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A STUDY ON ROUTE CHOICE BEHAVIOR UNDER ROAD PRICING CONSIDERING TRAVELER'S DELAY PENALTY

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Abstract: This study aims firstly at construction of models which can describe the difference of route choice behavior affected by toll charged among drivers with different values of time, and secondarily at assessment for effect of toll charged as a kind of road pricing on the improvement of road network traffic flow. It is however difficult to obtain the actual data concerning this, and hence this study tries to analyze fundamental properties of traffic flow situation caused by road pricing, using simulation analysis based on models constructed by an experimental questionnaire survey for route choice behavior. It is found that it would be recommendable to raise the toll level with the increase in the percentage of high penalty driver for minimizing the average travel time on the entire road network.

Key Words: value of time, route choice, toll charged, simulation, delay penalty

1.INTRODUCTION

In order to refund the construction cost, a toll system has been employed for use of expressways in Japan, which is also functioning as a sort of road pricing. It is because the road network efficiency would be enhanced as a whole due to high choice probability for expressway by drivers with high value of time, resulting in a desirable dispersion of traffic flow between expressway and surface road. Especially for expressway in urban area with heavy traffic congestion at specific time and location, it can be expected that road pricing would effectively encourage drivers to choose more profitable routes depending on value of time for the trip purpose, and give benefits to both of the operator and the users of road network.

In order to examine the above view, this study aims firstly at construction of models which can describe the difference of route choice behavior affected by road pricing among drivers with different values of time, and secondarily at assessment for effect of road pricing on the improvement of road network traffic flow. It is however difficult to obtain the actual data concerning this, and hence this study tries to analyze fundamental properties of traffic flow

situation caused by road pricing, using simulation analysis based on models constructed by an experimental questionnaire survey for route choice behavior.

It is necessary for us to mention the research work done by Layard (1977) as our initial point to discuss the effect of toll upon reducing congestion. Layard focuses on the distributional effects of congestion taxes, and his research suggests that the tax discourages travels by people with low time values and may encourage some travels by people with high time values who are not willing to travel in congested conditions, using simple demand – supply relation. Though the theme of this study is almost the same as the research done by Layard, this study tries to explicitly consider the decision-making of travelers.

Here some recent studies related to effect of toll charged are reviewed briefly below. This study focuses on the effects of toll charged for expressway users upon traffic condition on the network including the alternative route without toll. The related researches have been done by MacDonald (1995) and Verhoef (2002). These researches provide us with the simple numerical examples showing the difference between the second-best tolls and the first-best tolls where tolls can be charged for all the routes. However, the responses of travelers to the toll charged are based on a very simple assumption of the single user class and the single time period.

The research works trying to relax the assumption of single time period and considering the departure time choice of travelers have been done by Liu and MacDonald (1999), Chen and Bernstein (1995) and so on. The research work, trying to relax the assumption of the single user class and considering heterogeneity of travelers, has been conducted by Small and Yan (2001), but the accumulation of related research works may not be enough for discussing the practical schemes of toll charged in order for reducing the congestion on the network including the alternative route without toll.

Focusing on a function of toll as a sort of road pricing, this study has two main purposes.
1) This study attempts to construct the models of route choice behavior of drivers with different values of time.
2) This study attempts to assess the effects of toll as a sort of road pricing upon traffic flow on road network, using the traffic flow simulation into which the route choice model mentioned above is installed.

Through this study, we try to find some suggestions to the question whether charging toll lead to improvement of traffic flow or not.

2. OUTLINES OF QUESTIONNAIRE SURVEY

This study conducts an experimental questionnaire survey about route choice behavior considering the difference in value of time among the drivers. The data on route choice behavior obtained by this survey must reflect the response of drivers to the different level of toll charged. However, it is difficult for us to obtain this kind of data under the real situation. Accordingly, this study applies a sort of stated preference survey to collect the data of route choice behavior.

2.1 Network Adopted

A hypothetical network adopted in this study is shown in Figure 1. From among conceivable

road networks on which route can be chosen freely, the simplest possible road network was used for the present study. The network shown in Figure 1 is composed of two routes connecting a single OD pair. The road types of route 1 and route 2 are assumed to be the toll expressway and the surface road without toll charged, respectively. The distance of each route is assumed to be 30 km.

