

EMPIRICAL ANALYSIS ON RELATIONSHIP BETWEEN TYPES OF TRAVEL DEMAND TECHNIQUES AND ESTIMATED USER'S BENEFIT STEMMING FROM TRANSPORTATION INVESTMENT

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Abstract: This paper aims to analyze empirically the impact of selecting travel demand forecast techniques on estimation of user's benefit stemming from transportation investment. Three techniques are discussed in the paper: the multinomial logit (MNL), user equilibrium (UE) and all-or-nothing (AON). These three techniques are compared in the empirical analysis of the urban railway project in Tokyo based on the same data set. Consequently, it is found that the user's benefit estimated by the MNL is largest, whereas the benefit by the UE is smaller than the benefit estimated by the MNL by about 10 % and the benefit estimated by the AON is smaller than the MNL by about 20%. Finally, some policy implications related to choosing the travel demand forecast techniques in transportation planning are discussed.

Key Words: travel demand analysis, user's benefit, urban-rail route choice, multinomial logit, user equilibrium assignment, all-or-nothing assignment

1. INTRODUCTION

Various types of techniques have been so far used for travel demand forecast and project evaluation in transportation planning. In most of practical transportation projects, the analysts can make their decisions on selecting the type of demand analysis techniques by their own technical ability or by their own experience. Furthermore, in general, the analysts seem to stick to a specific methodology due to the limitation of their own experience or due to their own preference. However, even if the same data set is used, the estimated results including future forecasted demand and expected user's benefit may be different among different types of demand forecast techniques. This could cause the inadequate analysis and it may result into the wrong decision-making. This can be considered as one of the main reasons why the traditional travel demand analysis has been criticized by many people. Thus, the knowledge about to what extent the different types of techniques impacts on the estimated results is very important for all of transportation planners, analysts and policy-makers. Though this is very important issue from a practical viewpoint, just few researches have reported this problem.

Therefore, this paper intends to analyze empirically to what extent different types of travel demand forecast techniques affect on the estimated results of user's benefit stemming from transportation investment. The demand forecast techniques for urban rail route choice behavior in the Tokyo Metropolitan Area will be used for the empirical analysis. Three typical techniques of travel demand forecast models are examined under the same data setting. All of them are so popular among transportation analysts and planners that we can expect the results of comparison will give us the useful information for better transportation planning.

The paper is organized as follows. First, Section 2 gives the review of three types of techniques for travel demand analysis and shows the methodologies for calculating user's benefit of transportation project. Next, Section 3 presents an empirical analysis, in which the utility function and link performance functions are formulated especially for the comparison of three travel demand models. Then, these methods are applied to the urban rail up-capacity project of the Tokyo Metropolitan Area. Finally in section 4, the results of this paper and further research are discussed.

2. TECHNIQUES OF TRAVEL DEMAND ANALYSIS AND USER'S BENEFIT ESTIMATION

2.1 Techniques for Travel Demand Analysis

This paper deals with three types of techniques for travel demand analysis: Multinomial Logit (MNL) model, User's Equilibrium (UE) assignment and All-or-nothing (AON) assignment. All are quite popular techniques in practical work of travel demand analysis. However, if reviewing the past transportation projects, we may find the fact that actual application of these techniques seems to vary among different types of projects. For instance, in Japan, most of urban-rail demand analysis is, in practice, based on the MNL or MNL-like model. The latest long-term urban rail investment plan of the Tokyo Metropolitan Area was based on the MNL and the Multinomial Probit (MNP) models (Morichi et al., 2001). On the other hand, the AON (or the incremental assignment based on AON) and UE assignments are more popular in the road traffic demand forecast. The experience of application of AON and UE to the urban-rail demand analysis has been quite limited so far.

