

# Development of the OD Estimation Method for Traffic Condition Prediction

Hironobu KITAOKA  
Toyota Central R&D Labs., Inc.  
(41-1 Yokomichi, Nagakute, Nagakute-cho, Aichi, Japan 480-1192,  
Phone:+81-561-63-6290, Fax:+81-561-63-5426, E-mail:kitaoka@mosk.tytlabs.co.jp)

Eiji TERAMOTO  
Toyota Central R&D Labs., Inc.  
(41-1 Yokomichi, Nagakute, Nagakute-cho, Aichi, Japan 480-1192,  
Phone:+81-561-63-6290, Fax:+81-561-63-5426, E-mail:teramoto@mosk.tytlabs.co.jp)

Hiroyuki ONEYAMA  
Ministry of Land, Infrastructure and Transport National Institute  
for Land and Infrastructure Management  
(1, Asahi, Tsukuba City, Ibaraki, Japan 305-0804,  
Phone:+81-29-864-2211, Fax:+81-29-864-4322)

Masao KUWAHARA  
Professor, Institute of Industrial Science, University of Tokyo  
(4-6-1 Komaba, Meguro, Tokyo, Japan 153-8505,  
Phone:+81-3-5452-6419, Fax:+81-3-5452-6420, E-mail:kuwahara@nishi.iis-u-tokyo.ac.jp)

## SUMMARY

In order to predict traffic condition using traffic simulation with good accuracy, we have developed the method of estimating more accurate OD (Origin-Destination) flow by minimizing the difference between calculated and observed traffic volume. Validity of this method was checked by applying it to the prediction of traffic condition, and it was found that the accuracy of prediction was improved by this method.

## INTRODUCTION

Services of the route guidance based on traffic conditions, such as traffic congestion, accidents, and traffic restrictions, have been realized thanks to the expansion of VICS (Vehicle Information Communication Systems) in Japan. In the future developments, it is desired more advanced traffic information, such as the route of the shortest travel time and the predicted arrival time, will be provided. For a system to offer such information it needs to be able to predict the future traffic conditions and also traffic conditions at location where information is not collected. In order to realize this, traffic conditions prediction by traffic simulation is effective, since traffic simulation can predict traffic condition over a wide area taking into account the influence of accidents and traffic restrictions.

In order to predict traffic conditions using traffic simulation, input data such as the road network, signal timing, and OD(Origin-Destination) flow (i.e., an OD matrix), are required. Above all, OD flow is the most important

for traffic simulation, but it is difficult to observe directly. Thus, we estimate it on the basis of the statistic data taken from questionnaires, such as "Road Traffic Census" and "Person Trip Survey" in Japan. However, estimated OD flow exhibits very large deviance from actual traffic demand because it based the information from questionnaire. Therefore, when the OD flow is used as input data, it is difficult to predict the traffic condition with high accuracy.

There have been several studies on OD estimation. Oneyama<sup>[1]</sup> proposed a method of estimating OD flow by the extended entropy maximization method. However, in this method, the travel time of all links are needed to determine the probability of choosing a route. In a wide area, this method is not suitable for estimating OD flow, since it is difficult to observe the travel time of all links.

In order to improve the accuracy of the traffic simulation, we have developed the method of estimating more accurate OD flow by minimizing the difference between calculated and observed traffic volume. The features of this method are as follows.

- In the process of OD estimation, change of travel time can be taken into consideration.
- The accuracy of estimation of traffic congestion can be improved by recognizing that there are two different traffic parameter relationships, depending on whether traffic is in the free flow range or in the congestion range.
- By using GA (Genetic Algorithm) to search for optimal OD flow, estimation can be performed at high speed.

Validity of this method was checked by applying it to the prediction of traffic condition at Toyota-city, Aichi Pref., and it was found that the accuracy of prediction was improved by this method.

## THE METHOD OF OD ESTIMATION

Figure 1 shows the structure of the algorithm of OD estimation. First of all, we input node data, link data, signal data, and OD flow into the traffic simulation model, and calculate the traffic conditions, such as traffic volume and travel time over each link. We use the macroscopic traffic simulator named **NETSTREAM** (NETwork Simulator for TRaffic Efficiency And Mobility)<sup>[2],[3]</sup>. Figure 2 shows screen sample of **NETSTREAM**. This traffic simulator has traffic flow module and route choice module. Second, in the OD estimation model, target volume module calculates the volume to be added to calculated flow volume in each link in order to make the estimated volume equal to observed volume. Then, the optimal OD search module searches for OD flow which fulfills the target volume of each link.

