BASIC STUDY ON TRAVEL TIME MEASUREMENT USING AUTOMATIC VEHICLE IDENTIFICATION SYSTEMS IN CONNECTION WITH TRAFFIC FLOW CHARACTERISTICS

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abstract: Two traffic surveys were conducted along with travel time measurements with AVI cameras and from the results of the traffic survey, an investigation was conducted to determine the relationship between the rate of recognition of vehicle license number and recording conditions such as direction of traffic flow and traffic jam conditions. Particular attention was paid to the accuracy and reliability of travel time measurements from the AVI system.

1. BACKGROUND AND STUDY OBJECTIVES

On Japanese expressway networks near big cities and along trunk corridors there are many bottleneck sections where congestion occurs every day during the peak period due to an increase in traffic demand. These daily traffic jams do serious harm to economic, industrialand social activities in urban areas, and various measures have been taken to cope with this situation. These measures include such things as on-ramp controls and the use of illuminated message boards to transmit constantly changing traffic information.

In this study, two traffic surveys were conducted along with travel time measurements with AVI cameras: traffic flow was recorded using TV cameras at junction connecting the outer loop expressway and an eastbound radial expressway in OSAKA, and travel time measurements using floating cars were taken along a 100km section of the Meishin Expressway during heavy traffic periods of in August.

From the results of the traffic survey, an investigation was undertaken to determine the relationship between the rate of recognition vehicle license numbers and recording conditions such as direction of traffic flow and traffic jam conditions. Particular attention was paid to the accuracy and reliability of travel time measurements from the AVI system.
The prime objectives of the study are as follows;
i) To investigate the relationship between travel time fluctuations and the development of traffic congestion at the junction where traffic between the New Kansai Airport and the Eastern Osaka Area flows.
ii) To investigate the most effective use of the AVI system to obtain accurate travel time measurements.

Although a great deal of research has been carried out in connection with those study objectives, including surveys on traffic flow characteristics and travel time fluctuations with respect to traffic congestion on expressways[1)~2)], as well as research into the effectiveness and availability of the AVI systems for automatic travel time measurements[4)~8)], very few studies have been undertaken that specifically connect characteristics of traffic congestion and the function of automatic travel time measurements on expressways.[9)] In this study two series of

traffic surveys were conducted: a long distance travel timesurvey and a junction traffic survey. The outline of the survey and traffic stream characteristics during the surveys are as follows.

2. OUTLINE OF THE SURVEY

2.1 Long Distance Travel Time Survey

2.1.1 Survey Method

The study section of the long distance travel time survey is the west bound traffic between the Gifu-Hajima interchange and a point about two kilometers upstream of the Ohtsu service area on the Meishin Expressway. A pair of CCD camera were placed on the shoulder of the ramp way overbridge of the Gifu-Hajima interchange, the pedestrian bridge at the Hataso parking area, and on an overbridge at the west end of the study section. The distance between the Gifu-Hajima station and the Hataso station is about fifty six kilometers,and the distance between the Hataso station and the Ohtsu station is about forty-nine kilometers.

The total study section length is therefore about a hundred and five kilometers. A route map of the stud section is shown in Fig.1. The survey was conducted for two days on Saturday 13 and Sunday 14 September, 1994.The CCD camera recording began at 7:00 AM and ended at 3:00 PM. The timing of the camera recording of the two downstream stations was selected to pick out as many of the vehicles recorded at the upstream as possible. However, there was some sporadic rainfall on the morning of the first day and there was some mechanical trouble with the recording process. As a consequence, data regarding the results of the survey is taken mainly from the second survey. Fig.2 shows the fluctuation of traffic volume at five minute intervals measured from the output of the loop detectors installed on the Meishin Expressway at a point nearest each camera recording station. Based on the daily report from the Traffic Control Office of the Nagoya Operation Bureau, Japan Highway Public Corporation (hereafter refered to as JHPC), there was no congestion through out the whole study section during the survey period. The travel time was also measured directly by floating test vehicles three times during the camera recording period.

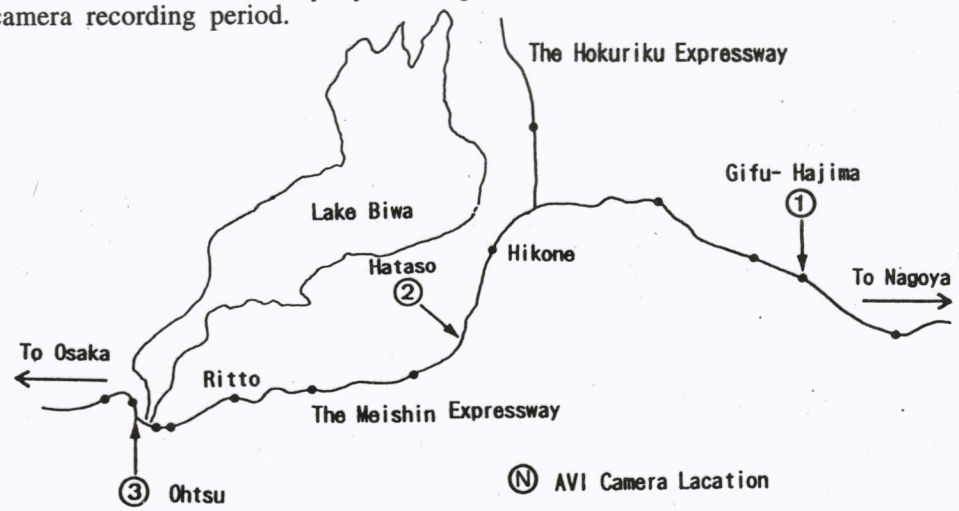

Figure 1 Route Map of the Study Section

2.1.2 Results of the Survey

Two sets of AVI systems were used to analyse the video tapes recorded at the three camera recording stations. The AVI systems recognize vehicle type numbers, vehicle numbers and vehicle use classification numbers automatically

