INVESTIGATION OF DAILY VARIATION OF ORIGIN-DESTINATION TRAFFIC DEMAND ON METROPOLITAN EXPRESSWAY USING AUTOMATIC VEHICLE IDENTIFICATION

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SUMMARY

This study observes daily variation of origin-destination traffic demand on the Metropolitan Expressway in Tokyo using the automatic vehicle identification (= AVI) technology, and analyzes the variation in relation to the day of the week as well as the network configuration. Obtaining OD demand needs a large-scale survey such as questionnaire survey and hence the survey are usually limited for particular one day. Thus, we could not get any information of the daily variation of OD demand. In the study, a plate number matching survey was conducted at several on- and off-ramps for five weekdays using on-line and off-line AVI systems. Using these data, we estimated hourly OD demand and its confidence interval, taking the recognition rate and mismatching errors into account. From these OD demand data, we formulated the relationship between OD demand and its coefficient of variation. Furthermore, we showed daily and hourly OD variations and discussed its causes, such as network configuration, day of the week and so on.

INTRODUCTION

OD traffic demand is one of the most important information for road traffic planning and road administration, and has been widely used for road network planning, traffic management planning, evaluation of road development effects and the other objective. It usually has been observed based upon the questionnaire survey. For example, Metropolitan Expressway Public Corporation distributed the questionnaire to find out on- and off- ramps and entrance time of the on-ramp of every trip on one particular day once every two or three years[2)]. About 8 to 10 % samples have been collected and the sample OD was expanded based upon the sampling rate, traffic volumes at several sections observed by traffic detectors, etc.

Although the questionnaire survey estimates the time-dependent OD demand for that particular day, it does not give any information on how the OD demand varies over different days. Since the OD demand is the basis of traffic management and the middle or long term network planning, we have to know not only OD on one single day but also the range of daily variation.

In our previous study[1)], OD variation has been analyzed for Metropolitan Expressway in relation to characteristics of OD pairs, the day of the week, and so on. In the study, time-dependent OD matrix has been estimated using ramp entering and exiting volume obtained by traffic counters installed on the Metropolitan Expressway for 57 weekdays and OD pattern made by the Metropolitan Expressway OD survey. As a result, it concludes that the daily variation of entering and exiting ramp traffic flow is about a few percent and the daily variation of OD traffic demand is about 20 percent. However, this analysis holds a large problem that they assume that the OD pattern of 57 days does not change and they estimate hourly OD demand using only one weekday's OD pattern based upon the Metropolitan expressway OD survey, although OD pattern varies day-to-day. To avoid this problem, it is necessary to analyze the OD variation based on observed data taking the daily variation of OD pattern into account.

In this study, we observe the daily variation of OD traffic demand on the Metropolitan Expressway in Tokyo using the automatic vehicle identification (= AVI) technique, and analyze the variation in relation to the day of the week as well as the network configuration. Recent development of ITS technologies enables us to use rich information obtained advanced instruments such as AVI system and road-to-vehicle communication using optical beacon, then it realizes to obtain dynamic OD demand that previously we could not get. In this study, to obtain plate numbers we make use of the on-line AVI system installed on Metropolitan Expressway and the off-line AVI system that can read plate numbers from video pictures automatically.

PLATE NUMBER MATCHING SURVEY

Selection Of Observed Ramps

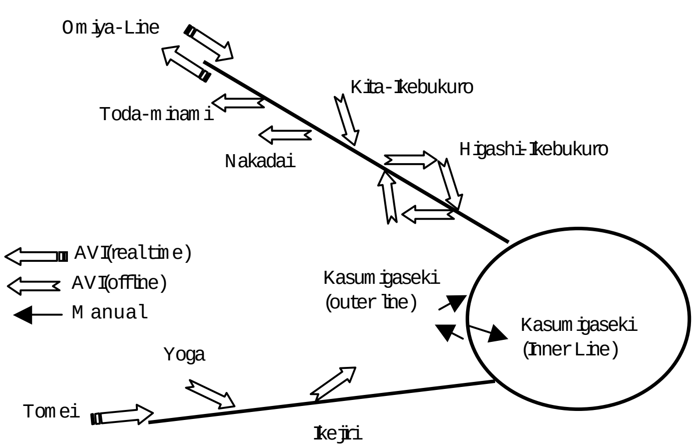

Fig.1 Observed Ramps and Methods

Roughly speaking, Metropolitan Expressway Network consists of directional and central city circle lines. Considering these network configuration and the spatial constraint for observation such as safety of observers and proper installation points of observation instruments, six on-ramps and seven off-ramps were selected for the observation sites (see Fig.1). Kasumigaseki ramp carrying heavy traffic was selected on the central city circle line. For directional lines, we chose ramps on the route No.5 Ikebukuro Line and No.3 Sibuya Line, which have the strongest relation to central city circle line according to the previous Metropolitan Expressway OD survey.