Change of OD flow also changes traffic conditions. By the conventional OD estimation method, change of travel behavior with change in traffic conditions could not be taken into consideration. However in this new method, we input the searched OD flow into the traffic simulation model, and calculate traffic conditions again. If traffic conditions thus change, the resultant change of travel behavior can be calculate by route choice module. Then, we calculate OD flow again. Thus, we calculate iteratively the traffic conditions and the change in OD flow.

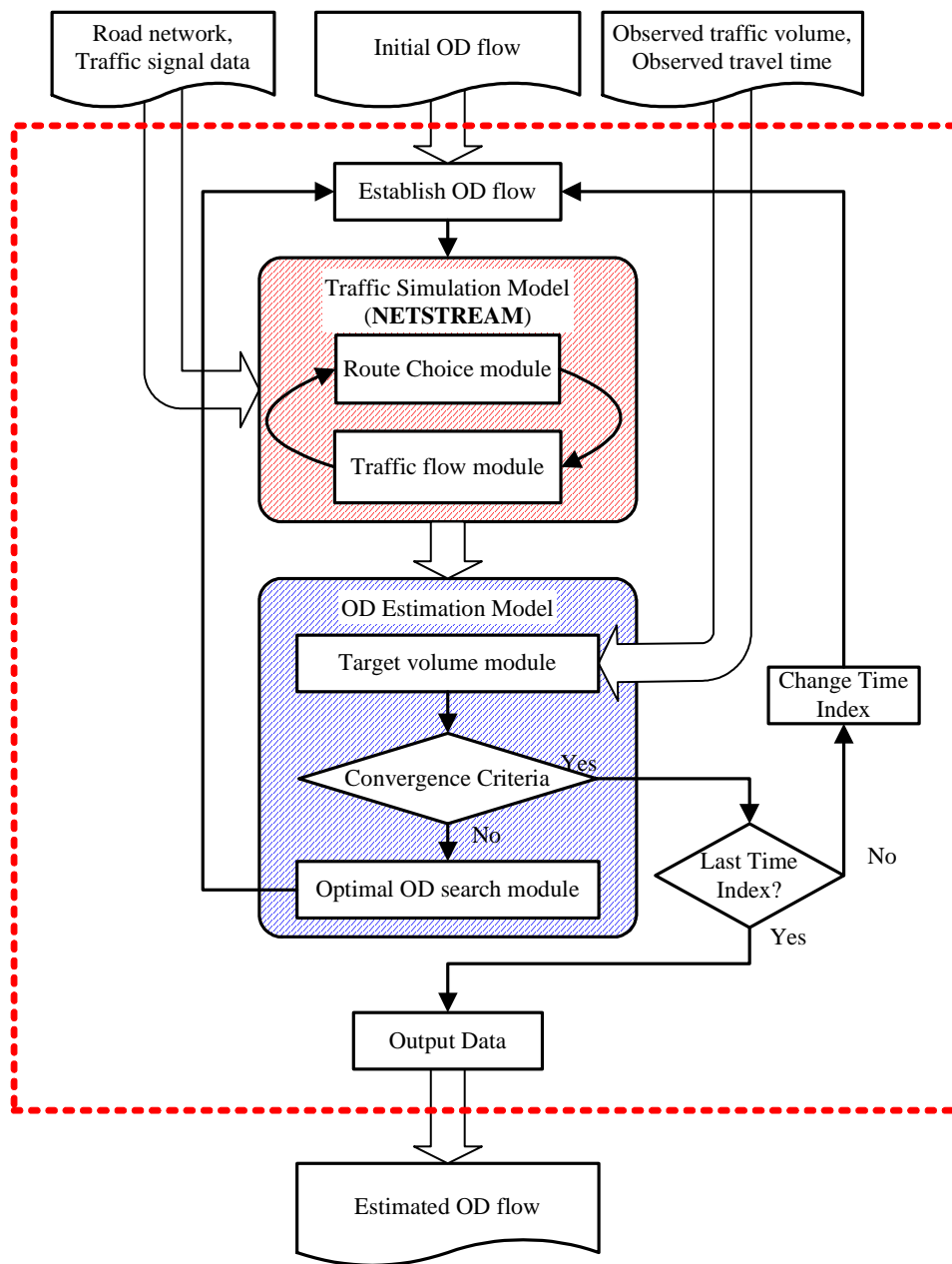


Figure 1. Structure of the algorithm of OD estimation

## Traffic simulation model

### Traffic flow module

In **NETSTREAM**, the relationship between traffic flow  $Q$  and traffic density  $K$  is given for every link, and each vehicle is moved using this  $Q$ - $K$  relationship. Figure 3 shows this  $Q$ - $K$  relationship in **NETSTREAM**. In this model, relationship between the speed  $V$  and density  $K$  is defined as equation (1), known as Greenshields formula.