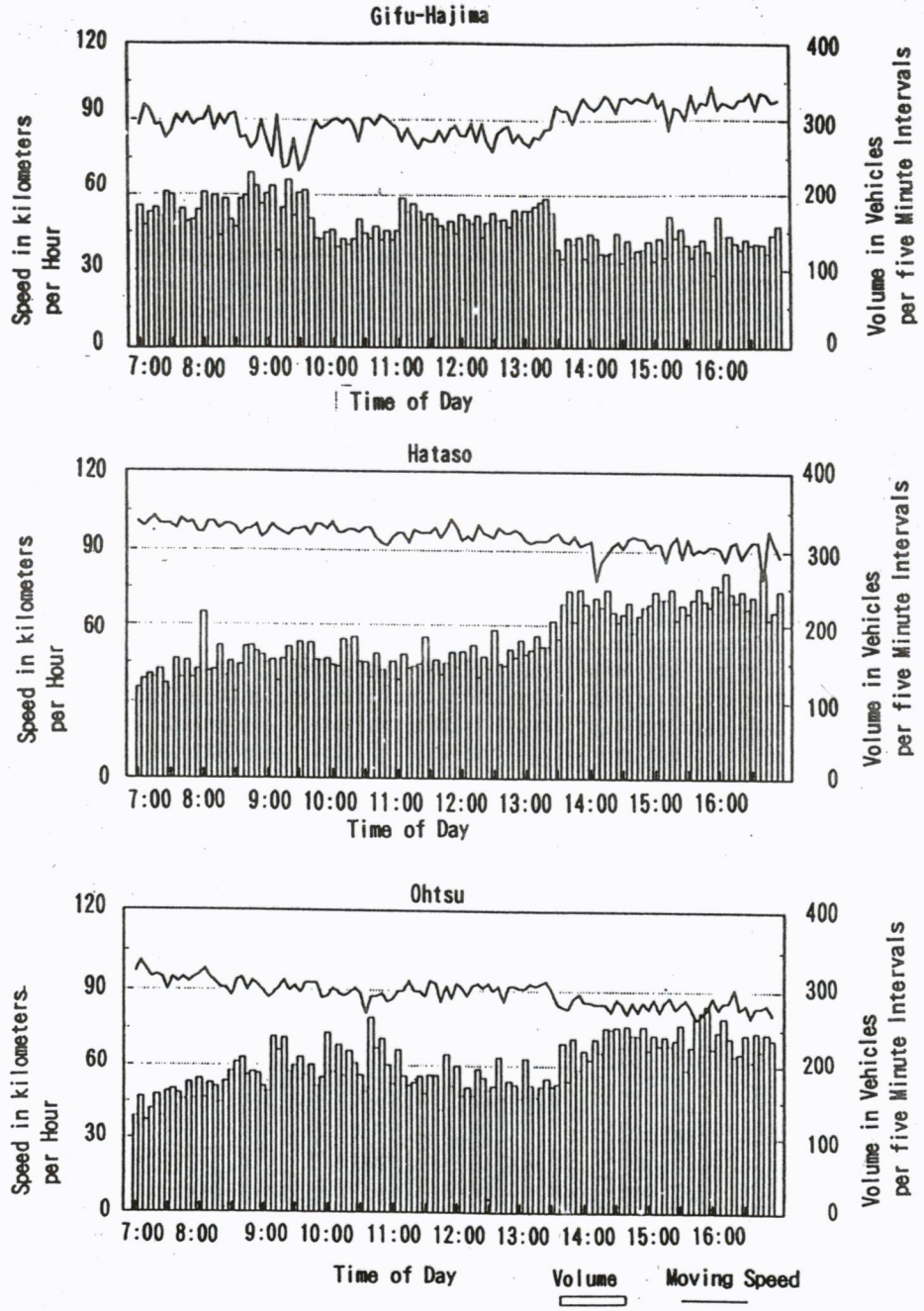

Figure 2 Fluctuation of Traffic Volume and Moving Speed at Five Minute Intervals

from the video tapes and record that data onto floppy disks together with the time each recognized vehicle passed. The rate of recognition is the ratio of the number of recognized vehicles to the total number of vehicles that passed through the camera location during the survey period. Fig.3 shows the fluctuation of the average rate of recognition of the two CCD cameras at each recording station. The rate at the Gifu-Hajima station varies between 30~85% and the rates for the Hataso and Ohtsu stations vary between 20~65% and 5~75%, respectively. At the Gifu-Hajima and the Ohtsu Stations, the rear number plates were recorded while at the Hataso station, the front number plates were recorded. The rate of recognition at Hataso during the whole recording period and that of the Ohtsu station during the morning period are rather low because of inadequate adjustments when the cameras were set up.

Next the data of the recognized vehicles on floppy disks underwent a matching process. This process matches up the upstream and downstream vehicle data. The travel time of each matched up vehicle can be computed by taking the time differences between the time it passed the upstream and downstream camera positions. The results of matching up all the data of both the upstream half and downstream half study sections are shown in Fig.4. The figure indicates a wide spread of computed travel time. This is partly because there are many vehicles with the same vehicle number issued from different land transport offices and partly because some vehicles spend a long time in parking spaces on the expressway. However, Fig.4 indicates a very clear concentration of dot marks on a linear line during the whole recording period.

