MEASUREMENT OF TRANSPORT INVESTMENT BENEFIT:
EMPIRICAL COMPARISONS BETWEEN OD-BASED APPROACH AND
ROUTE-BASED APPROACH

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Abstract: The objective of this paper is to analyze the properties of the route-based approach and the OD-based approach in the measurement of the user’s benefit derived from a transportation investment, and to propose a practical method to resolve the problem we may find in calculating the consumer’s benefit based on the route-based approach when evaluating a newly introducing investment. In this paper, the MNL model is used for the travel demand analysis. To evaluate the two approaches, the empirical comparison is conducted by applying the two benefit calculation methods to a simple numerical simulation and a railway project in the Tokyo Metropolitan Area. We conclude that the user’s benefit calculated by the proposed method can be approximation.

Key Words: user’s benefit, transportation investment, consumer surplus, logit model, measure of accessibility

1. INTRODUCTION

The measurement of user’s benefit derived from the transportation investment mostly relies on the consumer surplus theory, in which the change of consumer’s welfare is converted into the monetary value. Such a method may cause a difficulty when alternative modes or routes are available to consumers in a transportation network. For instance, when a specific link in a network is improved by an increase of its capacity, the change of service level of the route including the improved link may change the service level of the other routes as well. Mohring(1976), Williams(1976) and Agnello(1977) show that the user’s benefit of a specific origin-destination pair can be calculated by summing up all the user’s benefits stemming from the alternative routes. We call this method of benefit evaluation as a “route-based approach”. When applying the route-based approach, the user’s benefit of a certain route is evaluated by the area to the left of transportation demand curve of the route. On the other hand, Williams(1977), Small and Rosen(1981) show that the measure of accessibility or the inclusive value can be a measure of consumer’s surplus when using the discrete choice model. Especially, when the travel choice behavior is expressed as the logit model derived from the assumption that the stochastic utility components are independently and identically distributed with the extreme value or double–exponential distribution, the measure of consumer’s surplus can be evaluated in a closed form:

\[
CS = -\frac{1}{\lambda} \left[ \ln \sum_j \exp(\lambda V_j) \right]
\]  

(1)

where \(CS\) is the consumer surplus, \(V_j\) is the utility of an alternative \(j\) and \(\lambda\) is a scale
parameter of the logit model. Since this consumer’s surplus is defined as the expected consumer surplus of an origin-destination (OD) pair when considering the modal choice or the route choice between the given OD pairs, we call this type of evaluation method as an “OD-based approach”.

Because most of the textbooks on the transport economics or the transport planning such as Mohring (1976), O’Flaherty (1997) and Ben-Akiva and Lerman (1985) show just either of the two approaches, many practitioners in transport analysis seem confused with the difference of these two approaches. Just few researches have treated both of two approaches. Le et al. (1992) discusses this problem by focusing on the measurement of benefit for the newly introduced facility. They derive the original demand function “the Logit type of demand function” from the indirect utility function and the Roy’s Identity, and lead to the value of the equivalent valuation (EV) by introducing the “availability index” into the constraints of the utility maximization problem. However, their method relies on the definition of the indirect utility function and may not be applicable to the MNL demand function. In the context of which is better between two approaches, Jara-Diaz and Friesz (1982) discusses the problem when applying the route-based approach to the transportation investment without the newly introduced facility. This research shows that the benefit calculation shown by Mohring (1976) may have a trouble when the demand curve has a specific feature in the light of the shift direction of the demand curve, and concludes that the OD-based approach should be used to resolve the problem. However, their conclusion relies on the assumption that the travel demand is determined by the user’s equilibrium model derived from the Wardrop’s theorem. Neuberger (1971) shows a clear derivation of user’s benefit from the route-based approach. His presentation is valid for the transportation project without introducing a new facility, but may be invalid for the project with a newly introduced facility. Therefore, the objective of this paper is to review the relationship between the route-based approach and the OD-based approach in the measurement of the benefit derived from a transportation investment, and to present a practical method to resolve the problem of the route-based approach in the case of evaluating a new investment. In section 4, we evaluate the proposed method empirically by applying it to a simple numerical example and to a real transportation project. Section 5 summarizes the relevant aspects and conclusions.