Figure 2. Screen sample of NETSTREAM

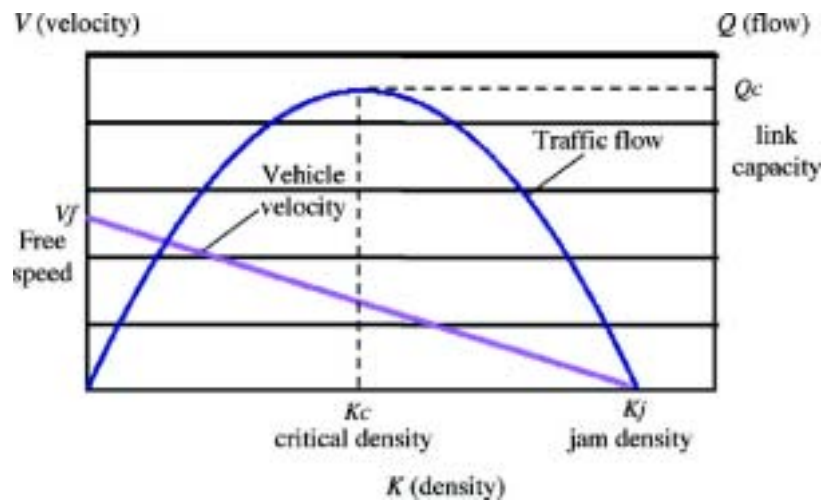


Figure 3. Q-K relationship in NETSTREAM

$$V = V_f \times (1 - K/K_j) \quad (1)$$

$K_j$  and  $V_f$  denote the jam density and free speed, respectively. And relationship between flow  $Q$  and density  $K$  is expressed in equation (2) based on equation (1) and the relation  $Q=K \times V$ .

$$Q = K \times V_f \times (1 - K/K_j) \quad (2)$$

The relationship between the maximum traffic capacity  $Q_c$  and  $K_j$  and  $V_f$  can be expressed by equation (3) since the link capacity  $Q_c$  is realized at critical density  $K_c=1/2K_j$ .

$$Q_c = (K_j/2) \times (V_j/2) \quad (3)$$

Therefore,  $V$  is obtained by equation (4) with space headway  $S = 1/K$ .

$$V = 4Q_d/K_j \times (1 - 1/SK_j) \quad (4)$$

Thus,  $L=V \times t$ , the distance traveled by the vehicle in the scanning interval  $t$  is calculated by equation (5).

$$L=4Q_d/K_j \times (1 - 1/SK_j) \times t \quad (5)$$

This calculation process of vehicle movements is performed for all vehicles from downstream.

### Route choice module

Each vehicle trip is generated from the origin to destination, and on departure time which are given by OD flow. For all Origin-Destination pairs, two or more routes are created beforehand, and for each vehicle is chosen a route using the probability of choosing a route given by route choice module. The route choice module determines the probability according to the LOGIT model based on travel time along each link.

When the number of efficient routes is  $n$  and sets travel time of the  $k$ -th route is  $t_k$ , the probability of choosing  $k$ -th route  $P_k$  is described as equation (6).

$$P_k = \frac{\exp(-\gamma t_k)}{\sum_{i=1}^n \exp(-\gamma t_i)} \quad (6)$$

Here,  $\gamma$  expresses the sensitivity of the probability of choosing a route to the change of travel time.

Moreover, the traffic simulation model records the information such as Origin-Destination, time of generated trips, and the probability of choosing a route of the passed vehicles of each link, and reports the information to the OD estimation model on-line.

### OD estimation model

#### Target volume module

When the observed traffic volume and the calculated traffic volume by the traffic simulation module are compared and there is variance, we calculate the target volume to minimize the difference.

