AN ANALYSIS OF THE EFFECT ON PEAK PERIOD TOLL IN TOKYO METROPOLITAN EXPRESSWAY

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Abstract: The objective of this study is to grasp commuters' opinion for the peak period toll system on urban expressway in Tokyo and to analyze the possibility of shift of departure time and its effect for the traffic flow by entrance time decision model. The questionnaire survey was conducted to obtain various data of users' consciousness to peak period toll. The convergence process is proposed in order to obtain the equilibrium solution of the distribution of travel time in the network.

1. INTRODUCTION

Over 6 million commuters usually enter to the CBD of Tokyo Metropolitan from suburban area in the morning peak period on weekday. Most of them use railway because their fare is fully supported by their company in many cases, and railway systems are always heavily congested from 7 a.m. to 9 a.m.. Some commuters use a private car or company car only in case that they have a parking lot in the CBD area. There is the expressway network called "Metropolitan Expressway (MEX)" in Tokyo, its length is about 260km with over 10 routes and it is extended to the whole suburban area of Tokyo, over a million vehicles enter in a day. They usually use the MEX because they expect faster service than arterial roads although the toll of 700 yen is charged for use of the MEX. Congestion usually starts at 6:30 a.m. and continues till noon. Figure 1 shows the hourly distribution of the number of entering vehicles of the MEX, which is surveyed in the 22nd Origin-Destination survey of the MEX, conducted on 20th of September, 1995. The number of entering private vehicles increases suddenly after 6 a.m. The congestion problem will be mitigated if a part of drivers come to use the MEX before 6 a.m..

Suppose that the congestion pricing such as peak period toll is implemented in the MEX, in which, for example, toll is raised from 6 a.m. to noon. Now, imagine a commuter who sometimes (once or twice of the week) use the MEX at 7:30 a.m. and can easily give up the use of car because he doesn't need it for his business. In this case, his commuting fare for railway is supposed to be supported and he pays by himself when commuting by private car. He will depart his home earlier or give up the use of car if he hates the increase of toll. But if he has a specific reason for the use or he hates the railway congestion, he will not give up it. Anyway, he is less discontented because he is not frequent user. On the other hand, frequent user of the MEX will be much discontented because actually he cannot give up the use

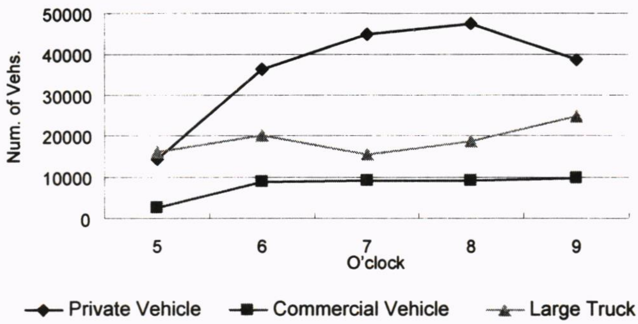


Figure 1. Hourly Distribution of the Number of Entering Vehicles in the MEX

of car.

There are many previous studies that focus on the behavior of departure time decision or entrance time decision. These are classified into two streams whether departure time and entrance time choice is determined continuously or discretely. The continuous modeling was mainly developed aiming at the determination of the optimum toll schedule. These models is estimated or parameterized by socio-economic statistics. However, continuous-based modeling idea has a difficulty in estimating parameters using questionnaire survey data. While, discrete approach was developed in the middle of 1980s. Palma, A. *et al* (1983) introduced the logit-based departure time choice model for single OD. This idea was extended for the combination model of multi-route choice and departure time choice considering elastic demand by Ben-Akiva, M. et al (1986). In Japan, Iida, Y. *et al* (1991) examined day to day departure time and route choice model based on Ben-Akiva, M. *et al*, but parameters were given and just check the network performance. Matsui, H. *et al* (1993) estimated the departure time model for employees who have different flexible working time, but this idea was based on the hourly traffic assignment technique and could not applied to relatively large and heavily congested network. There were very few models that could analyze the effect of toll change.

The objective of this study is (1) to grasp commuters' opinion for the peak period toll system in the MEX by a statistical method called LISREL, and (2) to analyze the possibility of shift of departure time and its effect for the traffic flow of the MEX by entrance time decision model. These objectives are achieved by the implementation of personal questionnaire survey for the MEX user in the morning peak period.

