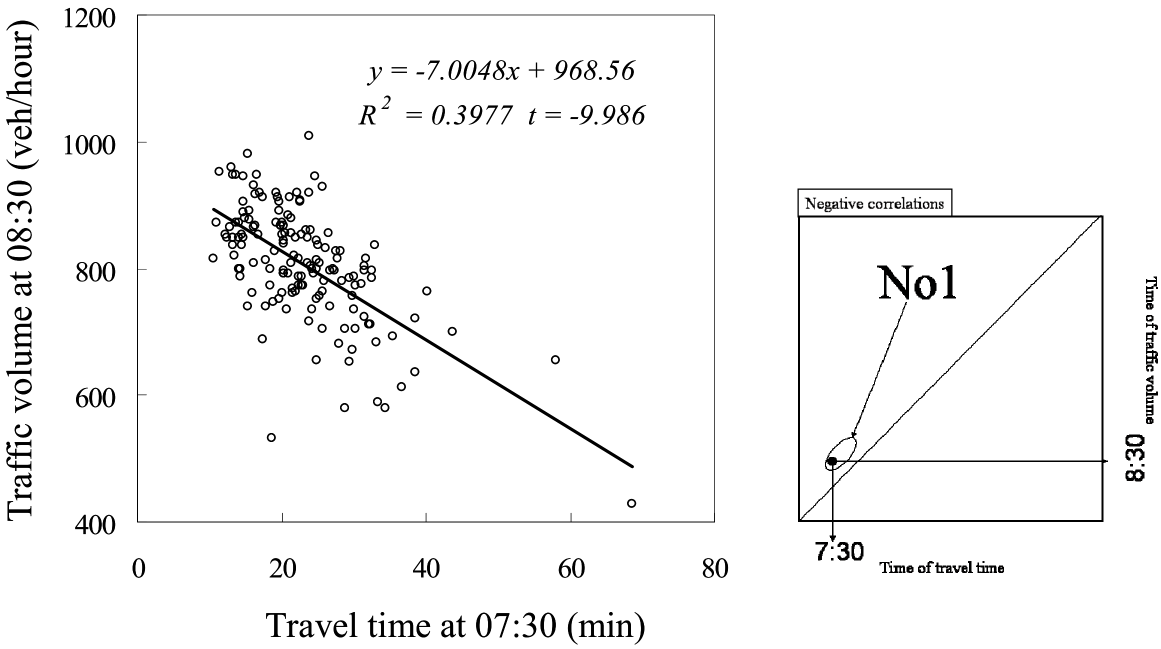

Figure 10. Scattered Plot of Travel Time at 7:30 and Traffic Volume at 8:30 in Osaka, Corresponding to No1 in the Correlation Graph.