2.2 Junction Traffic Survey

2.2.1 Survey Method

On Tuesday 20th and Wednesday 21st September 1994, the morning peak traffic was surveyed over an 800 meter-long section, including a loop ramp and its merging and diverging terminals connecting the north bound traffic on the Hanwa Expressway and the east bound traffic on the Nishimeihan Expressway. Seven video cameras were set up on the top of the frame structures for

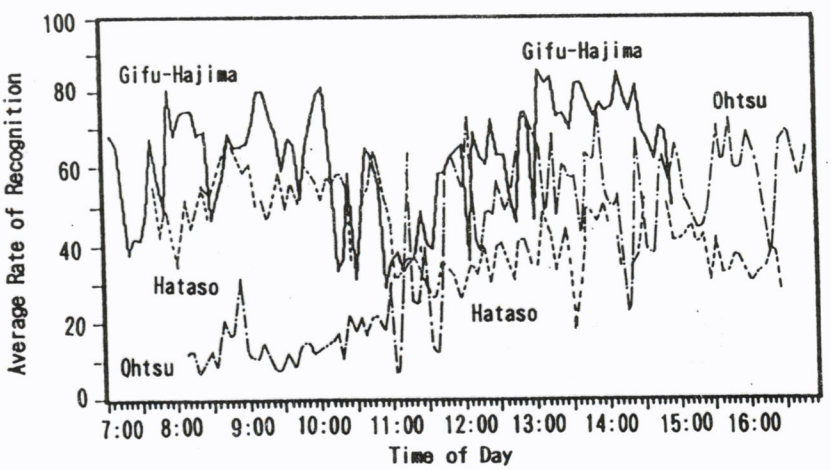

Figure 3 Fluctuation Rate of the Average Rate of Recognition

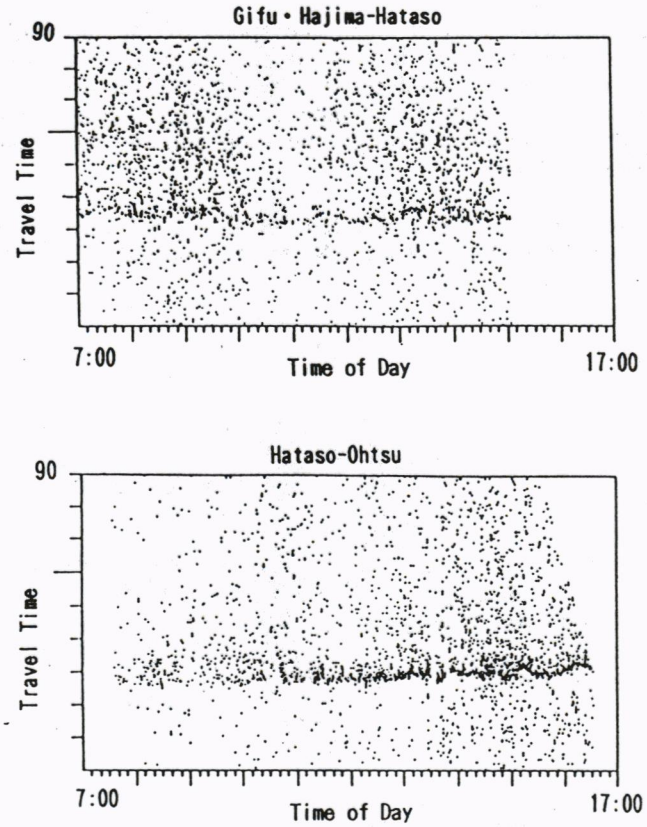

Figure 4 Matching Data

overhead signs. The location of the seven video cameras and their ranges are shown in Fig.5. Video recording began at 8:00 AM and 7:30 AM on the 20th and 21st, respectively, and continued for three hours on both days. In addition, travel time measurements using the AVI systems were conducted with the help of six CCD cameras which were also placed at the top of the frame structures for overhead signs located about one kilometer upstream of the Matsubara junction on the Hanwa Expressway and also about six kilometers east of the junction on the Nishimeihan Expressway as shown in Fig.6. The travel time measurements were taken during the whole period of the video camera recording.

Traffic congestion started from the Matsubara toll barrier and extended to the Matsubara Junction as usual in the morning peak period. However, the traffic jam extended to the north bound traffic lane of the Hanwa Expressway beyond the loop ramp of the junction only on Wednesday 21st. On that day, the traffic was congested beyond the loop ramp at the beginning of the video recording and the congestion cleared about one hour later. However, an hour later, congestion built up again due to an increase in business and industrial traffic. Fig.7 shows the fluctuation at five minute intervals in lane traffic volume and the average speed over five minutes for each lane measured from the output of the loop detectors installed on the Hanwa Expressway at a point upstream of the Matsubara Junction. The weather and pavement conditions were favorable and there were no traffic accidents or incapacitated vehicles during the traffic survey.

2.2.2 Results of the Survey

When the recordings were played back, the speed of the moving vehicles was measured by measuring the time it took to pass through two points which are marked on the video screen based on the lane marks on the pavement. The speed measurements were made for a lane connecting the northbound traffic on the Hanwa Expressway passing through the loop and the east bound traffic on the Nishimeihan Expressway.

Two periods of ten minutes were selected for the speed measurement: one was between 8:30 AM and 8:40 AM for the period of decreasing