The outline of the questionnaire survey is explained in Chapter 2. The user's opinion of the Peak Period Toll program in the MEX is analyzed in Chapter 3 based on the survey. In Chapter 4, the Entrance Time Decision model is formulated and estimated using SP data from the survey. In Chapter 5, the effect of the peak period toll is calculated using the Network Simulation Model. And conclusion and further study are described in Chapter 6.

2. OUTLINE OF THE SURVEY

The questionnaire survey for the MEX users was conducted on Feb. 13, 1997, from 6.a.m. to 8.a.m. at the 5 toll plazas in the MEX. 567 commuters were sampled. Table 1 shows the contents of the survey. According to the study objectives, we asked the possibility of shift of departure time by the implementation of peak period toll (Part B) and the attitude to several congestion mitigation programs in the MEX (Part C). In Part A, we also asked the travel times between home and office by passing the MEX on the survey day and in non-congested state. Figure 2 shows the SP survey format of Part B. Imaginary, toll after 6 a.m. is raised and toll before 6 a.m. is discounted, travel time before 6 a.m. is increased and travel time after 6 a.m. is decreased compared with his/her actual travel time in this question. We set 3 patterns of the combination of travel time and toll. Each respondent chooses his preference of 3 alternatives, "depart at same time as today", "depart earlier to avoid the increase of toll", and "give up the use of the MEX", accounting the trade-off of toll, travel time and margin time. This part is used in Section 4 in order to estimate the Entrance Time Decision Model. In part C, respondent is put to the vote for 10 congestion mitigation programs in the MEX such as "Network Extension", "Peak Period Toll", "Plate Number Scheme" and so on.

Table 1. Outline of the User Survey

Date		Feb. 13, 1997
Time		AM 6:00-8:00
Site		5 Concentrated Toll Plazas in the MEX
Number of Samples		1949 (567 for Commuting)
Contents	Part A	Travel Conditions of the MEX on Ordinary and Survey Day
	Part B	SP Survey of Departure Time Decision under Peak Period Toll
	Part C	Opinion to Several Congestion Mitigation Programs in the MEX
	Part D	Individual Parameters

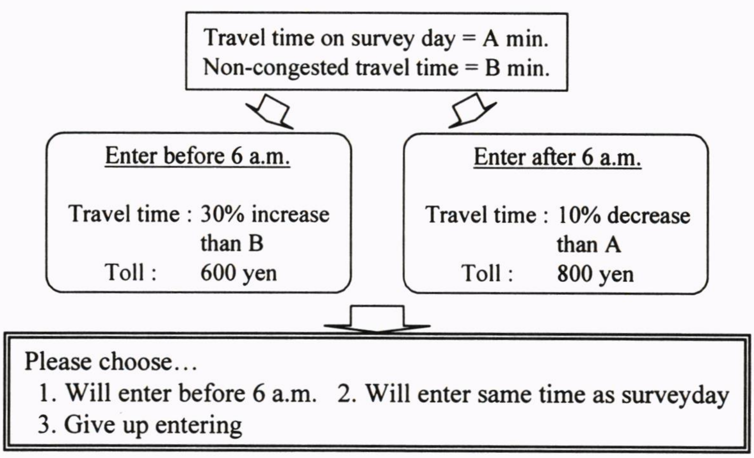


Figure 2. SP Survey Format in Part B

3. USERS' OPINION OF THE PEAK PERIOD TOLL IN THE MEX

3.1 Users' Opinion of the Congestion Mitigation Programs

Using part C of the survey, the user's opinion of the congestion mitigation is analyzed. The responders choose one opinion of 4 categories, "Absolutely agree", "Agree", "Slightly disagree" and "Disagree", for 10 congestion mitigation programs in the MEX.

Figure 3 shows the share of 4 categories for 10 programs. It is easily found out that the constructive programs such as "Development of Traffic Information System", "Network Extension" are highly approved, while the regulative ones such as "Plate Number Scheme" are not highly approved. It is suggested that users are still unsatisfied with the network length and anticipate the improvement of service level although they know that toll will be raised up in order to insure the construction cost. About half of users agree "Implementation of Peak Period Toll". It is suggested that users are obliged to agree this program for anticipating the mitigation of traffic congestion although they will pay highly toll.