In this paper, the urban rail project will be used for the empirical comparison among three techniques. The urban rail network in the Tokyo Metropolitan Area is so dense that passenger can choose a route from an origin to a destination among various alternative routes. And it is so congested especially in the morning peak-hour that passengers take the dis-utility of in-vehicle congestion into an account quite much when they choose their rail routes. Thus, the possibility of consideration of congestion effect is one of key issues in choosing the demand analysis technique. From this point of view, UE assignment can be the first candidate to deal with the congestion because it can consider the congestion effect through an increase of travel cost due to the congestion by introducing the flow-dependent link performance function. In addition to UE, we can also consider the congestion effect even by MNL. If we use the flow-dependent MNL model, in which the link performance function is introduced into the conditional indirect utility function of route, we may get the equilibrium solution by an iterative simulation. On the other hand, AON cannot take the congestion of link into an account. Thus, we can discuss the impact of congestion effect on the travel demand by comparing the results of AON and others.

The second issue in choosing the technique is whether passenger's behavior is deterministic or stochastic. In other words, rail travelers have the perfect information about the network or not. If we can say that all travelers have such the rich experience that they know very well the properties of transportation network, travel time/cost and level of congestion, the perfect-information assumption may hold true. Whether this assumption is applicable depends upon the characteristics of transportation market, in general. If we assume the perfect information of user's perception, the UE and AON are preferable.

The third issue is the technical problem in MNL. When using MNL, usually the analysts need to define the alternative routes of travelers for all pairs of origin and destination by some exogenous information. This may cause the bias to the analysis. On the other hand, they do not need to consider the choice set of travelers in applying UE and AON.

Finally, the definition of link cost should be regarded as one of the technical problems in applying UE and AON. In UE and AON, travel time and travel cost should be defined by each link to calculate the minimum-cost path of each OD pair, but it is sometimes difficult to define the link-based fare in rail network because the fare table of rail service is normally not set by link-base but OD-base. This may cause several technical problems. Firstly, the initial fare is in most case included in the fare from one origin station to the other station, but how can it be allocated to the links? Second, even if the rest of fare is well separated from original fare and if it may be in proportion to the distance, the unit fare per distance is sometimes

discounted when the distance becomes longer. Thus how can we define the proportional rate of fare? On the other hand, when applying MNL, we need not care about this problem because the utility is defined by route-base.

In order to set the same condition among three methods, the common data set of OD flow matrix and the levels of service are prepared. In addition, in order to use the consistent model parameters among different techniques, the link performance functions used in UE and AON are derived from the estimation results of MNL.

MNL

The MNL is one of the discrete-choice type models, in which a consumer chooses a route from an alternative set based on maximization of his/her utility with the random factor (Ben-Akiva and Lerman, 1985). The conditional indirect utility function of a route from one origin to other destination is formulated as:

$$\begin{aligned}
 U_{ij,r} &= V_{ij,r} + \varepsilon_{ij,r} \\
 &= \theta_c \cdot GC_{ij,r} + \varepsilon_{ij,r}
 \end{aligned}
 \tag{1}$$

where $V_{ij,r}$ is the universal component of the indirect utility under the condition of choosing the r th route from zone i to j , $\varepsilon_{ij,r}$ is the error component of the utility following the i.i.d. Gumbel, $GC_{ij,r}$ is the generalized cost including travel time and travel cost of the r th route from zone i to j and θ_c is a unknown parameter. When the total volume of traffic flow from zone i to j is given as Q_{ij} , the expected volume of traffic flow $q_{ij,r}$ choosing the r th route from zone i to j is expressed as:

$$\begin{aligned}
 E[q_{ij,r}] &= Q_{ij} \cdot p_{ij,r} \\
 &= Q_{ij} \cdot \frac{\exp(\lambda V_{ij,r})}{\sum_{r' \in R_{ij}} \exp(\lambda V_{ij,r'})}
 \end{aligned}
 \tag{2}$$

where $p_{ij,r}$ is a probability of choosing the r th route from zone i to j , λ is a scale parameter corresponding to the Gumbel distribution with $\lambda^2 = \pi^2 / 6\sigma^2$ (σ^2 is a variance of the Gumbel distribution). When simulating the traffic flow, the iterative calculation is required to get an equilibrium solution because the indirect utility function of the model includes the traffic volume of own route.

