COST-BENEFIT ANALYSIS FOR IMPROVEMENT OF TRANSFER AT URBAN RAILWAY STATIONS

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INTRODUCTION

In many urban cities, commuters are required to transfer at public transport terminals. For example, in the Tokyo Metropolitan Area, more than 80% of railway users transfer from one train to another train at stations. The average number of transfer is 0.85 times per trip. More than a half of the transfers takes more than three minutes per transfer. Economic loss due to transfer at terminals could be substantial. Even though the modal shift policy from automobile to public transport is often stressed from the viewpoint of global or local environmental issues, automobile users will find it unattractive to shift to railway or transit without any improvement of transfer facilities. Additionally, since more aged people and handicapped people have recently actively travelled, their special needs have to be considered as well. Therefore, the so-called "seamless" public transport network is strongly expected. To pursue the seamless public transport system, we need to discuss a master plan for public transport, which should consider where are bottlenecks; what should be done with the bottlenecks; what is the priority of projects; etc. For a reasonable and logical discussion, we need a technical tool, which enables planners or engineers to assess the economic efficiency of station improvement.
Some researchers have suggested several numerical methods to evaluate transfer at stations. Firstly, Japan Transport Economics Research Centre (1979) suggested a formula to convert resistance of transfer into a generalized level distance by the ratio between energy consumption of going up stairs and of walking on a level passage. This formula is quite useful to evaluate the resistance of stairs, however, it cannot be applied to evaluate congested stations. We often observe that transfer time increases when a passage or a stairway in a station is crowded. To discuss bottlenecks and how we improve the transfer at congested stations, we need to know the relationship between capacity and flow volume. Next, some simulation models of pedestrian's movement in a crowded railway station have been proposed, such as Ando (1990), Turner et al. (1991) and Buckman et al. (1994). Those models can simulate movement of each person in space by computer, and determine walking velocity as a function of the flow density based on traffic flow theory. Those simulation models enable us to predict the flow pattern in a certain station on a condition that passenger characteristics are given. They are very powerful tools to analyze station space locally, however, they do not deal with changes in passengers' rail route choice as a result of improvements. Because the Tokyo Metropolitan Area has such a dense railway network, a local improvement will affect the entire railway network. In regards to the network effect of railway project, some researchers, such as Hunt (1990), Yai et al. (1993, 1997), proposed public transport route choice models including transfer cost. For example, Yai et al. (1993) suggested a rail route choice model, which includes several parameters of transfer time at stations. Though this seems most suitable for our purpose, it does not consider congestion at stations because this is not developed for the purpose of evaluating transfer at stations. In light of the literature review, a planning tool with the desirable specification is not currently available. This paper aims to develop such a numerical tool for a socio-economic evaluation for projects for improving transfer at urban railway stations. After the completion of the tool, we applied it to some rail station improvement projects. This tool can determine user's benefit and railway operator's benefit, when the Origin-Destination Matrix of rail users and level-of-service data are given.

Certain keywords are defined in advance. The transfer at railway stations includes several types of movements. This paper treats only transfer between different trains of different urban rail lines. In other words, we focus on the passengers' flow from one train of one urban rail line to another. Therefore, this paper does not cover the transfers like: access transport mode to rail service; express train to local train; inter-city rail service to urban rail service; etc. We also categorized transfers into two types due to the location pattern of stations. One type is transfer from one platform to another in the same station, while the other is transfer between two different stations located far from each other. This paper covers both types of transfers. However, stations too far apart are not considered. Moreover, we define a unit of transfer. There may be more than two transfers in a terminal station when two or more railway lines run through the station. This is because there are more than two platforms there. Then, we count a unit movement from one platform to another as a unit transfer.