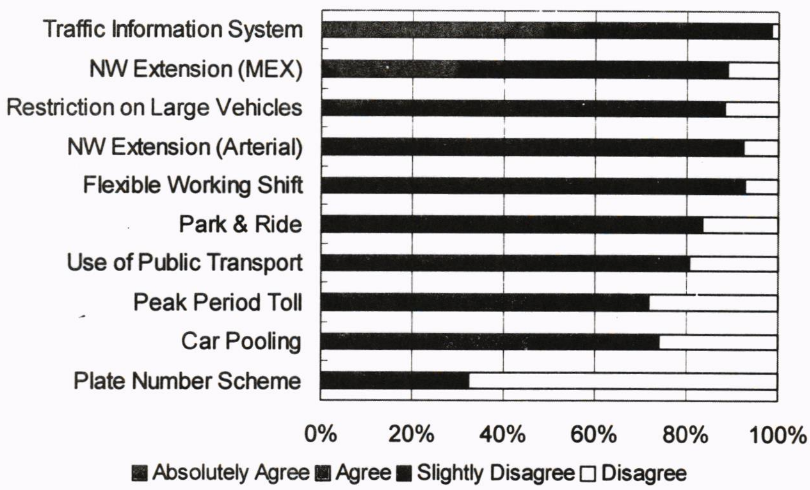


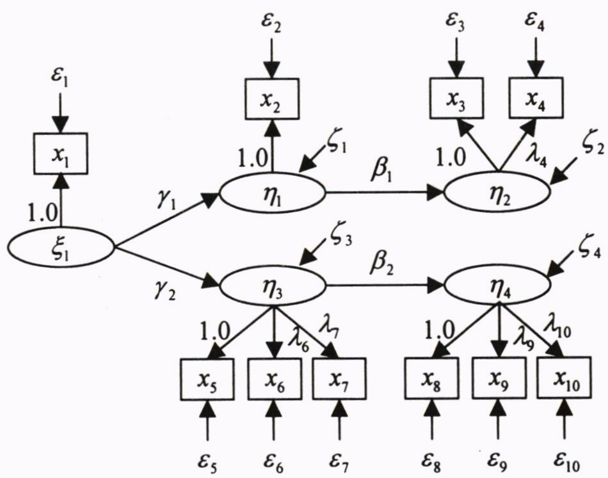
Figure 3. Users' Opinion of the Congestion Mitigation Programs

3.2 Users' Consciousness for the Congestion Mitigation Programs

In this section, the statistical method called LISREL is applied in order to obtain the quantitative relationship among factors of users' attitudes to the congestion mitigation programs in the MEX. In LISREL analysis, we assumed that users are unsatisfied with driving condition in the MEX and this causes desire for facility improvement and approval of TDM programs. According to this assumption, we introduce 5 latent variables in Table. Each latent variable is explained by some questions (also listed in Table 2) in the survey. All x are standardized with 0

Table 2. List of Latent Variables and Explanatory Variables in LISREL

Factor	Variable(Program)
Unsatisfactory for Driving Condition: ξ_1	Restriction for Large Vehicles: x_1
Desire for Improvement of User Service: η_1	Development of Traffic Information System: x_2
Desire for Construction: η_2	Network Extension of the MEX: x_3
	Improvement of Arterial Road: x_4
Approval of Campaign: η_3	Encouragement of Flexible Working Shift: x_5
	Encouragement of Car Pooling: x_6
	Encouragement of Public Transport Use: x_7
Approval of Regulation: η_4	Implementation of Peak Period Toll: x_8
	Implementation of Park & Ride: x_9
	Implementation of Plate Number Scheme: x_{10}



Structural Model

$$\begin{aligned} \eta_1 &= \gamma_1\xi_1 + \zeta_1 \\ \eta_2 &= \beta_1\eta_1 + \zeta_2 \\ \eta_3 &= \gamma_2\xi_1 + \zeta_3 \\ \eta_4 &= \beta_2\eta_3 + \zeta_4 \end{aligned}$$

Measurement Model

$$\begin{aligned} x_1 &= 1.0\xi_1 + \varepsilon_1 & x_6 &= \lambda_6\eta_3 + \varepsilon_6 \\ x_2 &= 1.0\eta_1 + \varepsilon_2 & x_7 &= \lambda_7\eta_3 + \varepsilon_7 \\ x_3 &= 1.0\eta_2 + \varepsilon_3 & x_8 &= 1.0\eta_4 + \varepsilon_8 \\ x_4 &= \lambda_4\eta_2 + \varepsilon_4 & x_9 &= \lambda_9\eta_4 + \varepsilon_9 \\ x_5 &= 1.0\eta_3 + \varepsilon_5 & x_{10} &= \lambda_{10}\eta_4 + \varepsilon_{10} \end{aligned}$$

Figure 4. Path Diagram and Equation of LISREL

average and 1 standard deviation, and x is large value if it is approved. Structural Model and Measurement Model are described with path diagram in Figure 4.