2. TRANSPORTATION INVESTMENT WITHOUT INTRODUCING A NEW ROUTE

When the transportation investment does not introduce a new route or a new link to the existing network, to calculate the user’s benefit derived from the investment is possible both by the route-based approach and the OD-based approach. Here, the transportation investment without introducing a new link means for example an increase of the capacity of the route and improvement of the quality of the route. This kind of projects is expected to reduce the travel time of the invested route. As Mohring (1976) shows, the benefit stemming from the improvement project can be calculated just by taking an account of the improved link when the price of the transportation service is based on the marginal cost. Unfortunately, however, the price of most of the transportation service including the highway, railway, air transport, etc. is not based on the marginal cost, but on some kinds of political regulation. Therefore, we need to sum up the benefit derived from all routes or all links in the transportation network.

The user’s benefit derived from the transportation project without introducing a new link is calculated by the following Marshall-Depuit’s formula:

\[
UB = \frac{1}{\theta_C} \sum_r \int_{V_r^w} x_r dV_r
\]

(2)

where \( UB \) is the user’s benefit, \( x_r \) is the travel demand of the route \( r \), \( \theta_C \) is the marginal utility of travel cost and \( V_r \) is the utility of using the route \( r \), \( V_r^w \) is the utility when
transportation project is conducted and \( V^o \) is the utility when doing nothing. We assume the marginal utility of travel cost is constant. If formulating the travel demand as the Multinominal Logit (MNL) model, the user’s benefit is expresses as:

\[
UB = -\frac{N}{\theta_C} \sum_r \int_{V^o_r}^{V^w_r} P_r dV_r 
\]

(3)

where \( P_r \) is a probability of choosing the route \( r \) and \( N \) is the total demand from an originating zone to a destination zone. The probability of choosing the route \( r \) can be expressed as the well-known Logit formula:

\[
P_r = \frac{\exp(\lambda V_r)}{\sum_t \exp(\lambda V_t)}
\]

(4)

Because the user’s benefit formula (2) is a line integral, the value of \( UB \) generally depends on the chosen path of integration. However, when the demand function is expressed as the logit model, the solution of the line integral is independent from the integral path. This is because the Logit model satisfies the integrability conditions for line integrals by Green’s theorem.

To calculate the line integral, we can assume several paths. For example, let the number of alternative routes two from an originating zone to a destination zone. Assume that the utility of route 1 and 2 are \( V_1 \) and \( V_2 \) respectively. Consider a transportation investment along either of routes and changes of utilities at both routes. Then, the change of a set of utilities by the transportation investment can be illustrated as a movement from a point \( W_0 \) to \( W \) in the Figure 1.

We can define many paths between \( W_0 \) and \( W \). As Neuberger (1971) shows, one of the simplest paths may be \( C_i \) in the Figure 1, in which we assume a linear path of integration, i.e. all the trips originating from the same zone will make the same proportion of their utility changes at the same. We define \( \alpha (0 \leq \alpha \leq 1) \) to be the surplus change from the originating from the zone. Then we define the utility as the following way:

\[
V_r = V^o_r + \alpha (V^w_r - V^o_r)
\]

Then we calculate the line integral as follows:

\[
UB = -\frac{N}{\theta_C} \sum_{r=1} \int_{V^o_r}^{V^w_r} P_r(V) dV
\]

Figure 1. Several paths of the line integral in the case of two routes from originating zone to destination zone.
We can derive the same formula in another way as well. Another possible path is for instance $C_2$ or $C_3$, in which one utility is changed at a time, while the others are held constant at their original or final values, depending on whether they have been already changed.

As a result of the line integral, we find that the user’s benefit based on the route-based approach derives the same value as the benefit calculated by using the accessibility measure shown in (1). The differences between (1) and (5) are two: one is that (1) is defined as the utility term while (5) is defined as the monetary term, and the other is that (1) is defined for individual while (5) is defined for the aggregated demand of origin-destination. Since the consumer’s surplus can be converted into monetary term by using the marginal utility of travel cost. And it can be aggregated into the population when the original utility function is the Gorman type function (Varian, 1978), we can derive the same formula both from the route-based approach and the OD-based approach.