Survey Methods

To obtain the time-dependent OD demand, we observed plate numbers at selected six on-ramps and seven off-ramps for consecutive five weekdays from February 22 to 26, 1999 from 7 am. to noon. The plate numbers and passing times of entering and exiting vehicles at the ramps were recorded either manually, by video recorders, or by the on-line AVIs installed on Metropolitan Expressway. For the manual survey, four digits of each plate number were recorded, and for the video recording, the recorded images were analyzed by the AVI software to automatically obtain the four digits. Observation methods at the selected ramps are shown in Fig.1. Together, we obtained the detector data and the toll collection counts at the ramps.

Observation Results

Fig.2 shows the percentage of properly recorded plate numbers (recognition rate) at the on-ramps. This percentage is calculated by (the number of plates recognized) / (the number of vehicles). Traffic counts of detectors at the same date and time are used as the number of vehicles. We verified the error of detector counts were within 5 percent in comparison between detector data and the toll collection counts at the on-ramps.

In the observed data, the recognition rate of plate number were over 80 percent at normally observed points, though there are some differences by observed points. However, there were incomplete data at some ramps, such as the Higashi-Ikebukuro off-ramp, the Yoga on-ramp on the 22nd and the 23rd of February, the Kasumigaseki off-ramps and the Omiya-Line off-ramp on the 24th because of weather condition and inexperience of observers.

Let us consider recognition rate according to the survey methods as follows.

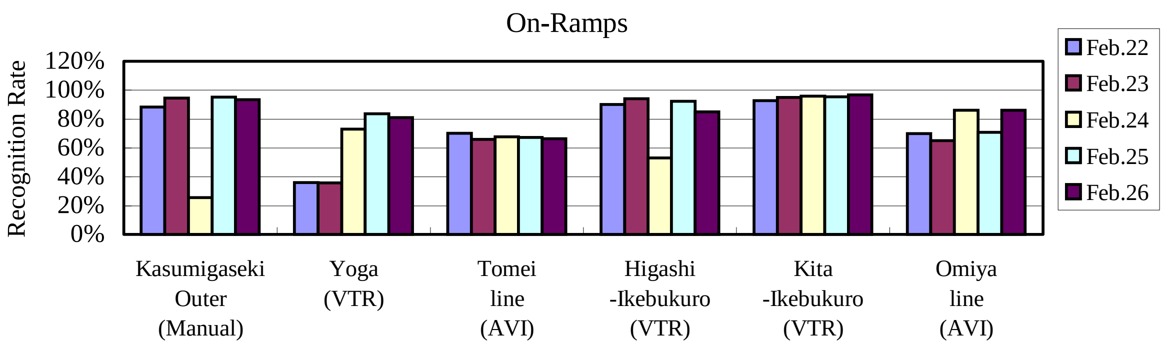

Fig.2 Recognition Rate at On-Ramps

AVI system on Metropolitan Expressway

The recognition rate by AVIs on Metropolitan Expressway indicates 70 – 90 %.

Off-line AVI system using video recorder

The recognition rate by the off-line AVI system, that read plate numbers by the video pictures, depends on the quality of video pictures. The off-line AVI system cannot recognize a plate number if the size of the plate number in the picture is not large enough and if the brightness of the picture is insufficient.

Eye measurement by observers

Accuracy of eye measurement is the highest of three methods. The recognition rate was as high as 90%, if an observer mastered operation of the machine.

ESTIMATING RAMP-TO-RAMP OD DEMAND

Let us explain how to estimate ramp-to-ramp OD demand from the plate number data obtained by the field survey. The observed plate numbers are matched at the on- and off-ramps. First, based on the traffic condition observed by traffic detectors, we estimated travel time of a vehicle (say vehicle A) from its on-ramp to every off-ramp by its entrance time at the on-ramp. Then, from the estimated travel time we estimated approximate exit time of the vehicle A for every off-ramp and specify the vehicles to be matched with the vehicle A as the vehicles exiting the off-ramps within +/- 30% of estimated travel times.