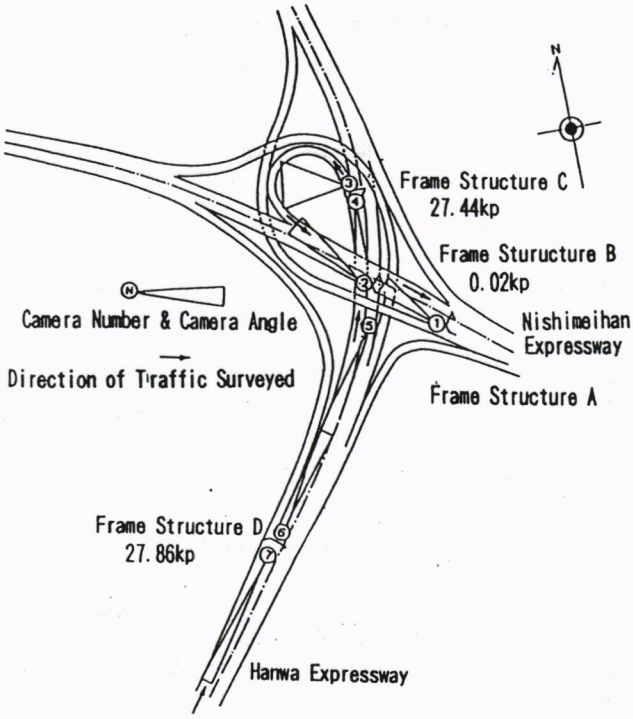

Figure 5 Video Camera Location and Camera Angle

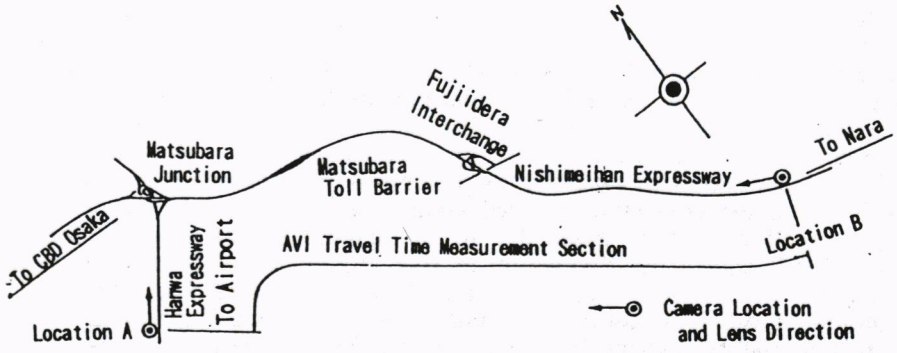

Figure 6 Route Map of Study Section

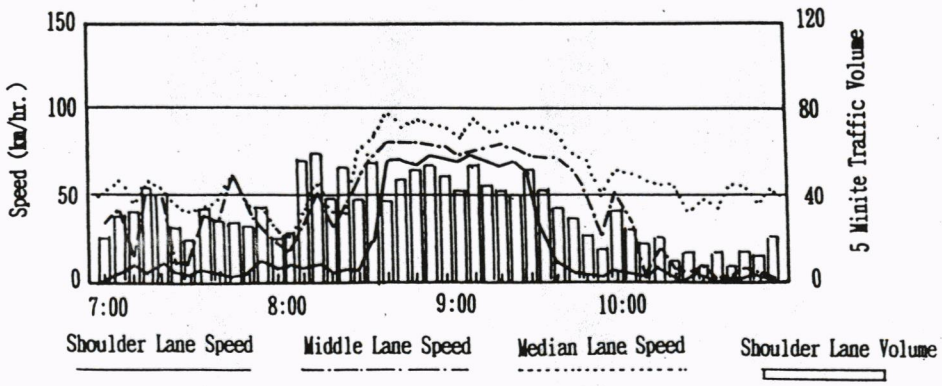

Figure 7 Shoulder Lane Five Minute Traffic Volume and Lane Traffic Speed at 27.57kp of The Hanwa Expressway

congestion and the other was between 9:35 AM and 9:45 AM for the period of increasing congestion. The results of the speed measurements are shown in a contour diagram on a time and space field with five speedmeasurement ranges which are as follows: below 10km/hr, 10-20km/hr, 20-30km/hr, 30-40km/hr, and above 40km/hr. Fig.8(A) and (B) show the speed contour diagrams for the periods of increasing and decreasing congestion, respectively. The two diagrams were drawn up by connecting the timings of the speed range boundary for each speed measurement station. Fig.8(A) shows that heavy congestion with traffic moving at a speed of below 10km/hr started from the beginning of the measurement period and traffic congestion extended backwards southbound on the shoulder lane of the Hanwa Expressway beyond the diverging nose to the loop. It can also be seen that strip domains with relatively higher speeds of 10-20km/hr appear with about a two minute time interval and continue upstream.

The 10-20km/hr speed strips were produced by a vehicle or vehicles merging into the congested shoulder lane of the Nishimeihan Expressway from a point a little upstream of themerging lane. Then the vehicles behind often proceeded to the end of the merging lane producing a stream of vehicles with a slightly higher moving speed than the upper section.

On the other hand, the speed contour diagram for 8:30 AM to 8:40 AM, which corresponds to the period of decreasing congestion shows irregular speed range distribution without the development of higher speed strip ranges. This situation was brought about by a slightly greater merging capacity on the on-ramp terminal of the Nishimeihan Expressway after congestion had cleared with respect to the through traffic on the Expressway. On that occasion there were some vehicles which merged directly even into the median lane. However, as a whole, a slow decreasing congestion was observed during the period of speed measurement.

Finally the travel time between the upstream and downstream CCD camera recording station was measured using the AVI systems. Fluctuation in the rate of recognition of the two recording stations and the plottings of the travel time measurements using all the data of the recognized vehicles are shown in Fig.9 and Fig.10, respectively. The rate of recognition is between 65 and 85 percent, which is considered fairly good. Fig.10 indicates a very wide spread of travel time measurements as shown in the Meishin measurements. However,a very clear curvilinear concentration is manifested during the noncongested period.