UE assignment

The User Equilibrium (UE) assignment is one of the traffic assignment techniques, in which it is assumed that the transportation system falls into the stable equilibrium when all users maximize their individual utility including the congestion in choosing their routes (Sheffi, 1985).

The conditions of the user equilibrium are formulated as follows:

$$q_{ij,r}^* \cdot (GC_{ij,r}^* - GC_{ij}^*) = 0 \tag{3}$$

$$GC_{ij,r}^* - GC_{ij}^* \geq 0 \tag{4}$$

$$q_{ij,r}^* \geq 0 \tag{5}$$

where $q_{ij,r}$ is the volume of traffic flow and $GC_{ij,r}$ is the generalized cost. The symbol* means the status of the equilibrium. The relationship between the traffic volume of a route and the traffic volume of an OD pair, the relationship between the traffic volume of a link and the traffic volume of a route and the relationship between the generalized cost of a route and the generalized cost of a link are respectively shown as,

$$\sum_{r \in R_{ij}} q_{ij,r} = Q_{ij} \tag{6}$$

$$X_l = \sum_{ij} \sum_{r \in R_{ij}} q_{ij,r} \delta_{ij,r,l} \tag{7}$$

$$GC_l = \sum_{ij} \sum_{r \in R_{ij}} GC_{ij,r} \delta_{ij,r,l} \tag{8}$$

where X_l is the traffic volume of link l , $\delta_{ij,r}^l$ equals to 1 if a link l is on the route r else if 0, GC_l is the generalized cost of link l . The generalized cost of the link is dependent upon the traffic flow of the link X_l .

The abovementioned conditions of the user equilibrium are theoretically equal to the following optimization problem,

$$\min Z = \sum_l \int_0^{X_l} GC_l(\omega) d\omega \tag{9}$$

s.t. eq.(6) to (8).

This optimization problem can be solved by such an algorithm as the Frank-Wolfe method (Sheffi, 1985). In the equilibrium situation, the traffic volume of a specific route cannot be calculated independently while the generalized costs are equal among all alternative routes of an OD pair.

AON assignment

The All-or-nothing (AON) assignment is one of traffic assignment techniques, in which all of the traffic flow from an origin to a destination is simply allocated to a route with the lowest cost among the alternative routes. This technique does not consider the change of generalized cost due to the traffic congestion. The traffic volume assigned by this method is shown as,

$$q_{ij,r} = Q_{ij} \quad \text{if } GC_{ij,r} = \min\{GC_{ij,1}, GC_{ij,2}, \dots\} \tag{10a}$$

$$= 0 \quad \text{else.} \tag{10b}$$

2.2 User’s Benefit Estimation

In the user’s benefit estimation, the theory of the consumer’s surplus is used for the cases of UE and AON (Small, 1981; Mohring, 1978). The “rule of half” is applied, shown as eq.(11),

$$UB = \frac{1}{2} \sum_{ij} \sum_r (q_{ij,r}^o + q_{ij,r}^w) (GC_{ij,r}^o - GC_{ij,r}^w) \tag{11}$$

where $q_{ij,r}$ is the traffic volume of the r th route from zone i to j and $GC_{ij,r}$ is the generalized cost of the route. The subscript “ w ” means the case with the project while the “ o ” means the case without the project.

Since the route-based traffic volume cannot be calculated independently when the UE assignment is applied, the eq.(11) cannot be used directly for estimating the user’s benefit. However, the rule of half in eq.(11) can be transformed under the UE assignment as follows,

$$\begin{aligned}
 UB &= \frac{1}{2} \sum_{ij} \sum_r (q_{ij,r}^o + q_{ij,r}^w) (GC_{ij}^{*o} - GC_{ij}^{*w}) \\
 &= \frac{1}{2} \sum_{ij} (GC_{ij}^{*o} - GC_{ij}^{*w}) \sum_r (q_{ij,r}^o + q_{ij,r}^w) \\
 &= \frac{1}{2} \sum_{ij} (GC_{ij}^{*o} - GC_{ij}^{*w}) (Q_{ij}^o + Q_{ij}^w)
 \end{aligned}
 \tag{12}$$

because the generalized cost of every route is equal to each other.