If the vehicle that has the same plate number as the vehicle A exists at only one off-ramp within the time period, we consider that the vehicle A arrived at this off-ramp. If these vehicles exist at two or more off-ramps, we chose a vehicle exiting with minimum difference from the estimated exit time. If no vehicle that has the same plate number exists at observed off-ramps, we consider that the vehicle A went to an off-ramp outside of the study points. Doing these operations for all vehicles entering observed on-ramps, we estimated the raw OD matrix, which has not been expanded, by the entrance time from on-ramps.

We obtain the expanded OD demand table dividing the raw OD matrix by the recognition rate. That is, let $Y^{od}(t)$ be the number of matched vehicles entering from on-ramp o at time period t and exiting off-ramp d, then the expanded OD demand $X^{od}(t)$ can be estimated by:

$$X^{od}(t) = Y^{od}(t) \cdot \frac{1}{P^{od}(t)}, \qquad (1)$$

where $P^{od}(t)$ is the recognition rate of traffic entering from o at time period t and exiting d. Using the recognition rate of the on- and off-ramps, that have been observed as shown at Fig.2, $P^{od}(t)$ is assumed as:

$$P^{od}(t)=P^{o}(t)\cdot P^{d}(t), \qquad (2)$$

where $P^{o}(t)$ is the recognition rate of vehicles entering from on-ramp o at time period t, and $P^{d}(t)$ is the recognition rate of vehicles exiting off-ramp d at time period t.

In this survey, the average of expansion rate $1/P^{od}(t)$ was 1.9.

ERROR OF ESTIMATED OD DEMAND

To analyze traffic counts in the traffic survey, it is important to know how much errors exist caused by the survey. We consider three kinds of errors mentioned below and estimate the confidence interval of the OD traffic demand.

Errors by Recognition Rate

Since we cannot obtain 100% recognition rate, so we estimate OD demand multiplying raw OD demand $Y^{od}(t)$ by expansion rate $1/P^{od}(t)$. Since $Y^{od}(t)$ is the number of vehicles observed at the probability $P^{od}(t)$ out of OD demand $X^{od}(t)$,it obeys the binominal distribution $(X^{od}(t),P^{od}(t))$. So, the variation $\mathrm{Var}(Y^{od}(t))$ becomes $Y^{od}(t)(1-P^{od}(t))$, and the variation $\mathrm{Var}(X_1{}^{od}(t))$ caused by the recognition rate of OD estimator $X^{od}(t)$ can be estimated as:

$$\begin{aligned} Var(X_1{}^{od}(t)) &= \frac{1}{P^{od}(t)^2} \cdot Var(Y^{od}(t)) \\ &= \frac{Y^{od}(t)}{P^{od}(t)} \cdot \left(\frac{1}{P^{od}(t)} - 1\right) \quad . \end{aligned} \tag{3}$$

To see the equation (3), the variation becomes larger as the recognition rate $P^{od}(t)$ being smaller.

Errors by Mismatching

Mismatching errors are caused by matching a vehicle entering from another on-ramp or exiting another off-ramp by mistake because we didn't observe all ramps in Metropolitan Expressway at this survey. Especially, we may make mismatching when a vehicle from an observed ramp to a non-observed ramp has the same four digits as one from a non-observed ramp to an observed ramp. At this survey, because limited ramps are observed, the number of non-observed ramps is enormously large. So, we cannot ignore these errors.

To examine these errors, mismatching simulation was carried out. That is, random four digits are allocated to the whole OD demand, matching are executed by the same method explained at the previous chapter and the number of mismatching are counted. Executing this simulation at a thousand times, we obtained the expectation $\mathrm{E}(X_2{}^{od}(t))$, and the variance $\mathrm{Var}(X_2{}^{od}(t))$ of mismatching of traffic entering from *o* at time period *t* and exiting *d*,.