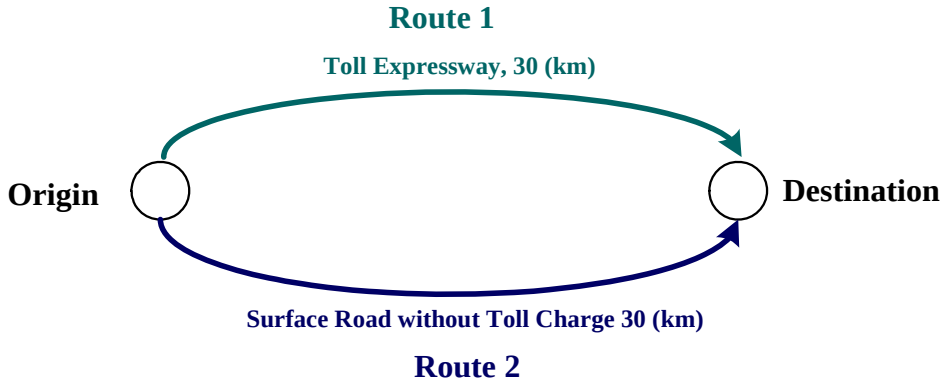

Figure 1. Hypothetical Network Used in Experimental Questionnaire Survey

2.2 Scenarios of Questionnaire Survey

In order to analyze the response of drivers with different values of time to the toll charged, this study assumes the two different scenarios classified by the delay penalty that a driver has to owe:

1) Scenario 1: A traveler on business is required to arrive at an airport to take international flight within 60 minutes,
2) Scenario 2: A traveler is planning to meet his / her friend at a department store 60 minutes later.

Clearly, it is expected that the value of time of respondents in Scenario 1 might be higher than that in Scenario 2 because of his / her purpose of trip.

2.3 Design of Questionnaire Survey

In the real situation, the travelers choose their route considering a lot of factors, such as travel time and its fluctuation, distance to destinations, toll charged, fuel consumption and so on. However, this study focuses on the average travel time, the maximum delay and the toll charged as the factors influencing route choice of travelers , in order for clarifying the relation between the value of time of travelers and their route choices. It is assumed that the average travel time, the maximum delay time and the toll price, consisting of 3 levels for each shown in Table 1, are used as the factors in the experimental questionnaire on the route choice behavior for both of the drivers with high and low values of time.

But the toll is not taken as the factor for choosing surface road, which is supposed to be free of charge. Accordingly, this questionnaire survey can be reduced to a problem of design of experiment composed of 5 factors with 3 levels, and thus 27 questions are produced using the orthogonal array manual. Additionally the contents of the experimental questionnaire are designed so as to have a good balance of proportion among the traffic conditions, namely the predominantly profitable and unprofitable states for choosing expressway and the intermediate states.

Table 1. Factors Affecting Route Choice Behavior in Experimental Questionnaire

Route Type	Average Travel Time	Maximum Delay from Average Travel Time	Toll
Route 1 Expressway	35 minutes	5 minutes	0 Yen
	45 minutes	10 minutes	500 Yen
	55 minutes	15 minutes	1000Yen
Route 2 Surface Road	45 minutes	5 minutes	
	55 minutes	10 minutes	
	65 minutes	15 minutes	

The number of respondents of the questionnaire survey is 28, and each respondent is required to reply to nine different questions. Accordingly the total sample size of route choice data reaches 504.

3. ROUTE CHOICE MODELS

3.1 Way to Estimate Route Choice Model

In order to statistically analyze the influence of the toll charged upon route choice behavior considering the difference in the value of time of the traveler, this study estimates the logit-type route choice model using the data obtained through the experimental questionnaire mentioned above.

In this study, two different models shown below are estimated so as to explicitly confirm whether the value of time of travelers may affect their decision-makings of route used.

Model 1: This route choice model explicitly considers the influence of the difference in delay penalty among drivers upon their route choice behavior. Namely, the explanatory variables of this model, such as the maximum travel time, the toll charged and so on, are different between the scenario 1 with high delay penalty and the scenario 2 with low delay penalty.

Model 2: This model does not consider the influence of the difference in delay penalty among drivers upon their route choice behavior.