When the MNL is applied to the demand analysis, so-called the “logsum value” is used for estimating the generalized cost of an OD pair. The logsum value is defined as the expected maximum value of utility, which is widely used for the index of welfare (Williams, 1977; Small and Rosen, 1981). In order to estimate the user’s benefit, the logsum value is converted into the money term as the generalized cost shown as,

$$GC_{ij} = \frac{1}{\mu} \left[\ln \sum_r \exp(\mu GC_{ij,r}) \right]
 \tag{13}$$

where μ is the scale parameter that is related to the variance of error term in utility function.

3. EMPIRICAL ANALYSIS: URBAN RAIL IMPROVEMENT PROJECT

3.1 Project Description

The three types of demand analysis techniques are compared empirically by analyzing an example project of the urban rail up-capacity in the Tokyo Metropolitan Area. This project aims to reduce the travel time between Higashi-kitazawa and Isumi-tamagawa of Odakyu Odawara line depicted in Figure 1. The improvement section is 12 km long, in which the

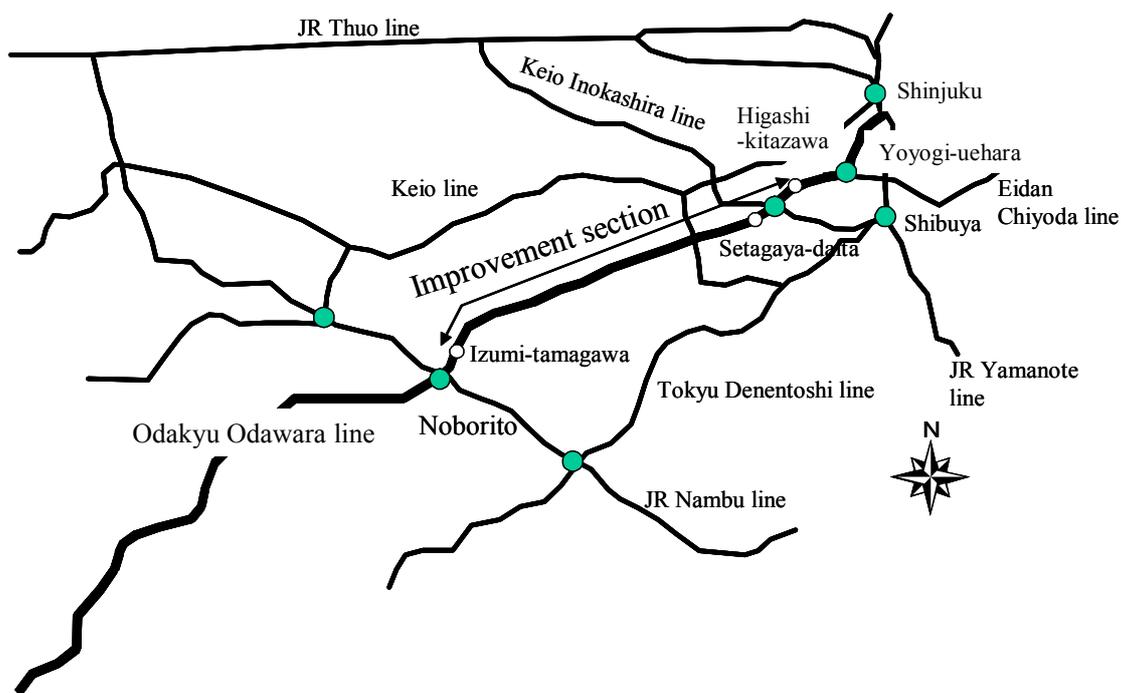


Figure 1. Map of Case Project: Odakyu-Odawara Line

capacity of the rail line is increased by adding a new track. The increase of capacity can allow an express truck in addition to the local truck. The Odakyu Odawara line runs western part of Tokyo, which is mainly used for connecting the western suburban residential area and Sinjuku, one of the major sub-centers of Tokyo. There are more than four alternative routes connecting between the western suburban area and the CBD, that is, JR Chuo line, Keio Inokashira line, Keio line and Tokyo Denentoshi line. Thus, the passengers of western suburban area who use the other route rather than the Odakyu Odawara line may change their rail route to the improved line when the capacity of Odakyu Odawara line is increased. This may reduce the congestion of alternative routes as well.

In the analysis, it is assumed that the OD matrix does not change even after the project. This may cause some bias in the estimated result, but it is not critical just for the technical comparison. Moreover, even from a practical viewpoint, the expected bias may be quite small because most of the people in the suburban area usually do not change their transportation mode nor their home place by such a small-scale improvement project as this case.