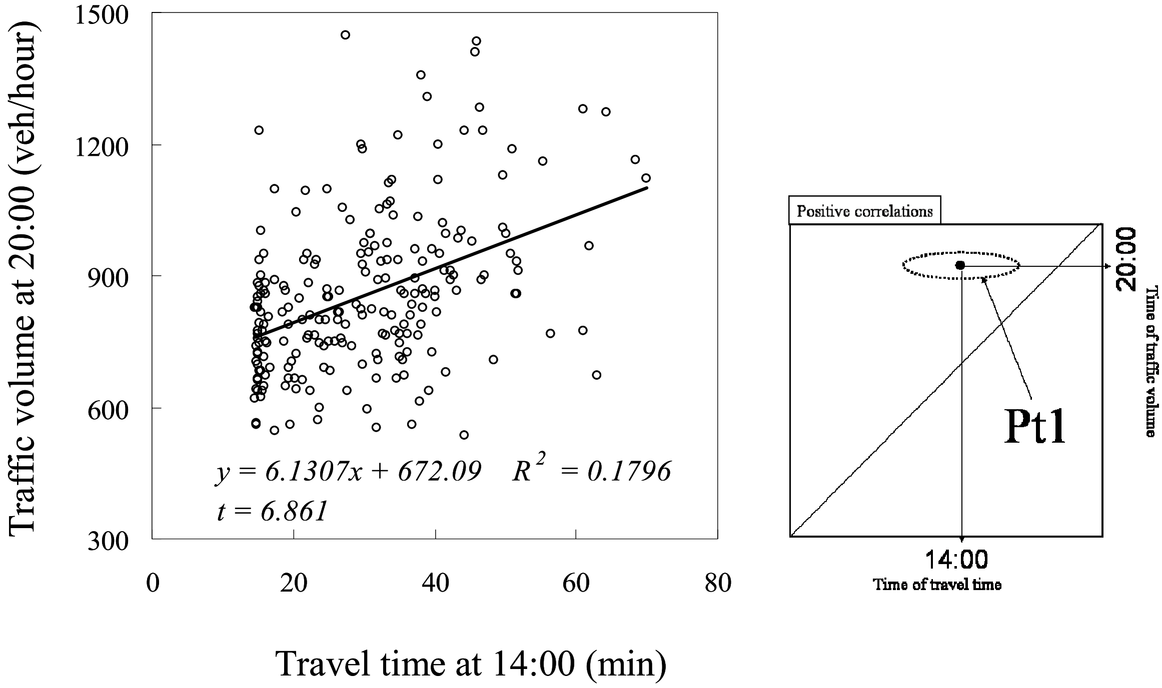

Figure 11. Scattered Plot of Travel Time at 14:00 and Traffic Volume at 20:00 in Tokyo, Corresponding to Pt1 in the Correlation Graph.

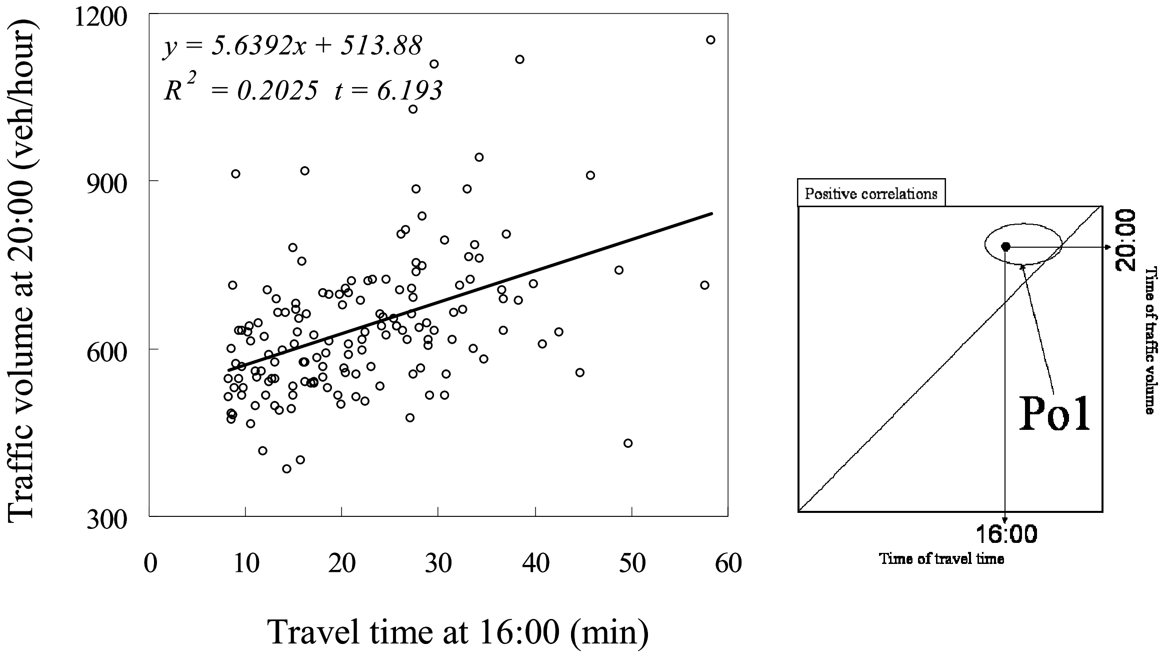

Figure 12. Scattered plot of Travel Time at 16:00 and Traffic Volume at 20:00 in Osaka, Corresponding to Po1 in the Correlation Graph.