It can be concluded that the user’s benefit derived from the route-based approach has the same value as the benefit derived from the OD-based approach in the transportation investment without any introduction of new link.

3. TRANSPORTATION INVESTMENT WITH A NEWLY INTRODUCED ROUTE

Next, we move to the transportation investment with a newly introduced link. When applying the OD-based approach, we can calculate the user’s benefit derived from the newly introduced route in the same way as the benefit derived from the improvement of existing route. Even if the choice set of a consumer changes between before and after the transportation investment, the OD-based approach can take an account of the change. For example, suppose that there are two routes: route 1 and route 2 from an originating zone to a destination zone before the investment, and a new route 3 is added to the existing two routes by the investment. This simple example is depicted as Figure 2.

In this case, the user’s benefit derived from the investment when the accessibility measure is
used is calculated as:

\[
UB = -\frac{N}{\lambda \theta} \left\{ \ln \left[ e^{AV_r^o} + e^{AV_r^w} + e^{AV_r^v} \right] - \ln \left[ e^{AV_r^o} + e^{AV_r^v} \right] \right\}
\]  

(6)

where \( V_r^o \) is the utility of route \( r \) before the investment and \( V_r^w \) is the utility after the investment. Since the measure of accessibility is monotonic with respect to choice set size, any addition to a person’s choice set leaves the individual no worse off than before the addition. This property is quite meaningful for a project with the newly introduced facility, because the user’s benefit is always positive even if the utility of the additional route is extremely lower. It should be mentioned, however, that in an actual situation, the traveler may not add the new route to his/her choice set if the new one provides too low service. In this sense, how to set the choice set becomes very important.

On the other hand, we may have a problem when applying the route-based approach to the transportation investment with a newly introduced facility. The reason is simply because it is impossible to define the utility of a newly introduced route before the investment. As shown in Figure 3, the price or the disutility of the newly introduced route may be infinitely large when the route does not exist, but it is difficult to find the exact value of it in the computation of the user’s benefit. Especially when using the MNL model for the travel demand function, the difference in utility between the different routes should be infinitely large due to its formulation, and no guarantee to achieve a finite solution of the integral of consumer’s surplus.

4. EMPIRICAL ANALYSES OF USER’S BENEFITS IN THE NEWLY INTRODUCTION INVESTMENT

To resolve the above-mentioned problem of the route-based approach, we propose a practical method to define the utility of the newly introduced route before the transportation investment. Then, we evaluate how much the simulated benefit by the proposed method can be approximate to the benefit simulated by the OD-based approach.

4.1 Proposed Method

In general, it is expected that the consumers have the limited ability to recognize the choice set. For example, in the real highway network, there are so many alternative paths connecting between origin-destination zones, but it is impossible to list up all of the possible alternative routes. Therefore, the consumer may need to choose a route in a two-step way. The first step may be a screening stage to make a choice set in which the consumer eliminates routes based on his/her specific criteria. This kind of transportation behavior could be treated as the non-compensatory model such as the Elimination by Aspects model proposed by Tversky(1972) and the sequential consideration of attributes model shown by Recker and Golob(1979). This research does not consider the first step more in detail, but assumes that the consumer always
fixes the size of choice set through the screening step. Next, at the second step, the consumer chooses a best route among the screened choice set. The transportation behavior at the second step may be expressed as the compensatory model, such as the MNL model.

The assumption of fixing the size of choice set can be reconsidered in another way by a simple example. Suppose a railway network, which involves two routes before the investment, and a transport investment introducing the third route. Then, it may be practical to consider the following ways:

Idea (a): It is sure that there is not the third route before the investment, but should exist another transportation mode instead like a highway between origin-destination zones.

Idea (b): If the railway network is large enough, the consumers easily find another route connecting between origin-destination zones. Then, it is natural to consider there should be the third route, which could be one of the choice set even before the investment.

Like these ideas, this assumption seems quite natural to some degree especially from a practical point of view.

Under those assumptions, we propose to use the utility of other mode in the idea (a) or other route in the idea (b) for the utility of the third route before the investment. It is clear that this method is inconsistent with the economics theory, because the mode or the route whose utility is used in the proposed method is different from the new route introduced by the investment. In other words, this is a comparison of the utilities between different goods. However, we may achieve the approximated user’s benefit by this method because the consumer may compare the utilities of different goods through a revision of their choice sets.