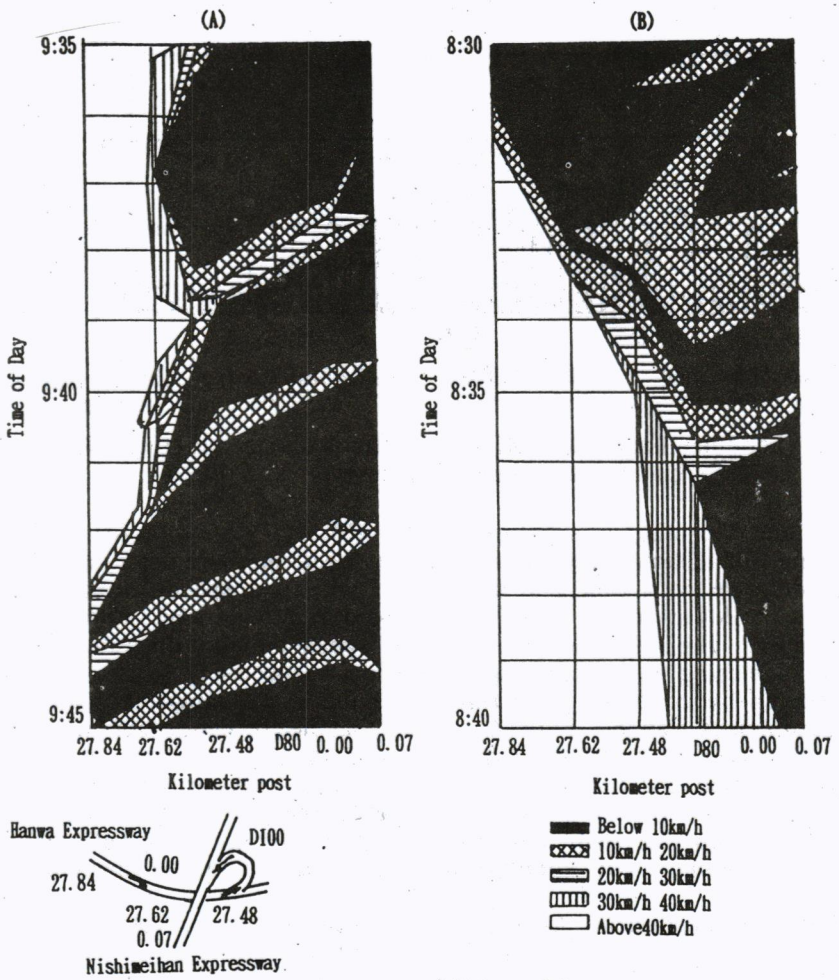

Figure 8 Speed Contour Diagrams

3. TRAVEL TIME EVALUATION USING AVI SYSTEM

3.1 Coefficient Smoothing Method

The travel time measurements through AVI systems include many unusual travel time value because of the mixture of vehicles with the same licence number issued from differentlocal transport office and because of vehicles spending time in the parking areas, amongst other reasons. In order to overcome this situation, a statistical method called the coefficient smoothing method is used to examine whether present measurements remain within a prescribed range or not. The outline of the cofficient smoothing method is as follows:

First of all, a standard value for acceptable criteria T_n is determined by the following equation :

$$T_n = \alpha\, T_{n-1} + (1-\alpha)\, t_n$$

where T_{n-1} ; smoothed out travel time value up to t_{n-1}

t_n ; travel time of nth accepted data

$(n=1,2,3\cdots)$

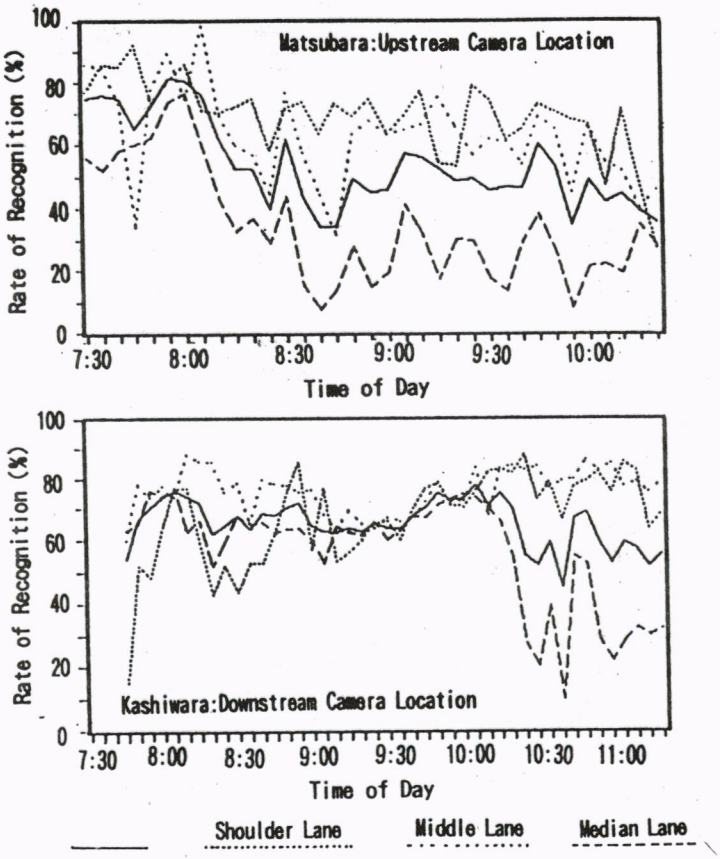

Figure 9 Fluctuation of Rate of Recognition

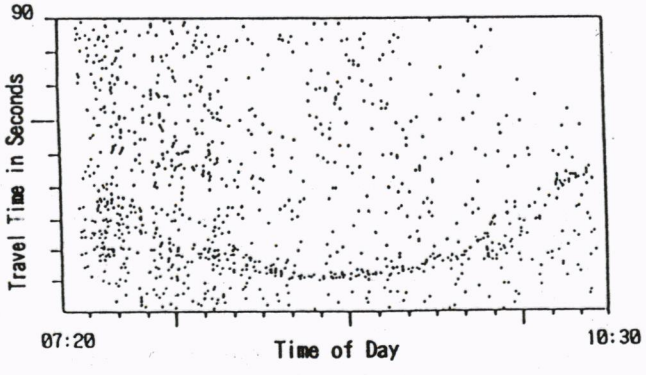

Figure 10 Matching Data

Each vehicle is classified according to the following range.

- acceptable range

$T_n - \delta T_n \leqq t_i \leqq T_n + \delta T_n$

t_i ; ith travel time computed from the AVI data processor ($i=1,2,3\cdots$)

δ ; coefficient for acceptable criteria .($0 \leqq \delta \leqq 1$)