The result of parameter estimation is shown in Table 3. All parameters are significant and GFI index is relatively high. It is suggested that (1) user who is unsatisfied with driving condition tends to approve "Campaign Programs" rather than "Service Improvement" and (2) user who approves "Campaign Programs" tends to approve "Regulative Programs" because parameter β_2 is very near to 1 and highly significant. This result also suggests that user who tends to support the campaigns such as "Encouragement of Public Transport Use" or " Encouragement of Flexible Working Shift" possibly tends to support "Implementation of Peak Period Toll". This suggests the possibility that peak period toll may be approved if some campaigns for commuting are well succeeded.

Table 3. Result of Parameter Estimation

Parameter	Estimate	*t*-value
γ_1	0.60	2.63
γ_2	1.09	2.33
β_1	0.94	2.38
β_2	0.86	6.34
λ_4	1.33	3.74
λ_6	0.61	5.73
λ_7	1.14	7.66
λ_9	1.12	6.73
λ_{10}	0.75	5.62
Number of Samples	567	
P-value	0.00004	
GFI (AGFI)	0.97 (0.96)	
AIC	120.54	

3.3 Relation between the Consciousness and Entrance Time Decision

In this section, one latent variable in the LISREL model, "Approval of Regulation", is focused on. It is assumed that respondent who choose "Early Entrance" for all questions in part B of the survey tends to be cooperative for shifting his/her departure time under the implementation of "Peak Period Toll". We divide all samples into two segments, one includes respondents who choose "Early Entrance" for all questions and another includes the rest. The t-test of the score of "Approval of Regulation" is examined. The result of t-test shown in Table 4 suggested to justify our hypothesis.

Table 4. *T*-test of the Relation between Opinion and Choice for Peak Period Toll

Segment	Shift before 6	The rest
Average	0.0891	-0.178
Variance	1.23	1.23
Number of Samples	366	201
Degree of Freedom	412	
t-value	2.58	

4. ENTRANCE TIME DECISION MODEL OF THE MEX

4.1 Model Formulation

In this section, the Entrance Time Decision Model is formulated based on the discrete logit choice modeling idea. Normally, time decision is considered as continuous phenomenon. However, the continuous modeling has a difficulty in estimating from the questionnaire survey data. This is because we introduce the discrete choice model.

Now, all users who commute to their office are assumed to enter into the MEX from 5:30 a.m. to 8:00 a.m. because most offices start at 8:30 or 9:00. This time period is divided into 5 segments with 30 minutes time interval. Each driver chooses one of 5 alternatives of time period. It is assumed that there are drivers who give up using the MEX if the Peak Period Toll is implemented. We need one more alternatives for this choice (Figure 5). The choice probability of alternative t P_t is expressed as follows,

$$P_t = \frac{\exp V_t}{\sum_{t=1}^{6} \exp V_t} \tag{1}$$

where V_t is the utility of alternative t. V_t is assumed to be determined by some valuables derived from travel conditions and start time for working and some individual parameters as follows,

$$V_t = \theta_1 T_t + \theta_2 M_t + \theta_3 D_t + \theta_4 C_t + \sum_k \delta_k + \xi \tag{2}$$

where T_t is travel time of alternative t (=1,...,5), M_t is margin time of alternative