This study applies the Maximum Likelihood method for estimating the parameters of both models. In the survey to collect the route choice behavior, each respondent is required to give us his / her preference on route repeatedly. Accordingly, the serial correlation of errors should be considered in the error term of the route choice model, in principle. However, this study focuses on the overall tendency among the value of time, toll charged and traveler's behavior, and hereby this study does not explicitly consider the serial correlation of errors. This is on of the research subjects that should be treated in our further study.

3.2 Estimated Parameters of Route Choice Models and Basic Analysis

Table 2 shows us the estimated parameters of Model 1 explicitly considering the influence of the difference in delay penalty among drivers upon their route choice behavior. The table includes statistically significant parameters only. Based on the estimated parameters, this study attempts to make a comparative analysis of the decision-making on route between

Scenario 1 with higher delay penalty of travelers and Scenario 2 with less delay penalty of travelers.

Table 2. Estimated Parameters of Model 1

Variables			Estimated Parameters
Specific Variables of Toll Expressway (Route 1)	Constant		0.299
	Toll Charge	Scenario 1 with High Penalty	-0.00127
		Scenario 2 with Low Penalty	-0.00356
Common Variables for Both Routes	Maximum Travel Time	Scenario 1 with High Penalty	-0.144
		Scenario 2 with Low Penalty	-0.0747
Sample Size			504
$-2(L(c)-L(\theta))$			248.5 > $\chi^2_{0.05}$ = 9.49
Likelihood Ratio ρ^2			0.358
AIC (Akaike Information Criterion)			0.911

It is found that the absolute value of estimated parameter of toll charge of Scenario 2 is almost three times as large as that of Scenario 1. In addition, the absolute value of estimated parameter of maximum travel time of Scenario 1 is almost twice as large as that of Scenario 2. Accordingly, it can be said that the travelers owing high delay penalty tend to pay more attention to the travel time and less attention to the toll charged.

Table 3 indicates the estimated parameters of Model 2 not considering the influence of the difference in delay penalty among drivers on their route choice behavior. This model is mainly used for comparison of the estimated value of time with Model 1 explicitly considering the difference in delay penalty among drivers. All the estimated parameters shown in Table 3 are also statistically significant.

Table 3. Estimated Parameters of Model 2

		Estimated Parameters
Specific Variables of Toll Expressway (Route 1)	Constant	0.261
	Toll Charge	-0.00197
Common Variables for Both Routes	Maximum Travel Time	-0.0887
Sample Size		504
$-2(L(c)-L(\theta))$		165.9> $\chi^2_{0.05}$ = 5.99
Likelihood Ratio ρ^2		0.233
AIC (Akaike Information Criterion)		1.067

3.3 Estimated Value of Time of Travelers

Using the estimated parameters of Model 1 and 2 explained above, three kinds of value of time are estimated in this section. The values of time of travelers estimated here are as follows:

1) the value of time of traveler with high delay penalty,
2) the value of time of traveler with low delay penalty, and

3) the value of time of traveler not considering the difference in delay penalty among travelers.

The first and second values of time are estimated using the parameters of Model 1 and the third one is estimated using the parameters of Model 2.

Figure 2 indicates the estimated values of time of travelers. Among the three types of value of time, the value of time of traveler with high delay penalty becomes highest and is 113.6 (yen/minute). And the value of time of traveler with low delay penalty becomes lowest and is 21.0 (yen/minute). The value of time of drivers owing high delay penalty is 5.5 times as large as that of drivers owing low delay penalty. Though the values of time mentioned above are estimated using the data obtained through simplified stated preference survey, it can be said that the value of time may change according to the delay penalty that drivers should owe. Also it is expected that the response of drivers to the toll charged may depend upon the delay penalty they should owe.