3.2 Demand Analysis and Simulation

Network Setting

The origins and the destinations in the analysis are defined not as rail stations but zones. Since there may be more than one stations in a zone, the transportation network should include the access links from a zone to several stations whereas the egress links from several stations to a zone. This means that a route from one zone to another zone includes an access link, a line-haul link and an egress link. The OD matrix covers the whole Tokyo Metropolitan Area including 1,877 zones. The rail network prepared for the passenger flow simulation includes 4,850 nodes and 9,796 links.

MNL

The MNL is applied to the rail route choice under the condition that the OD matrix is given. The conditional utility function of a route from one zone to another zone is formulated as follows,

$$\begin{aligned}
 U_{ij,r}^a &= \theta_C^a C_{ij,r} + \sum_{k \neq C} \theta_k^a X_{k,ij,r} + \varepsilon_{ij,r}^a \\
 &= \theta_C^a C_{ij,r} + \theta_1^a T_{1,ij,r} + \theta_2^a T_{2,ij,r} + \theta_3^a T_{3,ij,r} + \theta_4^a Cong_{ij,r} + \varepsilon_{ij,r}^a
 \end{aligned}
 \tag{14}$$

where $U_{ij,r}^a$ is the utility of the r th route from zone i to j for travel purpose a , $C_{ij,r}$ is the total travel cost [yen], $T_{1,ij,r}$ is the access/egress travel time [minute], $T_{2,ij,r}$ is the line-haul travel time [minute], $T_{3,ij,r}$ is transfer time including waiting time at stations [minute] and $Cong_{ij,r}$ is the index of in-vehicle congestion. As for the travel purpose, the traffic is categorized into four types: home-to-work, home-to-school, private and business. The in-vehicle congestion index is defined as follows,

$$Cong_{ij,r} = \sum_{l \in L_{ij,r}} z_l^2 \cdot T_{2,ij,r,l}
 \tag{15}$$

where z_l is the congestion rate of a route and $T_{2,ij,r,l}$ is the line-haul travel time of link l . The congestion rate z_l is defined as follows,

$$z_l = \frac{\sum_{ij} \sum_r \sum_a q_{ij,r,l}^a}{cap_l}
 \tag{16}$$

where $q_{ij,r,l}^a$ is traffic volume of the r th route from zone i to j for travel purpose a and cap_l is the traffic capacity of link l .