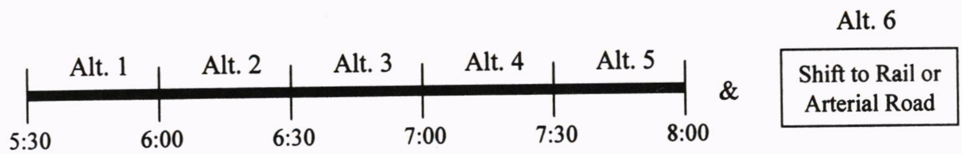


Figure 5. Choice Set in the Entrance Time Decision Model

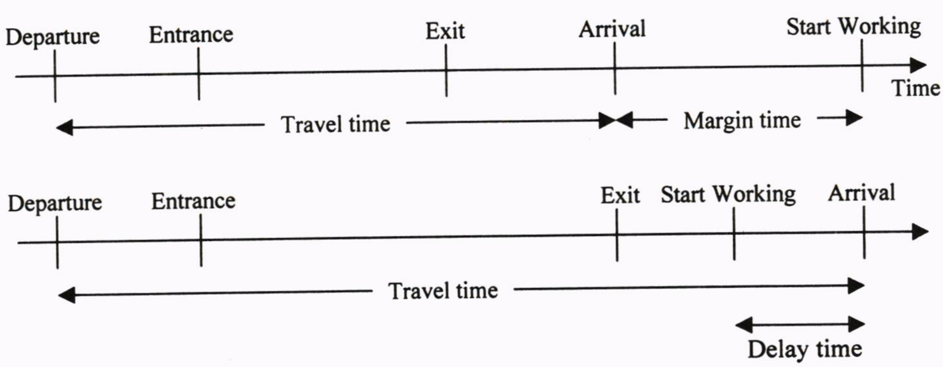


Figure 6. Definition of Explanatory Values of the Entrance Time Decision Model

t (=1,...,5), D_t is delay time of alternative t (=1,...,5), C_t is cost or toll of alternative t (=1,...,5), θ_k(k=1,...,4) are parameters and δ_k are individual dummy parameters in alternative 1. ξ is constant parameter only for alternative 6, so utility of alternative 6 is constant. Figure 6 shows the definition of travel time, margin time and delay time. Margin time should be zero if delay time is positive and delay time should be zero if margin time is positive This idea is based on Hendrickson, C. *et al* (1981).

4.2 Model Estimation and Modification

Using SP survey data, the model formulated in Section 4.1 is estimated. The result is shown in Table 5. Parameter of travel time is not significant because it does not vary largely among alternatives. It is suggested that (1) driver tends to consider delay time rather than margin time by comparing both parameters, (2) driver who uses the MEX not so frequently tends to shift his entrance time to early morning. About 25 % of users who enter less than once a week may be a main target of the shift by the Peak Period Toll.

Table 5. Result of Parameter Estimation of Entrance Time Decision Model

Variable	Parameter	t-value
Travel Time (min)	-0.0248	-0.488
Margin Time (min)	-0.0214	-11.9
Delay Time (min)	-0.0427	-3.75
Toll (yen)	-0.00280	-9.74
"Self-payer" Dummy (for Alt. 1)	0.363	1.57
"Low Frequent Use" Dummy (for Alt. 1)	0.567	2.41
"Eldery" Dummy (Alt. 1)	0.959	3.84
"High Income" Dummy (Alt. 1)	-0.521	-1.76
Constant (Alt. 6)	-3.43	-7.15
Likelihood Ratio	0.143	
Hit Ratio (%)	33.0	
Number of Samples	521	

The estimated model may be untrustworthy because estimation is based on SP data. We try to modify the model parameters in order to improve the reproductibity by the Bayesian model modification technique using aggregate trip data of the MEX. Table 6 shows the result. Parameter of travel time increases by the modification process.

Table 6. Result of Model Modification

Variable	Original	Modefied
Travel Time (min)	-0.0248	-0.0108
Margin Time (min)	-0.0214	-0.0272
Delay Time (min)	-0.0427	-0.0512
Toll (yen)	-0.00280	-0.00367
"Self-payer" Dummy (for Alt. 1)	0.363	0.363
"Low Frequent Use" Dummy (for Alt. 1)	0.567	0.251
"Eldery" Dummy (Alt. 1)	0.959	0.581
"High Income" Dummy (Alt. 1)	-0.521	-0.910
Constant (Alt. 6)	-3.43	-5.47

5. ANALYSIS OF THE EFFECT OF PEAK PERIOD TOLL IN THE MEX

5.1 Concept of the Time Period Traffic Assignment Model

The distribution of number of entering vehicles is obtained by estimated Entrance Time decision Model when the distribution of travel time is given. However, the distribution of travel time is derived again by the distribution of number of entering vehicles using some network traffic simulation model. The inconsistency between two distributions is problematic in order to forecast the future demands.

To solve this problem, we introduce the convergence process of distribution of travel time. The process is shown in Figure 7. Initial distribution of travel time based on actual one is given at first. The entrance time is determined by the modified model estimated in Section 4.2 (Table 6) for all users in Step1. The distribution of number of entering vehicles is aggregated in Step 2. The exit time is obtained using network simulation model referred in next Section for all users in Step 3. The revised distribution of travel time is obtained in Step4. If initial distribution and revised one is inconsistent, we proceed to Step 1 again after revising the distribution. If consistent, process may finish.

5.2 Network Simulation Model

Figure 8 shows the algorithm of the Network Simulation Model. This is based on macroscopic method, in which the network is divided into some links and link flow is determined by the link performance function such as speed-density function. However, exit time of each vehicle cannot be obtained by this method. We introduce the macro-based microscopic model in order to overcome this problem, in which we can specify individual vehicle by the vehicle list of each link. This idea is shown in Figure 9.