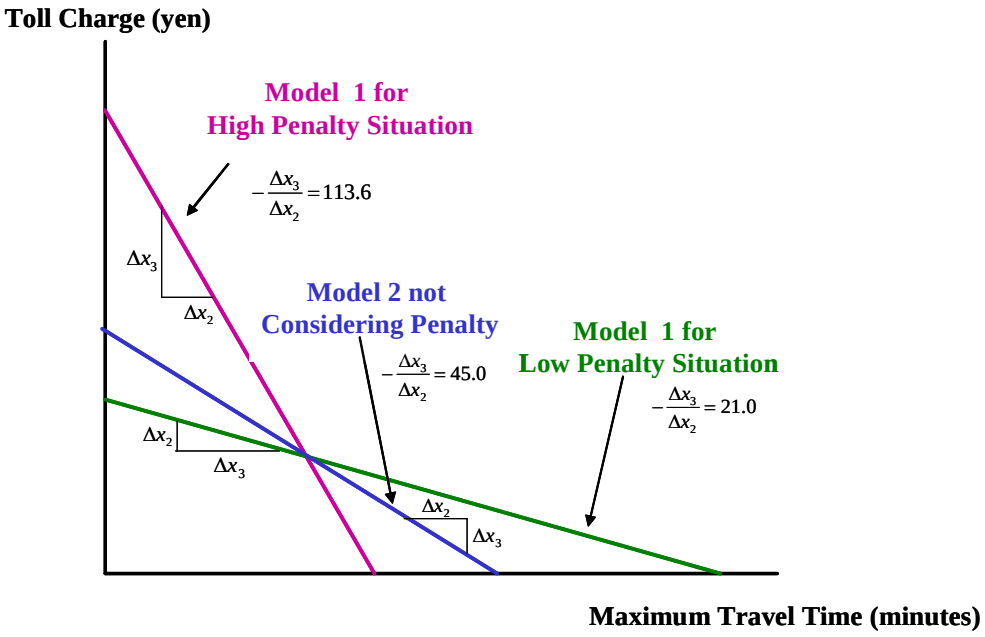

Figure 2. Estimated Values of Time of Travelers

4. ANALYSIS OF TRAFFIC FLOW USING SIMULATION

4.1 Simulation Settings

Based on the modes obtained in the previous section, this study attempts to assess the effects of toll as a sort of road pricing upon traffic flow on road network, using a simplified traffic flow simulation. The objectives of applying traffic simulation are as follows:

1) Analyzing influences of both the level of toll charged and the ratio of drivers owing high delay penalty upon the traffic flow on road network, and,
2) Analyzing how the level of toll charge might affect the difference in average travel time between drivers owing high delay penalty and drivers owing low penalty.

The road network used here is the same as the network shown in Figure 1, and the network is composed of two alternative routes, namely toll expressway and surface road, connecting an

OD pair. The travel demand loaded onto the network is shown in Figure 3, and this has a clear peak period in order to create the traffic congestion on the network.

In order for clearly analyzing the relation between the level of toll charged, the ratio of drivers owing high delay penalty and the traffic flow on road network, the following assumptions are made to simplify the simulation settings.

1) Each driver is assumed to belong to one of the two groups: the group of high delay penalty or that of low delay penalty. The route choice behavior is predicted mainly by Model 1 explained above.
2) Each driver is assumed to predict his / her maximum travel time based on travel time information provided. The predicted maximum travel time $\hat{x}_{max}$ is assumed to be given by the following equation:

$$\hat{x}_{max} = x_{inf} + \sigma \qquad (1)$$

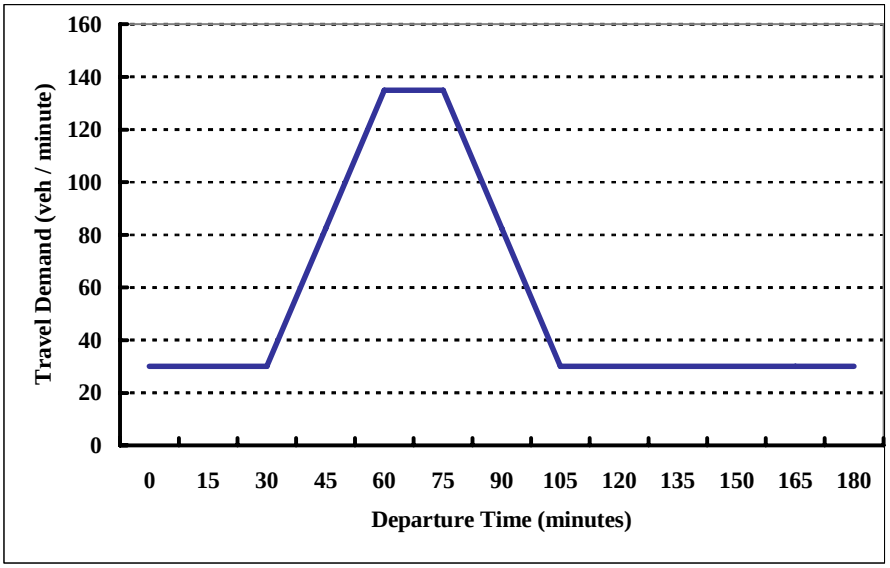

Figure 3. Assumed Travel Demand for Simulation

where, x_{inf}: travel time information provided,

σ: standard deviation of travel time distribution ($\sigma = \alpha(x_{inf})^{\beta}$),

α, β: parameters (α=*1.0*, β=*0.5*).

In this simulation model, the traffic condition is calculated using the "Block-Density method". It is assumed that each link of road network is composed of several blocks and the traffic density in each block is updated using the conservation law of traffic flow and the density-speed relation. The speed of each block is used for estimating travel time of road network.

4.2 Analysis of Toll Charged on Average Travel Time Based on Simulation Results

The objective of this section is to analyze the influence of toll charged upon traffic condition on road network, considering the ratio of drivers with high delay penalty. Figure 4 indicates the simulated average travel time for the five levels of toll charged: 0, 250, 500,750 and 1000 (yen). In the case where the ratios of drivers who owe high delay penalty are 0 (%) and 40

(%), the average travel time becomes minimum, when the toll is 250 (yen). If the ratio of drivers owe high delay penalty increases to 80 (%), the level of toll for which the average travel time becomes minimum shifts from 250(yen) to 500 (yen).

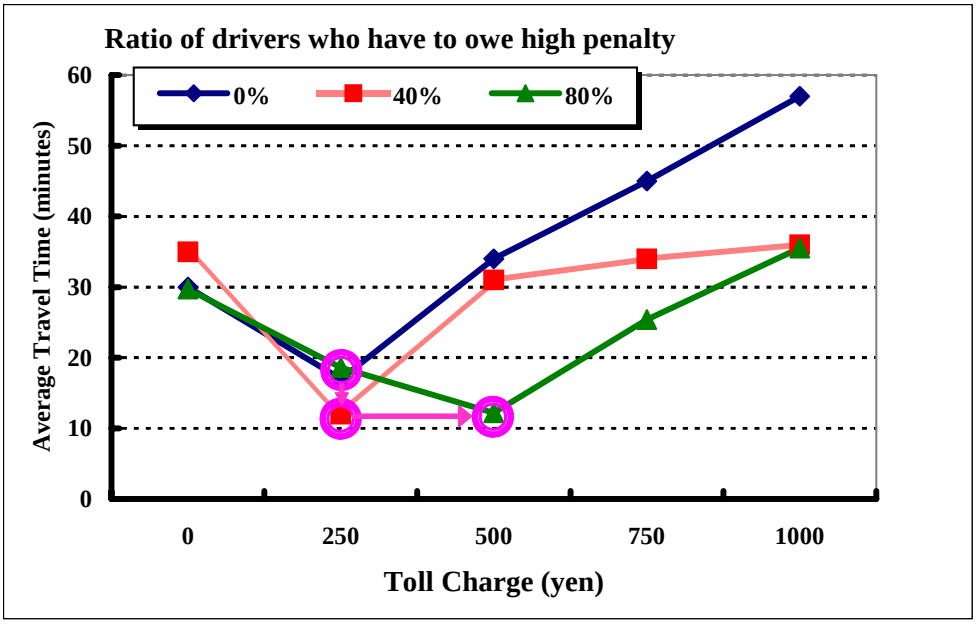

Figure 4. Relation between Toll Charged and Average Travel Time

Judging from the simulation results, it can be said that there is a possibility that the toll charged for users of expressway might lead to the reduction of congestion on the network. Also, it would be recommendable to raise the toll level with the increase in the percentage of high penalty drivers for minimizing the average travel time on the entire road network.