Figure 3 shows the relationship of density and flow with calculated and observed value. In Figure 4,  $dQ$  which is the difference of volume between calculated value  $C_o$  and observed value  $R_o$  is obtained by equation (7),

$$dQ = Q_r - Q_c \quad (7)$$

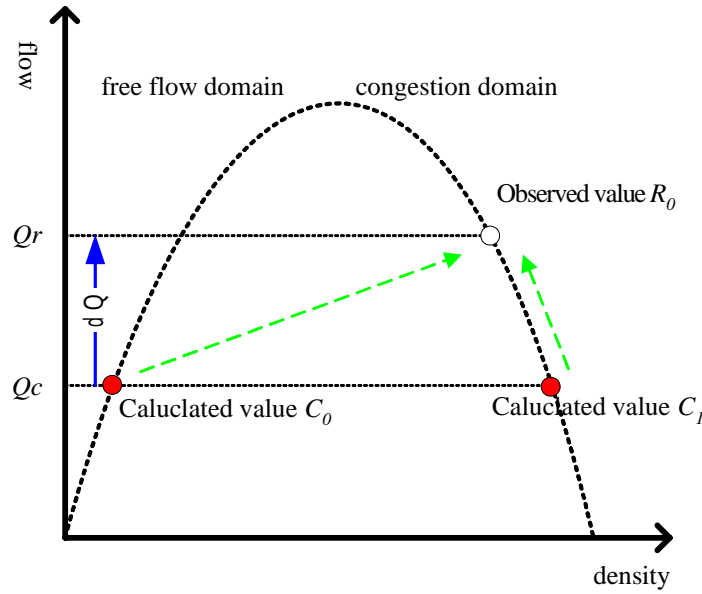


Figure 4. The relationship of density and flow with calculated and Observed value

And the difference of volume between calculated value  $C_1$  and Observed value  $R_0$  is obtained by the same equation.

Here, if the number of vehicles into the link increases, the traffic volume will also increase in free flow range, on the other hand, the traffic volume will not increase in congestion range. Therefore, in the case of the calculated value  $C_0$ , if the volume of  $dQ$  is added to the link, the calculated value is not equal to  $R_0$ . Moreover, in the case of the calculated value  $C_1$  is that of already congested traffic, and if the volume of  $dQ$  is added to the link, traffic congestion will become intense and the traffic volume will not increase.

As mentioned above, by this method, the target volume is determined by calculated value and observed value by a method differing depend upon whether traffic is in free flow range or congestion range. Table 1 shows the target volume by the combination of free flow range or congestion range.

Table 1. The target volume

		Calculated value	
		Free flow	Congestion
Observed value	Free flow	$dQ$	$-\alpha$
	Congestion	$\alpha$	$\beta$

Since the characteristic of the  $Q$ - $K$  relationship is unique in each link,  $\alpha$  and  $\beta$  differ for every link. However, in order to determine these values accurately, it is necessary to know the detailed  $Q$ - $K$  relationship, and, for that reason, long-term observation data is required. When the observation of  $Q$ - $K$  relationship is difficult,  $\alpha$  and  $\beta$  are given by the equation (8) depicting the average  $Q$ - $K$  relationship.

$$\alpha = |dQ|$$

$$\beta = -dQ$$

(8)

## Optimal OD Search module

In this module, we search for the optimal OD volume which satisfies the target volume of each link. For example, in the case of the traffic simulation of middle scale city, the number of OD pairs in a time period is about 10000 pairs, and there are three increments of change in volume in one OD pair (-1, 0, +1) in the minimum case. In this case, the number of combinations is  $3^{10000} = 1.6 \times 10^{4771}$ , and it is almost impossible to search for optimal OD flow out of all combinations. Therefore, in order to improve the estimation accuracy and speed, a technique which can search efficiently is required.

In this module, GA (Genetic Algorithm) [4] was used to search for the optimal OD volume in a short time efficiently. GA is widely used, when searching for a good solution in various optimization problems. In this method, the gene of GA was made the change in volume of each OD flow.

The relationship between  $dV_i$  which change in volume of the OD pair  $i$ , and  $dQ_L$  which denote change in volume of link  $L$  can be described as equation (9).

$$dQ_L = \sum_{i=0}^w (dV_i \times P_{iL}) \quad (9)$$

Here,  $P_{iL}$  denotes the probability that the OD pair  $i$  passes through Link  $L$ , this probability of choosing a route provided by traffic simulation model.