Errors by Recognition Mistake

Errors by recognition mistake are caused by observers or survey instruments recognizing the wrong plate numbers by mistake. We examine the accuracy of the four digits recognized by comparing them with manual recognition. And we confirm that the off-line AVI system can recognize the plate number with accuracy of almost 100%, once AVI system can recognize the number. We can suppose that on-line AVIs on Metropolitan Expressway have the same accuracy as the off-line AVIs. For the recognition accuracy by observers, it is difficult to evaluate it because effects of field condition or human characteristics are large. Therefore, we exclude recognition mistake errors from a quantative analysis, though there are more or less recognition mistake errors in the real data.

Table-1 Estimated OD Demand and its Standard Deviation

OD demand(Standard Deviation) Feb. 26, 1998 (Fri.)

D O	Kasumiga -seki, outer	Kasumiga -seki ,inner	Ikejiri	Higashi-Ikebukuro	Nakadai	Toda-Minami	Omiya line
Kasumigaseki outer	•	•	•	18(6)	28(4)	28(5)	21(6)
Yoga	•	474(43)	233(16)	71(13)	78(17)	59(8)	137(26)
Tomei line	•	575(35)	710(40)	117(20)	95(21)	99(20)	240(41)
Higashi -Ikebukuro	11(4)	•	•	•	51(5)	79(6)	91(7)
Kita-Ikebukuro	37(4)	•	•	5(3)	•	•	•
Omiya line	11(13)	•	•	33(11)	•	•	•

- OD demand : 5 hours OD demand from 7 a.m. to noon [veh / 5 hours]

Correction of Estimated OD Demand and Estimation of its Confidence Interval

Let us consider to correct estimated OD demand $X^{od}(t)$ and to estimate its confidence interval taking errors by recognition rate and mismatching into account. At first, we correct estimated OD demand by subtracting mismatching errors from estimated value obtained by equation (1) as follows:

$$X^{od}(t) = \frac{Y^{od}(t)}{P^{od}(t)} - E(X_2^{od}(t)) \cdot \qquad (4)$$

Assuming that errors caused by recognition rate and mismatching errors are independent, the variance of estimated OD demand $X^{od}(t)$ can be expressed as:

$$\begin{aligned} Var(X^{od}(t)) &= Var(X_1^{od}(t)) + Var(X_2^{od}(t)) \\ &= \frac{Y^{od}(t)}{P^{od}(t)} \cdot \left(1 - \frac{1}{P^{od}(t)}\right) + Var(X_2^{od}(t)) \ . \end{aligned} \qquad (5)$$

And the variance of daily OD demand Var(X^{od}) can be obtained by:

$$Var(X^{od}) = \sum_t Var(X_1^{od}(t)) + \sum_t Var(X_2^{od}(t)) \cdot \qquad (6)$$

We here consider the standard deviation, that is square root of the variance, as confidence interval of estimated value.

ESTIMATION RESULT

Estimated OD Demand and its Confidence Interval

Table-1 shows estimated 5 hours OD demand and its confidence interval (standard deviation) on 26th. February. And Fig.3 shows relationship between OD demand and its confidence interval of all OD pairs for observed 5 days. In these figures, larger dots mean 5 hours OD demand and smaller dots mean 1 hour OD. Because of 1 hour OD demand being small, rate of confidence interval is distributed at larger part. Average rate of confidence interval was about 15 %, except for incomplete data caused by weather condition and human error. Obviously, Fig.3 shows that smaller OD estimators result in larger confidence interval.

Variation of OD Demand

Relationship between OD demand and its variation coefficient

Fig.4 shows variation coefficient, derived by dividing standard deviation by average OD demand, of 5 hours OD demand for observed 5 days as black circle, and that of hourly OD demand as white square, for all observed OD pairs. Obviously, variation coefficient tends to become smaller according to average OD demand being larger. Suppose demand of an OD pair (say OD1) is 100 vehicles, then variation coefficient can be read about 0.4 from this figure and standard deviation is about 40 vehicles.

Here suppose demand of another OD pair (say OD2) whose average demand is twice as OD1. If the condition of OD2 such as user characteristics and network configuration is entirely same as that of OD1, then the variation ratio of OD1 to OD2 is simply 1:2 and then ratio of variation coefficient must be $1{:}1/\sqrt{2}$. That is, it indicate that variation coefficent becomes small in inverse proportion to square root of OD demand, although the real relationship become much more complicated because user characteristics and network are different by OD pairs. Assuming these relationship, we can estimate regression curve on the condition that variation coefficient becomes 0.4 when OD demand is 100 vehicles as:

$$\text{Variation coefficient} \quad 4 \;{}^{\wedge}\sqrt{\text{Average OD demand}} \qquad (7)$$

The regression curve is drown in Fig.4. If road users act as entirely random manner, the regression coefficient must be 1, not 4. This result suggests variation of OD is caused by not only random but also significant by influential factor.