4.3 Difference in Average Travel Time between Drivers with Low and High Delay Penalty

In this section, the average travel time of drivers with high delay penalty is compared with that of drivers with low delay penalty. Figure 5 indicates the difference in average travel time between the drivers with low delay penalty and those with high delay penalty. In Figure 5, the ratio of drivers who have to high delay penalty is assumed 40 (%). In this case, the average travel time for all the drivers becomes minimal, when 250 (yen) is charged for users of expressway as a toll, as shown in Figure 4. In addition, the average travel time of drivers with low delay penalty is almost the same as that of drivers with high delay penalty.

In the cases where the toll charged is assumed to be equal to or larger than 500 (yen), the difference in average travel time between the drivers with high and low delay penalty becomes larger, according to the increase in the toll charged. This is because the increase in toll charged may lead to the concentration of traffic on the surface street.

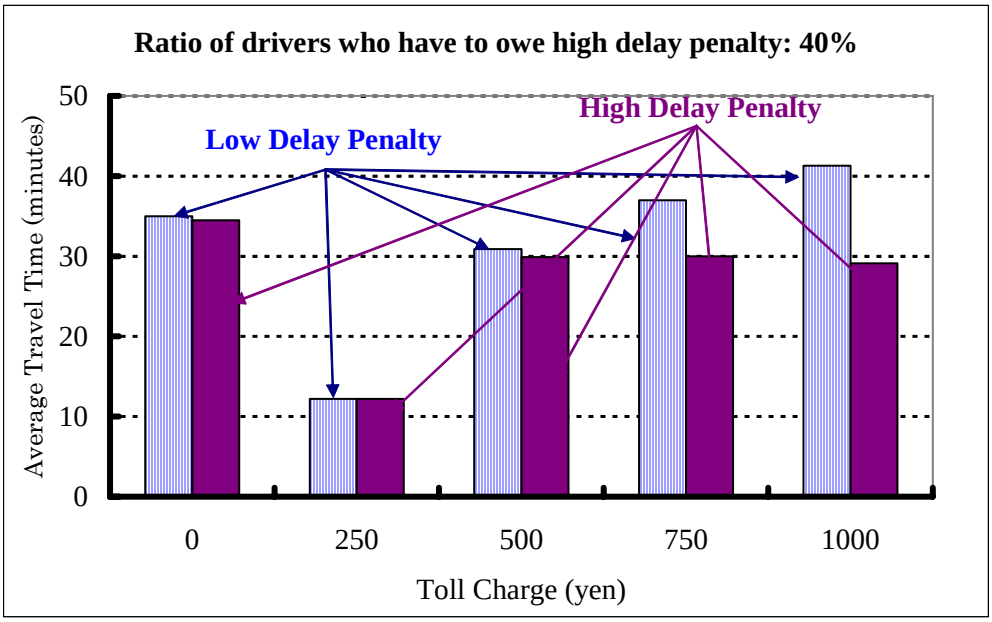

Figure 5. Difference in Average Travel Time between Drivers with Low and High Delay Penalty

5. CONCLUDING REMARKS

This study aims firstly at constructing the models which can describe the difference of route choice behavior affected by toll charged among drivers with different values of time, and secondarily at assessing the effect of toll charged as a kind of road pricing on the improvement of road network traffic flow. Due to the difficulty in obtaining the actual data on route choice behavior considering the difference in delay penalty drivers should owe, this study tries to analyze fundamental properties of traffic flow situation caused by road pricing, using simulation analysis based on models constructed by an experimental questionnaire survey for route choice behavior.

The major results are shown below.

1) It is expected that the value of time may change according to the delay penalty that drivers should owe. Also, there is a high possibility that the response of drivers to the toll charged may depend upon the delay penalty they should owe.
2) There is a possibility that the suitable level of toll charged would make the dispersion of traffic on routes available and the average travel time shorter.
3) It would be recommendable to raise the toll level with the increase in the percentage of high penalty driver for minimizing the average travel time on the entire road network.

As stated above, this study reveals that the route choice behavior models considering delay penalty could describe more properly the change in traffic flow situation on road network when users have different values of time. Also it is found that a role of expressway, which is to give a high quality of service to users with high value of time, could be realized by road pricing. The remaining research subjects are to make study on the effect of road pricing for elastic demand and to incorporate the effect of serial correlation of error into the route choice models.

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