The unknown parameters in the utility function are estimated by using the Metropolitan Transportation Census data of Tokyo which was collected in 1995. The present paper uses the

Table 1. Sets of Parameters Used in the Simulation (Morichi et al., 2001)

		Home-to-work	Home-to-school	Private	Business
In vehicle time	(min)	-0.094 (-8.09)	-0.060 (-5.77)	-0.049 (-2.86)	-0.050 (-3.29)
Access and egress time	(min)	-0.127 (-11.7)	—	-0.058 (-4.30)	-0.060 (-5.82)
Access time	(min)	—	-0.069 (-6.20)	—	—
Egress time	(min)	—	-0.0603 (-5.69)	—	—
Transfer time includes waiting time	(min)	-0.112 (-10.7)	-0.079 (-8.71)	-0.072 (-4.15)	-0.069 (-4.52)
Total cost	(yen)	-0.002 (-3.98)	-0.004 (-7.14)	-0.002 (-3.00)	-0.001 (-1.57)
Congestion index		-0.009 (-3.34)	-0.002 (-0.80)	—	—
Likelihood ratio		0.39	0.331	0.172	0.156
Number of sample		1,218	811	436	357
Value of time	(yen/min)	47	15	21	48

(t-statistic)

estimation results of Morichi et al. (2001) which are shown in Table 1.

In the passenger flow simulation, the in-vehicle congestion is considered only for travels of home-to-work and home-to-school by the iterative process. The process is as follows. First the initial congestion indices of all links are given to the system by using the observed data. Then the choice probability of alternative routes for all OD pairs are calculated based on the estimated parameters of Table 1 and the initial congestion indices. As a result of the first process, the tentative traffic volumes of all links in the network are achieved. In the next process, the choice probability of alternative routes for all OD pairs are calculated based on the estimated parameters of Table 1 and the tentative congestion indices achieved from the first process. In the same way, the probabilities are revised in the iterative process. Finally, when the results of the probabilities come to satisfy the convergence condition, the process will terminate and give us the final output.

In the simulations for travels of private and business, the congestion is not considered because these travels are mainly observed in the off-peak time when there is less in-vehicle congestion. The inter-relationship between the home-to-work travel and the home-to-school travel is taken into an account by simulating them sequentially many times. This means that when travel demand of the home-to-school is simulated, the other travel demand is dealt with the fixed demand. The in-vehicle congestion index can cover all kinds of travel purpose even when just one of the travel purposes is simulated.

UE assignment

The generalized cost functions used in the UE simulation are set based on the results of the parameter estimation of the MNL mentioned earlier. They are defined by three types of links: access/egress link, line-haul link and transfer link. The formulations of three types of link performance functions are shown as follows:

Access/egress link:

$$GC_l = \theta_1 / \theta_c T_{1,l} \quad (17a)$$

Line-haul link:

$$GC_l = C_l + \theta_2 / \theta_c T_{2,l} + \theta_4 / \theta_c Cong_{ij,r} \quad (17b)$$

Transfer link:

$$GC_l = \theta_3 / \theta_c T_{3,l} \quad (17c)$$

where $T_{3,l}$ is the travel time of link l for three types of links (1: access/egress, 2:line-haul and 3:transfer), C_l is the travel cost of link l . As for the fare setting, exactly to say, it is impossible to define the travel cost by link because the railway fare is defined only by the station-based table. However, in this paper, the link-based fare is estimated by separating the initial fare and the distance-based proportional fare. The linear regression analysis is done for estimating the initial fare and the distance-based proportional fare for all rail operators. The initial fare is given to the cost function of the access link while the distance-based fare is given to the cost function of line-haul link. When an additional initial fare is needed especially to change the different operator's rail lines, it is given to the transfer link.

In the UE simulation, actually the UE assignment is applied to only two types of travels: home-to-work travel and home-to-school travel, because the in-vehicle congestion is considered only for these two cases while it is rarely observed for other types of travels: private and business. For the private travel and business travel, not UE but AON assignment is used. In order to consider the inter-relationship of travel demands between home-to-work and home-to-school, the multi-class user equilibrium method is applied for the simulation. Finally the simulated results of all types of travels are summed up to the total traffic flows.

All-or-nothing assignment

The link cost performance functions are defined in the same way as the UE assignment. The travel demand is simulated separately by four types of travel purposes and all of the results are summed up to the total traffic flow.