This regression curve is estimated simply by relationship of numerical size. It is obtained by ignoring traffic characteristics, such as network, traffic condition, and user characteristics. So, there are many dots that do not fit with the regression curve. It is necessary to correlate these differences with factors above.

Daily Variation

Fig.5 shows daily OD variation for 5 days of representative three kinds of OD pairs: within same directional routes, from a directional line to a circle line, and from a directional through

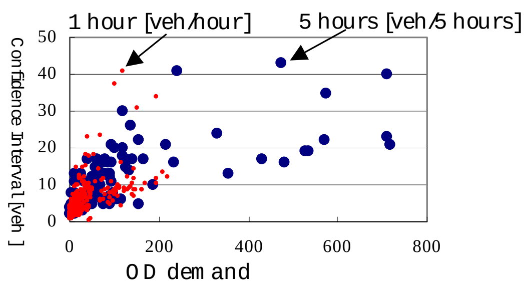

Fig.3 OD Estimator and its Confidence Interval

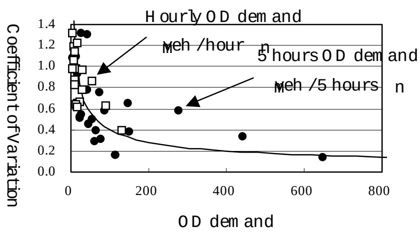

Fig.4 OD demand and Variation Coefficient

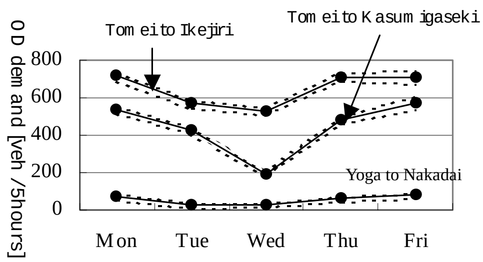

Fig.5 Daily OD Variation

a circle line to another directional line. Dotted lines in the figure mean confidence interval of estimated OD demand. It has a tendency that the OD demand on Wednesday is smaller than the other days, and the OD demand on Monday and Friday is larger. It is already known from previous survey by Metropolitan Expressway that traffic volume at the beginning and the end of week, especially on Friday is larger.

Daily variation seems to be small for the OD demand that have origin and destination on the same directional line, however the tendency by 3 kinds of OD pattern does not appear so clearly. OD variation characteristics depend on location of neighboring ramps, existence of alternative arterial road, and the other factors. Thus, to make causes of the variation clear we have to analyze the OD variation by each OD pair more in detail.

CONCLUSION AND FUTURE RESEARCH

In the study, to grasp the variation of OD demand of Metropolitan Expressway we carried out a plate number survey at several ramps for consecutive five weekdays. To read the plate number we used on-line and off-line AVIs at several observation points. Using these plate number data, we estimated hourly OD demand and its confidence interval, taking recognition rate and mismatching error into account. Total average of the confidence interval was about 15 % of estimated OD volume. From these OD demand data, we formulated the relationship between the OD demand and its variance coefficient; that is, the smaller the OD volume is, the larger its variance coefficient is. Furthermore we showed daily and hourly OD variation and discussed its causes, such as network characteristics, day of the week and so on.

And Future Research will be needed as follows:

1)Improvement of OD Demand Survey
In this study, observed OD pairs were so limited that we could see only a few aspects of OD variation in the Metropolitan Expressway. Furthermore, the probability of plate number mismatching became high. To know the whole aspects of OD variation in the Metropolitan Expressway network, most ramps should be observed. However, the survey method adopted in this study takes so many hands and time. We hope that the method of continual survey would be established, making good use of new ITS technologies such as AVI, PHS, and GPS.

2)Analysis of Factors of OD Variation
In this study, we thought network characteristics and day of the week as influential factors of OD variation. However, to make the factors clear, we have to analyze OD variation by each OD pair more in detail.

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