Moreover, the fitness  $f$  of GA is defined by the formula (10) for error in estimation of traffic conditions.

$$f = \sqrt{\sum_{j=0}^L (dQ_j - dT_j)^2} \quad (10)$$

Here,  $T_j$  denotes the target value of Link  $j$ , provided by the target volume module.

Therefore, in this method, the gene (OD flow) which makes the fitness  $f$  (traffic estimation error) smaller is searched by GA.

# RESULT OF OD ESTIMATION

In order to validate for this OD estimation method, we estimated OD flow for the Toyota-city, Aichi Pref. which is a middle-scale city, and predicted traffic conditions by our traffic simulation model using this estimated OD flow.

The calculated traffic volume was verified as compared with the observed traffic volume found by actual investigation. The calculated value of travel time was verified as compared with actual travel time of the sections measured by investigating vehicles.

Figure 5 shows the road network used in this validation. The network consists of 307 nodes, 932 links and 198 signals. The simulation time zone is 6:00 - 10:00 of a weekday. The initial OD flow was estimated using the "The 3rd person trip survey in Chukyo area zone" (1991), and classified every 30 minutes. From traffic investigation of 27 intersections in June, 2001, the traffic volume of 168 links was obtained, and this observation data was used as the observed traffic volume of OD traffic estimation. This was classified every 15 minutes.

Since the density has not been measured, we used average speed of sections instead of the density. Average speed of each section was obtained on the basis of the travel time data by the investigating vehicles. And when average speed was 10 km/h or less, the link was judged to be the congestion range. Otherwise, it was judged as the free flow range. 47 links of 168 links were monitored to determine whether they were in the congestion range or the free flow range every 15 minutes. The other links were all treated as being in the free flow range, since there was no travel time investigation data.

Search by GA was performed on 40000 generations, and traffic simulation and OD estimation were repeated

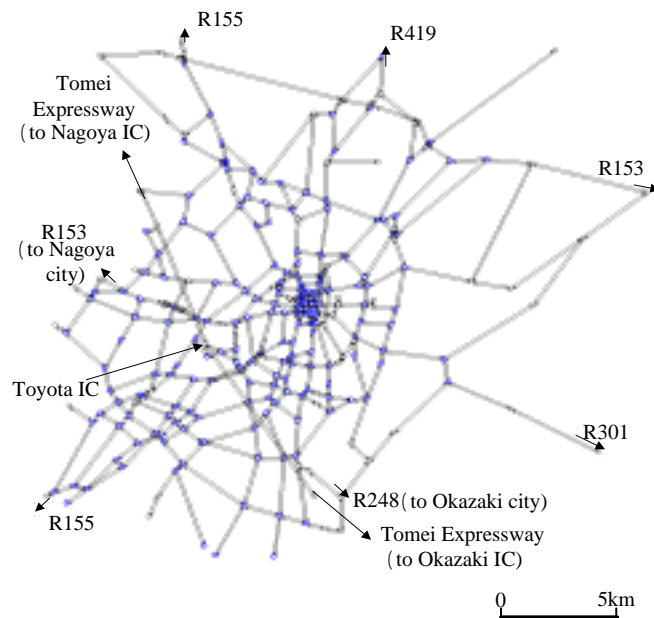


Figure 5. The network of Toyota-city



Initial OD flow:  $R=0.86$ ,  $PRMSE=28.7\%$   
 Estimated OD flow:  $R=0.96$ ,  $PRMSE=13.7\%$

Initial OD flow:  $R=0.67$ ,  $PRMSE=41.5\%$   
 Estimated OD flow:  $R=0.85$ ,  $PRMSE=24.3\%$

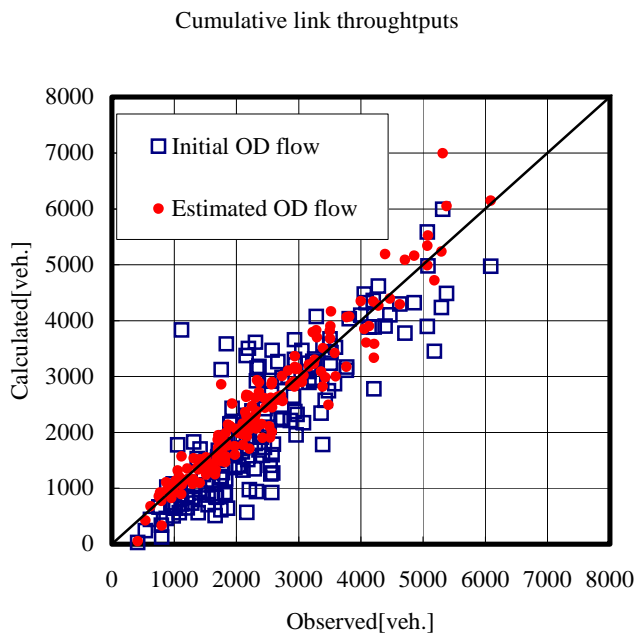


Figure 6. Correlation between calculated and observed cumulative link throughputs