3.3 Results

All of the data used for the simulation are as of the year 2000. For the simulation of UE assignment, the Frank-Wolfe method is applied. Although more than hundred time of iterative processes is tried for the UE assignment, the simulated traffic flows of several links could not be stable under the converge criteria of 5% of change before and after the iterative process. Especially it is found that the sections which have parallel services of express train and local train are sometimes dissatisfied with the converge criteria. Thus the algorithm is improved from the original Frank-Wolfe method in order to reduce the calculation time.

Results are shown in Table2,3 and Figure 2. First, the present traffic flow is simulated by the three techniques. The results of the simulations by a comparison of estimated traffic link

Table 2 Results of Demand Analysis by Three Methods

	Multiple correlation coefficient	RMS Error
MNL	0.97	4.4*10 ³
User equilibrium(UE)	0.963	5.3*10 ³
All-or-nothing(AON)	0.952	5.9*10 ³

Table 3 Results of User's Benefit of Three Methods

Trip purpose	MNL	UE	AON
Home-to-work	0.40	0.37	0.32
Home-to-school	0.02	0.02	0.02
Private	0.06	0.05	0.05
Business	0.05	0.04	0.04
Return-to-home	0.48	0.44	0.39
All	1.00	0.92	0.83

Note: Total user's benefit of MNL case is defined as 1.00

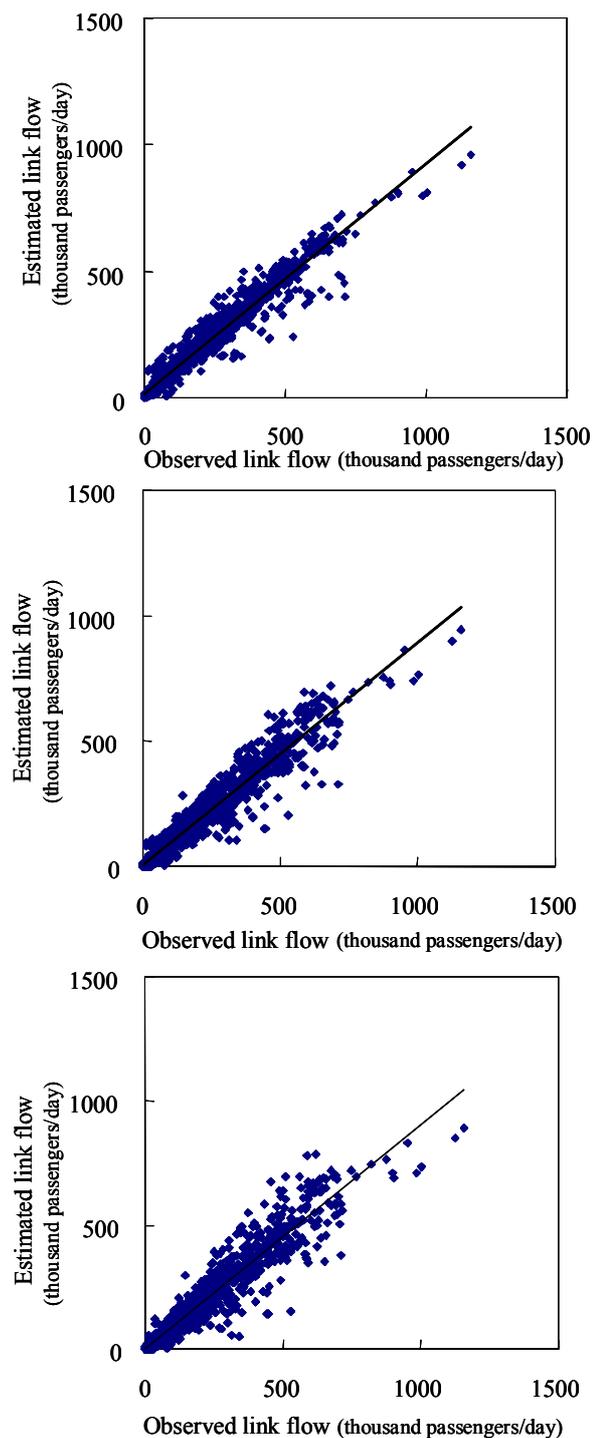


Figure 2. Correlativity between Observed Link Flows and Estimated Link Flows of Three Methods