For the verification of the approximation, we examine the proposed method both in a simple numerical example and in a case study of Tokyo Metropolitan railway network.

4.2 A Simple Numerical Example

To examine the property of the proposed method, a simple numerical example, in which two alternatives exist between an originating zone to a destination zone before the transportation investment and a new route is added to the existing network by the investment is considered. For the simplicity of the analysis, the utility level is set as the Figure. 4. In this example, the utilities of route 1 and route 2 are $\alpha$ and 1 respectively before the investment, while the utilities of route 1, 2, 3, are $\alpha$, 1 and $\beta$ respectively after the investment.

Suppose that the number of total travelers is set to one and $\lambda\theta_i$ is -1 of the logit model for the route choice behavior. Then, when using the OD-based approach, we calculate the user’s benefit derived from (6) by applying the MNL model to the transportation behavior. On the other hand, to apply the proposed method of route-based approach, we assume that the size of user’s choice set is fixed to be two both before and after the investment. To define the choice set after the investment, we use a following screening rule: the consumer will eliminate the route with the lowest utility among the choice set. This means that the choice set after the investment depends on the two routes with the largest utility and second largest utility. For example, if $\alpha > \beta > 1$, the choice set after the investment is $[\alpha, \beta]$ and if $\beta > 1 > \alpha$, then the choice set is $[1, \beta]$. To calculate the user’s benefit by the route-based approach, we use the linear approximation of the Marshall-Depuit’s formula to the demand curve, which follows a well-known “rule of a half”:

![Figure 4. A simple numerical example](image-url)
where \( x_r \) is the consumer’s demand of route \( r \) and \( p_r \) is the probability of choosing the route \( r \) derived from (4).

Then, the user’s benefits derived from the OD-based approach and the proposed method based on the route-based approach when a set of \( (\alpha, \beta) \) is given are shown in the Figure 5. The properties of the utility derived from both methods seem so similar that the difference between two methods can be judged to be small.

### 4.2 An Empirical Example

Then we apply the proposed method to the evaluation of a real transportation project. Here, the newly introduction of railway line in the Tokyo Metropolitan Area is used for the empirical example. The example used is the urban railway line connecting between the existing two stations in the central district of Tokyo, shown in Figure 6. This railway line runs underground and it is operated by a subway company. This investment is expected to save the travel time and to ease the in-train congestion.
The same methods as the simple numerical example are used to evaluate the user’s benefit. The size of choice set is defined based on the revealed preference of consumers. For example, over 80% of the total travelers between a specific origin-destination pair use the \( M \) routes, then we fix the size of choice set to be \( M \). The maximum size of the choice set is 16 alternative routes.

We use the MNL model for the route choice behavior of rail users. We use the model parameter given by Morichi et al. (2001), in which the model parameter is shown as Table 1.

As a result of the demand analysis, we calculate the user’s benefit by the OD-based approach and the route-based approach. It is shown in Figure 7. This means that the user’s benefit calculated by the proposed method is larger than the one calculated by the OD-based approach, but its difference is quite small by 5.7%. Consequently, we may consider that the proposed method is applicable to the benefit evaluation in the real project.

### 5. CONCLUSIONS

The analysis and estimation of the discrete choice models is enjoying popularity in the transportation planning and the results of them are often used for the benefit evaluation of the
transportation investment. If the demand analysis stage and the benefit evaluation stage are executed by the same engineer or the same planner, the OD-based approach should be appropriate and no need to use the route-based approach. Unfortunately, however, these two stages are separated in many practical cases. When the benefit analyzers cannot get the information about the details of demand analysis, such as the estimated coefficients of the demand model and the type of the utility function, it is almost impossible for them to use the OD-based approach. On the other hand, the route-based approach is quite easy to use and practical even in the less information situation in the benefit evaluation process, because it requires just the travel (generalized) cost and the simulated demand. In many cases, the travel cost can be calculated under a certain assumption and the transportation demand can be provided through the demand analysis process. However, the route-based approach has a disadvantage in the case of the newly introduced project as shown above. This paper proposes the practical method to resolve this problem and its validity is shown by the simple numerical example and the empirical example.

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