5.3 Simulation of the Effect of Peak Period Toll

In this Section, the effect of Peak Period Toll is simulated by the assignment process introduced in Section 5.1. Figure 10 shows the applied network. The

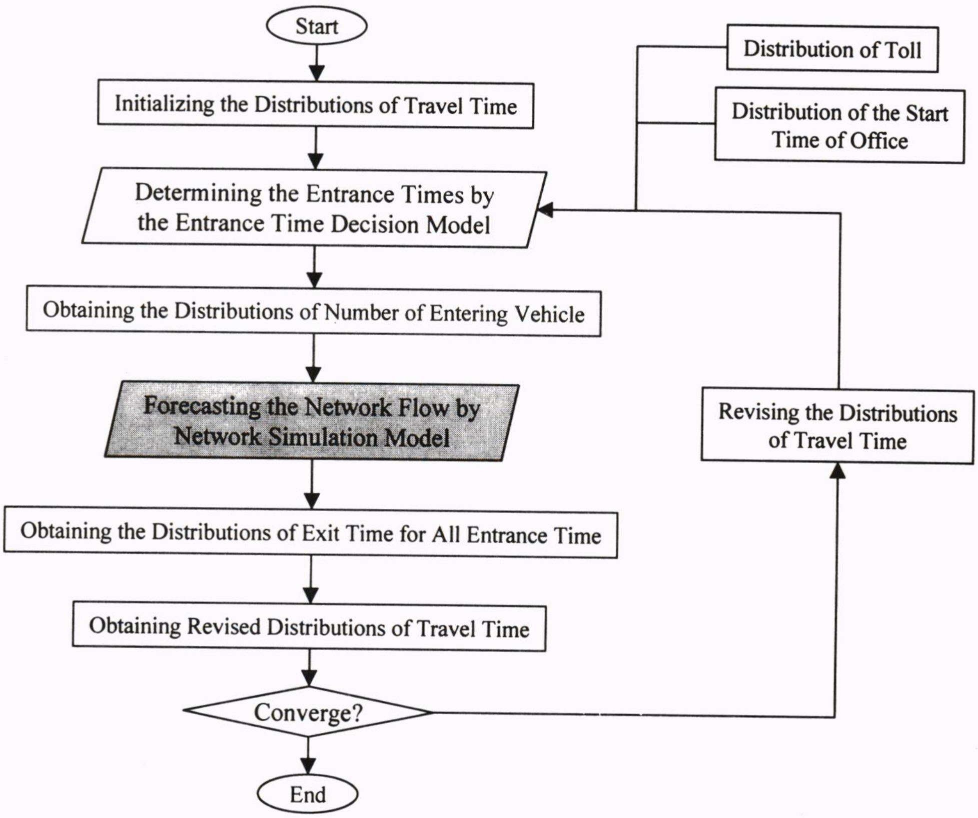


Figure 7. Flow of the Convergence Process

network length is set to be 20km considering the average trip length. We use the demand data of Line 3 (Shibuya) for inputting to the Network Simulation Model in this line. About 8,500 vehicles enter to Line 3 from 5:30 a.m. to 8 a.m and heavy congestion starts usually 7 a.m.. In the simulation, line is divided into 10 segments and each segment has calibrated speed-density function derived from actual travel speed and traffic volume censored every 5 minutes. We assume that only one on-ramp and off-ramp exist in the Network. Access time to entrance and egress time from exit is assumed 30 minutes and 15 minutes based on the survey data. The distribution of start time of office is also given by the survey data. 4 toll schedules, (1) unique toll of 700 yen, (2) 200 yen before 6 a.m. and 700 yen after 6 a.m., (3) 500 yen before 6 a.m. and 700 yen after 6 a.m. and (4) 400 yen before 6 a.m. and 1,000 yen after 6 a.m., are examined.

Figure 11 shows the final distribution of number of entering vehicles for 4 toll schedules. Schedule 1 is considered to be simulated actual distribution. In the case of schedule 2, the number of entering vehicles before 6 a.m. becomes twice compared with schedule 1. In the case of schedule 3 and 4, the number of entering vehicles before 6 a.m. shows drastic increase. Especially in the case of schedule 4, about 500 vehicles (about 6% of total demand) give up entering into the MEX preventing from paying highly toll.