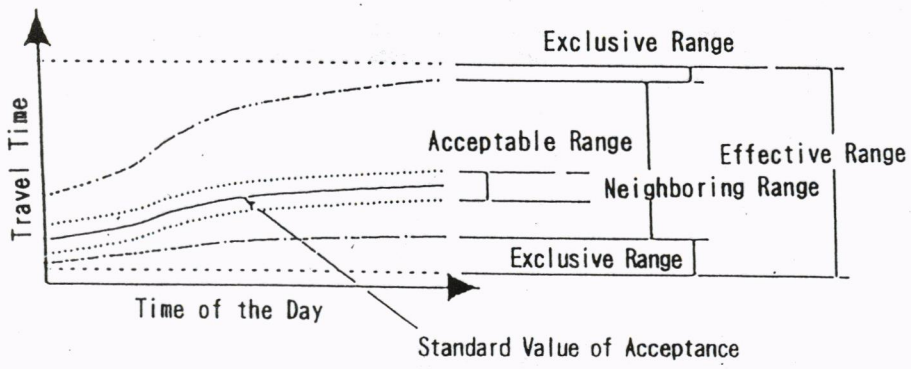

Figure 11 Standard Value for Acceptable and Effective Ranges

- Neighboring range
  $0.5T_n \leqq t_i \leqq 2T_n$
- Effective range
  $T_{min} \leqq t_i \leqq T_{max}$
  T_{min} and T_{max} are both pre-determined values.
- Exclusive range
  outside the effective range

All the ranges described above are shown graphically in Fig.11.
On the other hand, when traffic condition changes suddenly for instance in case of an accident, it is often the case to have sizable delay in computing the smoothed out travel time value Tn using equations described above. In order to prevent to get such delay, the value of Tn is to be replaced by t_n, if there are j continuous vehicles that satisfy the following conditions

$$t_{j-1}(1-\gamma) \leqq t_j \leqq t_{j-1}(1+\gamma)$$

where $j=2,3\cdots N$

γ : predetermined coefficient, $\gamma < \delta$

The value of α , δ , γ and N are determened more or less through the method of trial and error.

3.2 Long Distance Travel Time Measurement

Fig.12 A, B and C show the distribution of travel time in the acceptable range computedfrom the time differences through the upstream half, the downstream half and the whole study section, respectively. The distribution of the acceptable travel time through the upstream half section, Gifu-Hajima～Hataso, and the downstream half section, Hataso-Ohtsu, remain within a very stable constant range. However, that of the whole study section varies significantly although no traffic congestion was observed, On long distance travel time measurement using AVI systems, the matching rate decreases considerably because of an increase in off-ramp demand downstream. Furthermore, it is considered that the ratio of vehicles stopping at the service station parking lots increases more as the travel distance becomes longer. The value of α , δ , γ and N are 0.6, 0.2, 0.1,and 5, respectively. T_o, T_{max} and T_{min} are 35 minutes, 120 minutes and 10 minutes for the Gifu-Hajima～Hataso section and 28 minutes, 120 minutes and 20 minutes for the Hataso-Ohtsu section in Fig.12. It was concluded that the very low matching rate of the Gifu-Hajima～Hataso

section during the whole recording period and that of the Hataso-Ohtsu section during the morning recording period as shown in Fig.13 were due to the very low rates of recognition.

Fig.14 shows the fluctuation of the average value at five-minute intervals of the travel time in the acceptable range. The average travel time fluctuation of the Gifu-Hajima～Hataso, and Hataso-Ohtsu sections confirm that there was no traffic congestion on the study section during the recording period. The small cross