flows and observed traffic link flow are shown in Figure 2 and Table 2. The results of demand analysis show that the RMS error is smallest in MNL (multiple correlation coefficient is 0.970), next in UE (0.963) and the largest in AOL (0.952).

Next, these techniques are applied to the example project discussed earlier. In the application, the travel of return-to-home is also considered by applying the same parameters as the travel of home-to-work, though the in-vehicle congestion is not considered for the return-to-home travel. The results are shown in the Table 3. The estimated benefit is categorized by travel purpose and by demand analysis technique. This shows that more than 70% of total benefit

stems from the home-to-work and return-to-home in any method. The largest benefit is found in MNL, the next is UE and the smallest is AON. The estimated benefits among three methods vary by 10 -20 %. When looking at the estimated results by resource factor, the benefit stemming from reducing the in-vehicle congestion is one of the most critical factors impacting on the difference of the total benefit.

4. CONCLUSIONS

This paper analyzed how much the different techniques of travel demand analysis affect the user's benefit stemming from transportation investment. Three typical demand analysis techniques: the multinomial logit (MNL) model, user equilibrium (UE) assignment and all-or-nothing (AON) assignment, are examined in the paper. Three techniques are compared in the empirical analysis of the urban railway project in Tokyo. Consequently, it is found that the user benefit estimated by the MNL is largest, whereas the benefit by the UE is smaller than the benefit estimated by the MNL by about 10 % and the benefit estimated by the AON is smaller than the MNL by about 20%.

From these results, we can conclude that the types of demand analyses may impact significantly on the estimated user's benefit. This gives transportation planners several important lessons and cautions. First, we need to consider carefully the choice of techniques of travel demand forecast for the project evaluation. In some countries like Japan, the guidelines for cost-benefit analysis do not cover the methodology of travel demand analysis. However, the guideline could not make any sense if it allows analysts to select the demand analysis technique as they like. They should deal with the travel demand analysis which is consistent with the cost-benefit analysis method. Next, we can get the lesson for planning process as well. When selecting a travel demand analysis technique in the transportation planning process, the reasons for using a specific technique should be open to public discussion. Otherwise, there is the room to manipulate the estimated user's benefit by controlling the type of travel demand analysis. Thus, the public involvement in transportation planning is so important in order to achieve the trustable results. Third, we can point out the importance of sensitivity analysis. Even if a specific technique of travel demand analysis is available due to the work constraints and/or the practical limitation, the transportation planners must examine the results of the analysis very carefully. The sensitivity analysis may be useful for testing the redundancy of estimated results. If the estimated results are not stable, it should be reported to the decision-makers as well as the results. Finally, we also found that the estimated benefit is sometimes critically impacted by whether or not the congestion is taken into an account. Therefore it is necessary to examine the impact of congestion to the transportation network in the benefit calculation.

As far as the technical issues are concerned, there still remain some topics which should be further examined. First, the additional analysis is required to explore what the most appropriate demand technique is, because this paper compares just three techniques and apply them to a unique project. More extended analysis may be required. Second, the setting of choice set in the MNL model should be also more discussed. In this paper, we used the same data of choice set as the one used in the railway master plan of Tokyo, in which the choice set is generated by the analysis of passenger's revealed preference. Although the passenger's choice sets may be modified when the service is changed, we have not yet found out the good practical techniques to modify them. Finally we need to study how to define the link cost function especially under the condition that only the OD-based cost is given. In this paper we assume the proportional rate of fare to distance by the simple regression analysis, but it should be discussed in more details.

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