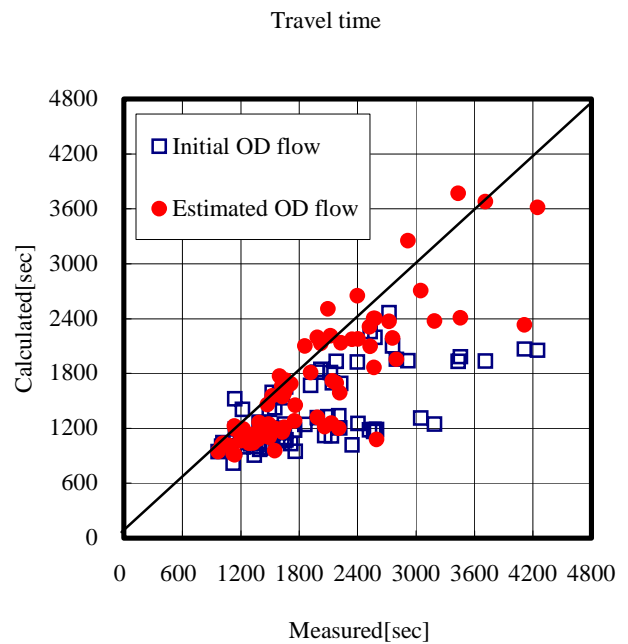


Figure 7. Correlation between calculated and measured travel time

16 times pre time period. Then, the OD flow of the time when error was the smallest was made the optimal result. Processing time was about 8 hours using a 2GHz Intel Pentium4 processor.

First, we compared cumulative link throughputs calculated from initial and estimated OD flow.

Figure 6 shows the correlation between calculated and observed cumulative link throughputs. The correlation coefficient between the link throughputs calculated with estimated OD flow and observed traffic volume shows as good as 0.94.

Moreover, Figure 7 shows the correlation between calculated and measured travel time in 6 sections. The correlation coefficient between travel time calculated from estimated OD flow and measured travel time indicates as good as 0.85. Especially calculated and measured travel time shows good agreement in congested conditions.

## CONCLUSION AND FUTURE TOPICS

In order to predict the traffic conditions with good accuracy, we have developed the method of estimating accurate OD flow by minimizing the difference between calculated and observed traffic volume.

As the validation, we have applied this developed method to the prediction of traffic conditions at Toyota-city, and demonstrated that the accuracy of prediction has been improved by this method. We found that estimation of travel time during congested condition especially improved.

In the future, we aim to develop on-line and real time OD estimation method to realize a system which offers the information of predicted traffic with good accuracy.

## ACKNOWLEDGEMENT

The authors would like to thank the "Toyota traffic simulation study group" comprised of Prof. HIROSHI OGINO, Toyota National College of Technology, Toyota Transportation Research Institute, the Ministry of Land, Infrastructure and Transport Chubu Regional Bureau, Aichi Police, Toyota City and TOYOTA Motor Corporation for their data support and advice. And the authors would like to thank members of Research-Domain 21, Toyota Central R&D Labs., Inc. for their assistance in preparation.

## REFERENCES

- [1] H.Oneyama, M.Kuwahara, T.Yoshii: "Estimation of Time Dependent OD Matrices From Traffic Counts", PROCEEDINGS of the Third Annual World Congress on Intelligent Transport Systems, ITS America, 1996.1
- [2] I.Tanahashi, H.Kitaoka, M.Baba, H.Mori, S.Terada, E.Teramoto: "Wide Area Traffic Flow Simulator NETSTREAM", IPSJ SIGNotes Intelligent Transport Systems Abstract No.009-002 ,2002
- [3] [http://www.tytlabs.co.jp/office/library/lib\\_01/netstream/](http://www.tytlabs.co.jp/office/library/lib_01/netstream/)
- [4] M.Sakawa, M.Tanaka, "Genetic algorithm", Asakura Shuppan, 1995