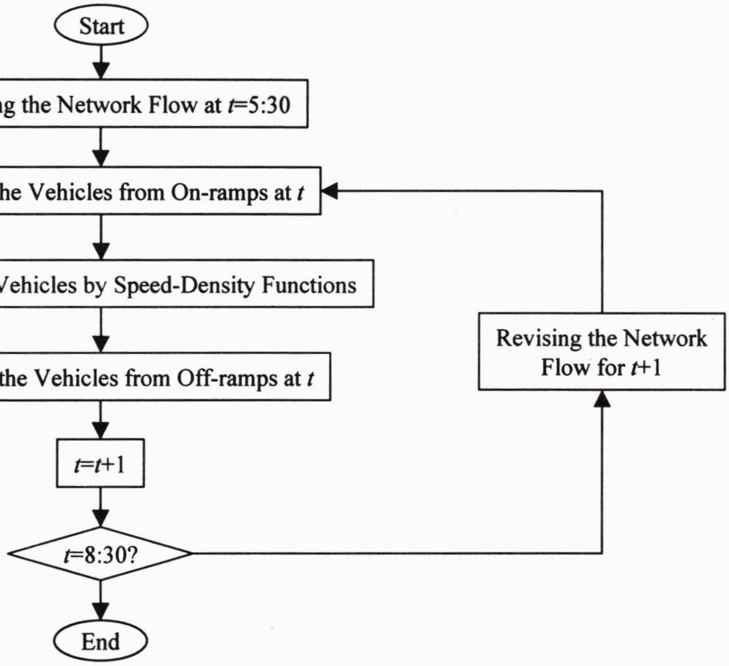


Figure 8. Flow of the Network Simulation Model

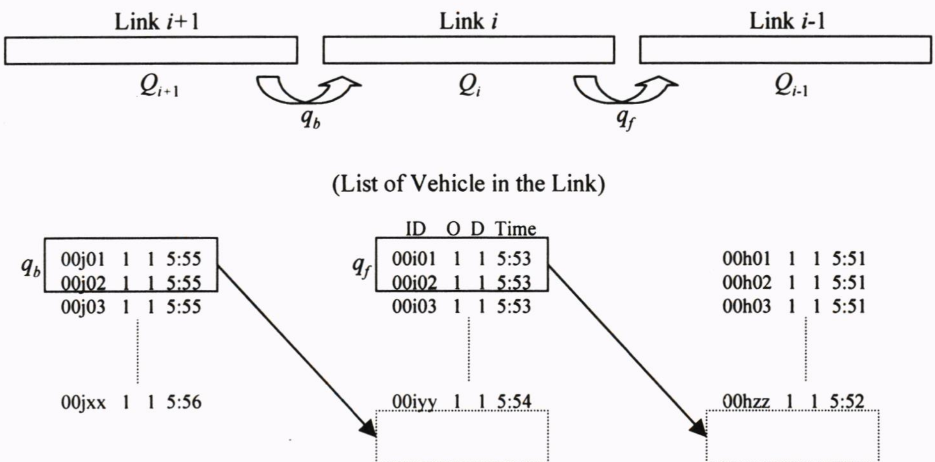


Figure 9. Basic Idea of Macro-based Microscopic Model

Figure12 shows the final distribution of travel time for 4 toll schedules. In the case of schedule 2, the congestion mitigation is not so typical, while it is typical after 6 a.m. in the case of schedule 3 and 4, however congestion occurs before 6 a.m.. It is suggested that the appropriate toll schedule may be, for examples, 500 yen before 6 a.m. and 800 yen after 6 a.m.. In this study, route choice between expressway and arterial road is not considered clearly. In the case of schedule 4, some driver may choose arterial route in order to avoid the congestion in the MEX. But over