Certain keywords are defined in advance. The transfer at railway stations includes several types of movements. This paper treats only transfer between different trains of different urban rail lines. In other words, we focus on the passengers' flow from one train of one urban rail line to another. Therefore, this paper does not cover the transfers like: access transport mode to rail service; express train to local train; inter-city rail service to urban rail service; etc. We also categorized transfers into two types due to the location pattern of stations. One type is transfer from one platform to another in the same station, while the other is transfer between two different stations located far from each other. This paper covers both types of transfers. However, stations too far apart are not considered. Moreover, we define a unit of transfer. There may be more than two transfers in a terminal station when two or more railway lines run through the station. This is because there are more than two platforms there. Then, we count a unit movement from one platform to another as a unit transfer.
STRUCTURE OF THE EVALUATION MODEL

Framework of the evaluation model

We developed an evaluation model for calculating benefit derived from transfer improvement projects. The evaluation model consists of three sub-models: transfer flow sub-model; rail route choice sub-model; and benefit sub-model. The framework of the model is shown in Fig. 1. First, the transfer flow sub-model determines the waiting time in a queue in front of a stairs leading to a platform; the velocity of flow going up stairs; going down the stairs; and walking on passage in a station. Both waiting time and velocity depend on the number of transferring passengers given by the rail route choice sub-model. The second sub-model, the route choice sub-model determines the passenger flow along the railway network. The route choice is determined with consideration to fare, riding time, congestion level in train and transfer time at stations based on the Origin-Destination Matrix. The transfer time at the station is given by the transfer flow sub-model. The third sub-model, the benefit sub-model, determines user's benefit and railway operator's profit, when it is given the route flow demand from the route choice sub-model. The user's benefit calculation is based on the consumer's surplus theory where the value of time is given by the ratio of the time coefficient to the fare coefficient of the route choice model when its utility function is linear. The railway operator's profit is also computed by the revenue from passengers' fare less the running cost.

Fig. 1 Structure of the Evaluation Model
Model Formulation

Transfer Flow Sub-model. The transfer flow sub-model consists of several formulas by which we can calculate the waiting time in a queue in front of stairs or gates and the velocity of the flow going up stairs; going down stairs; walking along a passage in a station; etc. As Lam et al. (2000), Cheung et al. (1997) and Daly et al. (1991) reported, we can find that the walking velocity decreases when the flows of passengers increase and that the waiting time increases when the arriving passengers increase. Therefore, we assume that the walking velocity and the waiting time depend on the flow density, that is

\[
\frac{\partial t_{\text{wait},x}(fd)}{\partial fd} > 0, \quad \frac{\partial v_x(fd)}{\partial fd} < 0
\]

where

\( t_{\text{wait},x}() \): Waiting time in front of facility \( x \)
\( v_x() \): Velocity of walking along facility \( x \)
\( fd \): Flow density.

We can then calculate the transfer time at the station by

\[
\sum_{x} \left[ t_{\text{wait},x} + \frac{l_x}{v_x} \right] = u
\]

where

\( u \): Transfer time
\( l_x \): Length or height of facility \( x \).

Route choice sub-model. The route choice sub-model is a model by which we can calculate the passenger flows of railway routes. Passengers are faced with a problem of determining which route to choose among several alternative routes. We assume that they select a route rationally based upon certain attributes of routes such as fare and travel time. However, we cannot observe all attributes in the route selection and the passengers also cannot achieve perfect information about the attributes of the entire network. From these perspectives we introduced the random utility theory into the route choice problem. As there are possibly more than two alternative routes between the origin station to the destination station, the model is the multinomial choice model. We applied the i.i.d. gumbel distribution to the error term, therefore the model used is the multinomial logit (MNL) model. This is expressed as

\[
P_{i,rs} = \frac{\exp(V_{i,rs})}{\sum_{j \in J_{rs}} \exp(V_{j,rs})}
\]

where

\( P_{i,rs} \): Probability of choosing route \( i \) from station \( r \) to station \( s \)
\( V_{i,rs} \): "Universal" utility function of route \( i \) from station \( r \) to station \( s \)
\( J_{rs} \): Choice set of routes from station \( r \) to station \( s \).

Finally, we can compute the flow demand of each OD pair by

\[
q_{i,rs} = Q_{rs} \cdot P_{i,rs}
\]

where \( q_{i,rs} \) is the flow demand of route \( i \) from station \( r \) to station \( s \) and \( Q_{rs} \) is rail travel demand \( i \) from station \( r \) to station \( s \).