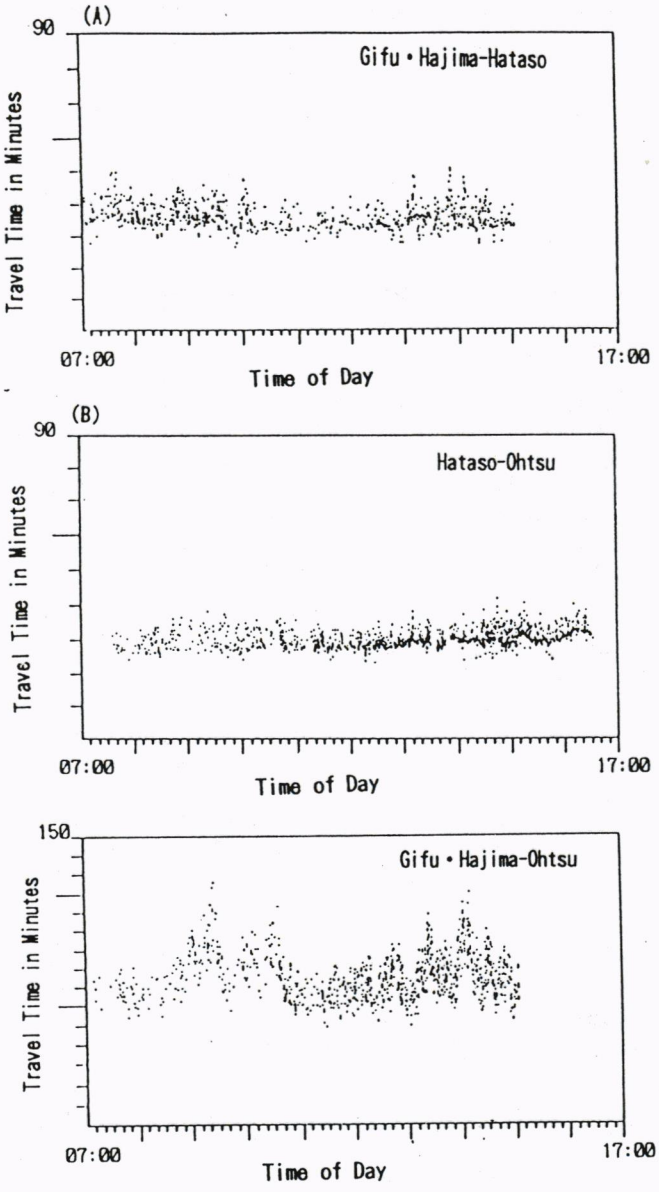

Figure 12 Distribution of Travel Time in the Acceptable Range

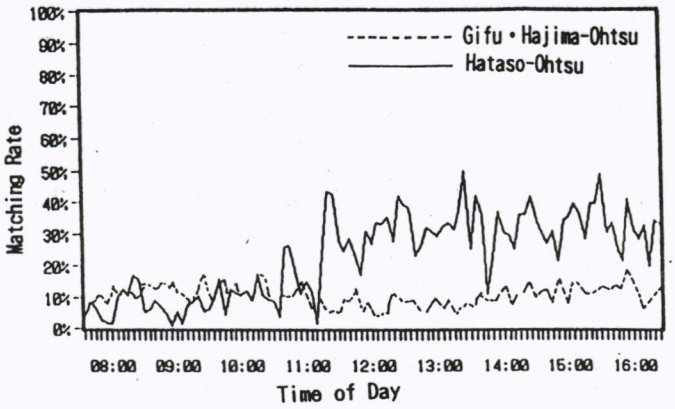

Figure 13 Fluctuation of Matching Rate

marks in Fig.14 show the direct travel time measurements of the floating test vehicles. The direct travel time measurements show a slightly longer travel time than that of the AVI measurements. This is because the test floating vehicles had to take the shoulder lane in order to confirm the time the test vehicles passed each 100m post, and this usually has a moving speed which is more than ten kilometers slower than median lane. However, the AVI average travel time of the Gifu-Hajima- Ohtsu section, that is the whole study section, shows wide fluctuation. In order to prevent such wide fluctuation, the compound value of the travel time of the upstream half and the downstream half of the study section as shown in Fig.15, is computed for the whole study section travel time instead of the direct travel time measurement shown in Fig.14 (C). Fig.15 also include the estimated present travel time through the average of each loop detector installed on the Meishin Expressway every two kilometers on average. The estimatespresent travel time from the detector outputs coincides measurment with the compound AVT travel time quite well.

3.3 The Results of the Junction Survey.

Fig.16 shows the distribution of travel time in the acceptable range computed from the time difference between all the three upstream cameras and also all the three downstream cameras. The value of α , δ , γ and N are 0.5, 0.2, 0.1 and 5, respectively. T_o is 40 minutes. T_{max} and T_{min} are 90 minutes and 3 minutes, respectively. The ratio of the matching rate of this survey is about15 percent, which is rather lower than expected. But the main reason for the low matching rate is the fairly low rate of traffic travelling to the east of the north bound traffic on the Hanwa Expressway.

Fig.17 shows the fluctuation of the average values of five-minute average travel time in the acceptable range. The significant variation between 9:45 AM and 10:00 AM was caused by the rapid development and dispersion of traffic jams on the approach section of the Matsubara junction.

4. CONCLUSIONS AND SUBJECTS FOR FUTURE STUDY

The conclusions of the study are as follows;
i) With the exception the instance where the setting-up adjustments were inadequate,