4. CONCLUSIONS AND DISCUSSIONS

This study examines the time dependent correlations between travel time and traffic volume on two urban expressways and found some positive and negative correlations. Negative correlations are found near the diagonals of the correlation graphs. This means that the correlations between travel time and traffic volume in neighbour hours exist. Some positive correlations are also found, but are not on the diagonals of the correlation graphs. This means that the positive correlations exist between different hours. Such correlations can be considered as an empirical evidence for externality of time.

Both negative correlations and positive correlations exist on both two expressways. This indicates that such correlations may be common to weekday's traffic on urban expressways running from suburban area to city centre. However, some differences can be also found. The positions where negative correlations exist are common but the strength of the correlations is different. The positions where positive correlations exist are slightly different. One of the reasons that can be considered is the difference in the level of congestion. Congestion of Ikebukuro Line in Tokyo is heavier than the Ikeda Line in Osaka and this can make such differences in the correlations.

There can be several reasons for the negative correlations; however, the reason that "drivers tend to avoid using congested roads" seems to be an adequate reason. Travel time information systems are widely equipped on Japanese urban expressways and they can alter driver's route choice in real time. Kim et al. (2004) shows a similar result with the more precise method, which considers OD traffic volume explicitly.

On the other hand, it is not easy to determine the reason why positive correlations occur. The scenario that "drivers change departure time from their origins due to the congestion" can be one of the reasons. Positive correlations Pt1 and Po1 indicates the relationship between travel time in evening and traffic volume at night, and "higher travel time in evening changes vehicle's departure time from peak hour to off-peak" is consistent. Of course, it seems to be not realistic that drivers check travel time and immediately postpone their departure. However, if drivers can predict travel time beforehand, they can decide to travel in off-peak hour in advance. The positive correlations are not so strong and therefore such scenario can be adopted. But the confidence of this scenario is not strong. It should be also considered that some "hidden factors" may exist between travel time in evening and traffic volume at night. For example, "daytime traffic volume" can be a hidden factor. Daytime traffic volume can make congestion in evening higher, and it can be considered that there is correlation between daytime traffic and night traffic.

This study found some significant correlations and provided a new viewpoint of analysis of traffic congestion. Also, it shows that some further statistical analysis is needed to determine the reason of the correlations. Several possible scenarios should be examined in different statistical methods. Several study sites whose characteristics are different should be adopted to confirm the results. The duration of the data should be longer and seasonal effect must be considered deeply. Such statistical studies may make the mechanisms of the correlations more clearly.

ACKNOWLEDGEMENTS

We thank to the Metropolitan Expressway Public Co. and Hanshin Expressway Public Co., which provide the traffic counter data for this study.

REFERENCES

Bajwa, S. I., Chung. E. and Kuwahara. M. (2003a) Sensitivity Analysis of short-term travel time prediction model's parameters , **Proceedings of 10th ITS World Congress**, Madrid, Spain, CD-ROM, November 2003.

Bajwa, S.I., Chung, E. and Kuwahara, M. (2003b) A travel time prediction method based on pattern matching technique", **11th REAAA and 21st ARRB Conference**, Cairns, Australia, 2003.

Kim, J. Y., Kurauchi, F., and Iida Y. (2004) Implementation of Dynamic Path Flow Estimation Model onto Real World Network, **Proceedings of 30th Infrastructure Planning**, Ube, Japan, CD-ROM, November 2004 (in Japanese).