Benefit sub-model. The benefit sub-model is a model for calculating the user's benefit
and the operator's profit after the travel flow demand is determined in the "with" case and "without" case. The "with" case means a situation in which the service is improved by a project, whereas the "without" case means a situation before the project.

We calculate the user's benefit based on the consumer surplus theory and applying the expected maximum utility of users. As noted by Williams (1977), we can apply the classical consumer surplus theory into calculating the benefit of users, expressed as

\[ UB = \frac{1}{2} \sum_{rs} \left( G_{rs}^{w} - G_{rs}^{w} \right) \left( Q_{rs}^{w} + Q_{rs}^{wo} \right) \]  

where
- \( UB \): User's benefit
- \( G_{rs}^{z} \): Generalized cost from \( r \) to \( s \) in the case of \( z \)
- \( Q_{rs}^{z} \): Flow demand from \( r \) to \( s \) in the case of \( z \)
- \( z \): \( z = w \) in the "with" case and \( z = wo \) otherwise.

Here, we define the passenger's utility converted into monetary units as the generalized cost. As noted by Ben-Akiva and Lerman (1985), the expected maximum utility of the logit model is written in monetary units as

\[ \frac{1}{\beta} \ln \sum_{i \in I_{rs}} \exp(V_{in}) \]  

where
- \( U_{in} \): Utility function of user \( n \) for route \( i \)
- \( V_{in} \): "Universal" or determined utility function of user \( n \) for route \( i \)
- \( I_{rs} \): Choice set of routes from station \( r \) to station \( s \)
- \( \beta \): Coefficient value of the fare.

Since we have several route choice sub-models for various age and travel purposes, we need to sum up all types of users' benefit. Moreover, because \( UB \) calculated by equation (4) is the users' benefit for a day, we have to convert the values to user's benefit per year by applying the appropriate conversion factor.

In addition to the user's benefit, we calculate the rail operator's net profit. This is the marginal earnings of rail operator's when the project is installed. Here, we regard that the operator's revenue stems only from the fare paid by rail users. Thus we can calculate the supplier's benefit (operator's net profit) by

\[ SB = \sum_{rs} \left( f_{rs}^{w} \cdot Q_{rs}^{w} - f_{rs}^{wo} \cdot Q_{rs}^{wo} \right) - MC \]  

where
- \( SB \): Supplier's benefit (operator's net profit)
- \( f_{rs}^{z} \): Fare from station \( r \) to station \( s \) in the case of \( z \)
- \( MC \): Marginal running cost by the project.

**MODEL ESTIMATION**

Based on the above-mentioned evaluation model, we estimate the transfer flow sub-model and the rail route choice sub-model. For estimating the transfer flow sub-model,
we conducted a survey on transfers at the Tokyo Metropolitan. For estimating the route choice sub-model, we used the Tokyo Metropolitan Transport Census 1995.

**Estimation of transfer flow sub-model**

*Survey on railway transfer in Tokyo Metropolitan Area.* The authors surveyed transferring passengers at 130 railway stations in the Tokyo Metropolitan Area in order to collect data for a transfer flow model. The surveyed 130 stations have 408 transfers. To get the data both in congested and non-congested situation, we examined both peak period (from 8:00 to 9:00) and in off-peak period (from 11:00 to 16:00). First of all, an observer checks transfer routes and location of stairs, passages and escalators etc. in a station. Next, he measures the width and length of stairs, passages and escalators and counts the number of steps of stairs. Then, he follows a passengers group when a train arrives at the station and opens its doors. He counts how many seconds it takes to walk from the door to the middle of the platform. He also times the velocity movements at stairs, passages, escalators as well as waiting time. As the result, average time of transfer is 4.4 minutes during peak hour and 3.6 minutes during off-peak hour. At any type of station, transfer time at peak hour is longer than at off-peak hour. Most of the observed transfers have a less than one minute difference of transfer time between peak time and off peak time. Table 1 shows the differences of walking or waiting time for elements of a transfer at peak and off peak periods. Waiting time in front of a stair (up) and a walking along a passage have larger differences than others.