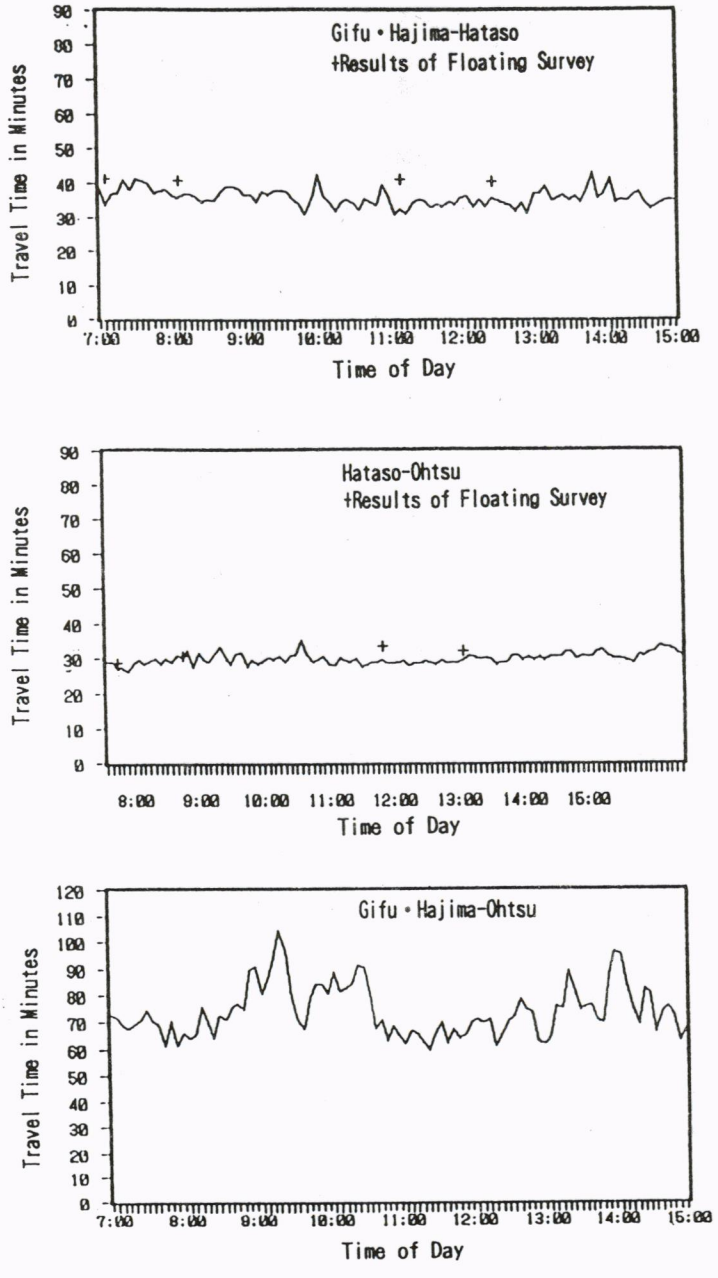

Figure 14 Fluctuation of the Average Travel Time at Five Minute Intervals

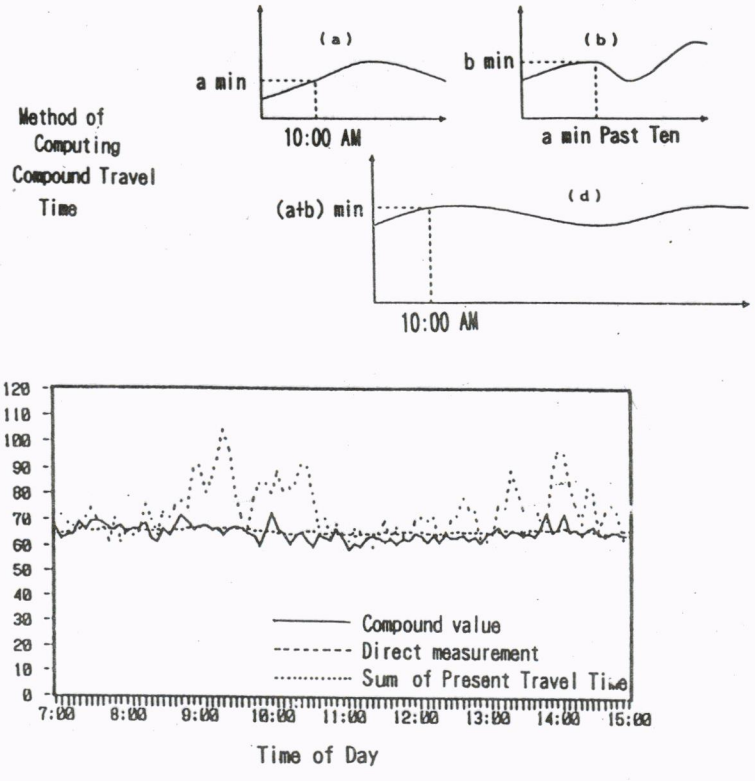

Figure 15 Compaund Travel Time of Whole Section

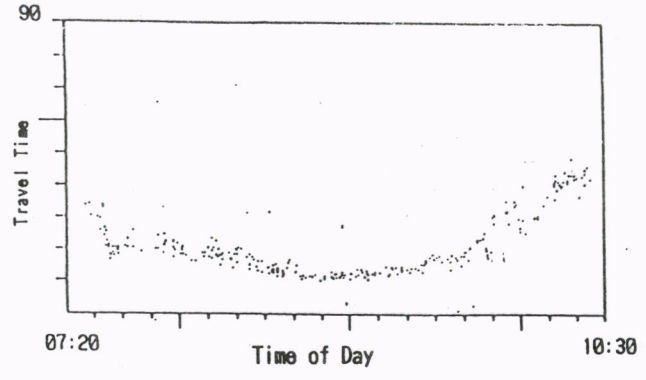

Figure 16 Distribution of Travel Time in the Acceptable Range

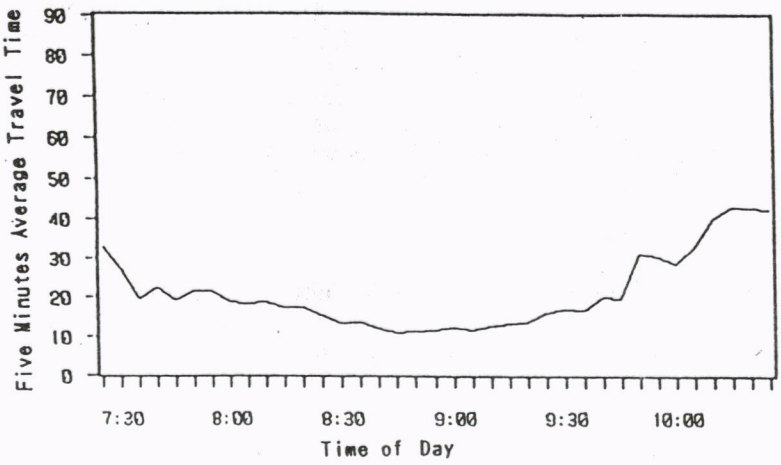

Figure 17 Five Minutes Average Travel Time in the Acceptable Range

the rate of recognition of the AVI systems remains between 60 to 80 percent.
ii) The average travel time at five-minute intervals measured with AVI system for expressway sections 50km in length coincides quite well with the estimated present travel time computed from detector outputs and also with the direct travel time measurements using the floating test vehicles, under traffic conditions without any congestion.
iii) The estimation of travel time for a hundred kilometer expressway section by compounding 50 kilometer length AVI travel time measurements shows quite stable and reliable results under traffic conditions without any congestion.
iv) Considering the characteristics of traffic flow confirmed by the traffic survey and the measurement of travel time using an AVI system, it must be recognized that there is a possibility of having wide fluctuations in travel time along sections which include a stretch of particularly congested lanes due to merging and diverging.

Subjects for future study are as follows;
i) To establish the reliability of traffic survey methods using the AVI system in order to accumulate experience in using AVI systems.
ii) To ascertain the most effective method of using the AVI systems for travel time measurements such as the effective span of the upstream and downstream camera locations.

REFERENCES

b) Journal papers

Yasuji Makigami et al; Simulation Model Applied to Japanese Expressway, **Journal of Transp. Eng., ASCE Vol.110, No.1**, pp94～111, January 1984
Yasuji Makigami et al; Basic study on the Effectiveness of Expressway Operations in WinterUsing Bottleneck Simulation Models, **Trans, of JACE** Vol.395/iv-9, pp105-114, July 1988
Kenji Kanayama; On Travel Time Measuring Technology Using License Plate Recognition by Image Processing, **Trans. IEE of Japan** Vol.109-D, No.7 1989, pp447～484.

c) Papers presented to conferences

Inji Shimokai; Development of Vehicle-License Number Recognition Systems

using Real-Time Image Processing and Its Application to Travel-Time Measurements, **Proceedings of the 41st IEE Vehicular Technology Conference**, St, Louis, MO, May19-22, 1991, pp798-804.
Y. Fujikawa, et al; Development of Vehicle-Licence Number Recognition Apparatus using Real-Time Image Processing and its Application to Trave-Time Measurement, **25th International Symposium on Automatic Technology and Automation**, Florence, Italy 1-5 June 1992, pp529-536.

d) Other documents

Osaka Operation Bureau, Japan Highway Public Corporation and Research Institute of System Science; Study Report on Highway Information Systems Part Ⅱ, March 1991.pp～Osaka Operation Bureau, Japan Highway Public Corporation; Report on the study for the High-way Traffic Information Systems, March 1992.