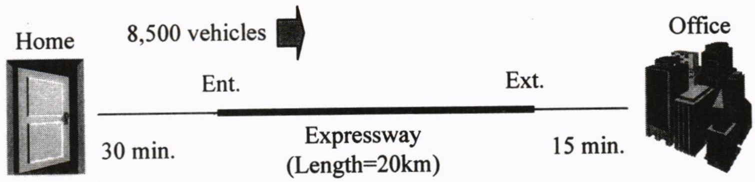


Figure 10. Applied Network

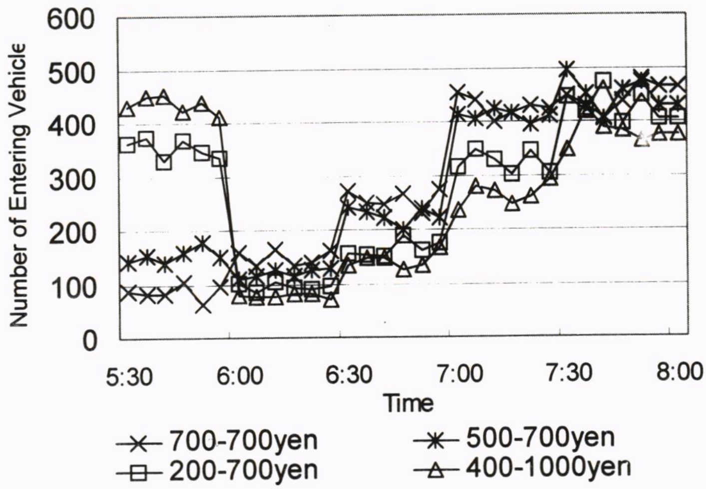


Figure 11. Final Distribution of Number of Entering Vehicles

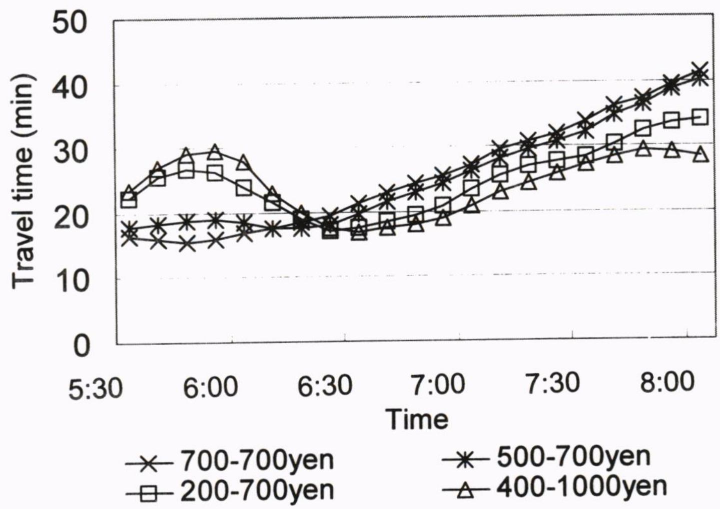


Figure 12. Final Distribution of Travel Time

70% of demand arises in the beginning of the MEX where connected to Inter-city Expressway, so number of such drivers is considered to be large.

These final distributions are obtained by 3 or 4 convergence processes if we use the actual distribution of travel time for initial one. Thus, we can confirm the possibility of proposed method.

6. CONCLUSION

This study is aiming to establish the effective process for analyzing the effect of the implementation of Peak Period Toll. Based on the questionnaire survey for the MEX users, we obtain the characteristics of users' opinion for several congestion mitigation programs. It is suggested that the implementation of Peak Period Toll may possibly succeed if easier congestion mitigation program such as Car Pooling is approved by users. We formulate the Entrance Time Decision Model using the discrete logit choice modeling idea and obtain reasonable parameters using SP survey data and aggregated actual trip data. The convergence process is introduced in order to obtain the equilibrium solution of the distribution of travel time. Several peak period toll schedules in the MEX are examined and we conclude that the convergence process works well when we give the actual distribution of travel time, and that users change their entrance time earlier when difference of tolls of two time period is relatively large.

For the further study, we should check the possibility of the convergence process when the applied network is extended. In this study, network only contains 1 origin and 1 destination. In large network, we cannot obtain completely consistent distributions for all OD, therefore we should pick up some important lines or ODs to check their consistency.

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REFERENCES

Ben-Akiva, M., Palma, A. and Kanaroglou, P. (1986) Dymanic model of peak period traffic congestion with elastic arrival rates. **Transportation Science 20**, 164-181.

Hendrickson, C. and Kocur, G. (1981) Scheduled delay and departure time decisions in a deterministic model. **Transportation Science 15**, 63-77.

Iida, Y., Yanagisawa, Y. and Uchida, T. (1991) Estimation of route choice and departure time in a stochastic equilibrium model. **Infrastructure Review 9**, 93-100. (in Japanese)

Matsui, H. and Fujita, M. (1993) Effects in reduction of the peak hour traffic congestion and leisure of mind in the morning through flextime system. **Journal of Infrastructure Planning and Management 470**, 67-76.

Palma, A., Ben-Akiva, M., Lefevre, C. and Litinas, N. (1983) Stochastic equilibrium model of peak period traffic congestion. **Transportation Science 17**, 430-453.