*Estimation results of transfer flow formulas.* The formulas were calibrated based on the surveyed data of transfer in the preceding section. Although we surveyed the waiting time at the ticket gate and the waiting time going downstairs in the survey, we could not find any significance considering in them. Therefore, we ignore the waiting time both at the gate and stairs with flow going down.

First, we estimated the relationship between the waiting time in a queue going up a stairs and the flow density. For simplicity, we adopt a linear equation as

\[ t_{\text{wait}} = 136.57 \cdot f_{d_{\text{up}}} + 4.273 \]  

(7)

where

- \( t_{\text{wait}} \): Waiting time in front of stairs (up-bound) [minutes]
- \( f_{d_{\text{up}}} \): Flow density at stairs, which is defined as

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**Table 1 Differences of transfer time elements between peak and off-peak time**

<table>
<thead>
<tr>
<th>Element of transfer</th>
<th>Peak</th>
<th>Off-peak</th>
<th>Peak/Off-peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waiting time in front of stair (up)</td>
<td>11.1</td>
<td>0.0</td>
<td>-</td>
</tr>
<tr>
<td>Walking time in stair (up)</td>
<td>14.2</td>
<td>11.5</td>
<td>1.24</td>
</tr>
<tr>
<td>Time in up-escalator</td>
<td>20.4</td>
<td>20.4</td>
<td>1.00</td>
</tr>
<tr>
<td>Walking time along level passage</td>
<td>113.8</td>
<td>102.3</td>
<td>1.11</td>
</tr>
<tr>
<td>Waiting time at ticket gate</td>
<td>2.2</td>
<td>0.0</td>
<td>-</td>
</tr>
<tr>
<td>Walking time in front of stair (down)</td>
<td>23.1</td>
<td>19.6</td>
<td>1.18</td>
</tr>
<tr>
<td>Time in escalator (down)</td>
<td>7.9</td>
<td>7.9</td>
<td>1.00</td>
</tr>
</tbody>
</table>
where

\[ N_{up} : \text{Average passengers going upstairs after getting down from a train} \]  
\[ \text{[passengers/train/hour]} \]

\[ \text{cap}_{up} : \text{Flow capacity of going upstairs [passengers/hour].} \]

The value in the parenthesis is the t statistic of the parameter. We calculated the flow capacity based on the product of the unit flow capacity per meter width and the width of the stairs. When there is an escalator together with the stairs, we consider the capacity of the escalator as well. As the up-bound capacity of a stair per meter width, we used 2,500 passengers per hour.

Next, we estimated an equation of velocity of walking up a stairs. Based on the observed data, we estimated the following formula:

\[ v_{up} = -0.9649 \cdot fd_{up} + 1.761 \]  
\[ ( -5.30 ) \]

where

\[ v_{up} : \text{Velocity of walking upstairs [steps/s]} \]

\[ fd_{up} : \text{Flow density at stairs, which is defined as equation (8).} \]

Then, we estimated an equation for the velocity of walking downstairs. We obtained the following formula

\[ v_{down} = -1.045 \cdot fd_{down} + 1.883 \]  
\[ ( -8.31 ) \]

where

\[ v_{down} : \text{Velocity of walking downstairs [steps/s]} \]

\[ fd_{down} : \text{Flow density at stairs, which is defined as} \]

\[ fd_{down} = \frac{N_{down}}{cap_{down}} \]  
\[ (11) \]

where

\[ N_{down} : \text{Average passengers going downstairs after getting down from a train} \]  
\[ \text{[passengers/train/hour]} \]

\[ \text{cap}_{down} : \text{Flow capacity of going downstairs [passengers/hour].} \]

We calculated the flow capacity in the same way as the case of upstairs. Here we used the same flow capacity as the one of up-bound.

Finally, we examined the relationship between the velocity and the flow density when walking along a horizontal passage. The estimated formula is

\[ v_{level} = -2.814 \cdot fd_{level} + 1.141 \]  
\[ ( -7.31 ) \]

where

\[ v_{level} : \text{Velocity of walking on a level passage [m/s]} \]

\[ fd_{level} : \text{Flow density at the passage, which is defined as} \]

\[ fd_{level} = \frac{N_{level}}{cap_{level}} \]  
\[ (13) \]

where
Average passengers going a level passage after getting down from a train
[passengers/train/hour]
cap_{level} : Flow capacity of the passage [passengers/hour].
We calculated the flow capacity in the same way as the case of stairs up-bound. Here
we used the same flow capacity as 3,000 passengers per hour.

**Estimation of route choice sub-model**

We estimated the route choice sub-model based on the personal trip data of the Tokyo
Metropolitan Transport Census 1995.

*Utility function of the model.* As the utility function of the logit model, we examined
two types when estimating the coefficients. One is a function with all elements of
transfer time, that is, the waiting time at upbound stairs, walking time at upbound
stairs, downbound stairs and level passage. The other is a function with just total
transfer time. Both of the equations are linear functions. The definitions of variables
used in the model are shown in Table 2. In regard to the in-train congestion, we
converted it into a generalized time based on the formula suggested by the Japan
Ministry of Transport (1999), expressed as

$$
cgt_{i,rs} = \sum_{a} \alpha \cdot \beta \cdot \alpha(r_a) \cdot cgr_a + \beta(r_a)
$$

where

$cgt_{i,rs}$ : Generalized time converted from the congestion of train of route $i$ from
station $r$ to station $s$
$\alpha_d$ : In-train time of train on link $a$

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Unit</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-train time($it$)</td>
<td>min</td>
<td>Sum of running time from an origin to a destination and waiting time at the origin station. The waiting time is defined as a half of the train service's interval at the station.</td>
</tr>
<tr>
<td>Fare($f$)</td>
<td>yen</td>
<td>Fare from the origin to the destination. The fare of commuters and school students are defined based on the fare of the season ticket.</td>
</tr>
<tr>
<td>Generalized time of in-train congestion($cgt$)</td>
<td>min</td>
<td>Generalized time converted from in-train congestion ratio($cgr$). The $cgr$ is a ratio of the passengers in a train to the capacity of the train.</td>
</tr>
<tr>
<td>Transfer time($tt$)</td>
<td>min</td>
<td>Total transfer time from one train to the other train at all transferring stations on the route.</td>
</tr>
<tr>
<td>Upstairs time($ut$)</td>
<td>min</td>
<td>Total time of waiting and walking at upstairs of all transferring station on the route.</td>
</tr>
<tr>
<td>Downstairs time($dt$)</td>
<td>min</td>
<td>Total time of walking downstairs of all transferring station on the route.</td>
</tr>
<tr>
<td>Escalator time($et$)</td>
<td>min</td>
<td>Total time of passing through escalators of all transferring station on the route.</td>
</tr>
<tr>
<td>Passage time($pt$)</td>
<td>min</td>
<td>Total time of walking along passages of all transferring station on the route.</td>
</tr>
</tbody>
</table>

**Table 3 Values of alpha and beta in congestion disutility function**

<table>
<thead>
<tr>
<th>Congestion ratio($cgr$)</th>
<th>$\alpha$</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.0 \leq cgr &lt; 1.0$</td>
<td>0.0270</td>
<td>0.000</td>
</tr>
<tr>
<td>$1.0 \leq cgr &lt; 1.5$</td>
<td>0.0828</td>
<td>-0.0558</td>
</tr>
<tr>
<td>$1.5 \leq cgr &lt; 2.0$</td>
<td>0.179</td>
<td>-0.200</td>
</tr>
<tr>
<td>$2.0 \leq cgr &lt; 2.5$</td>
<td>0.690</td>
<td>-1.22</td>
</tr>
<tr>
<td>$2.5 \leq cgr$</td>
<td>1.15</td>
<td>-2.37</td>
</tr>
</tbody>
</table>
\( cgr_a \): In-train Congestion ratio of link \( a \)
\( A_i \): A set of links along route \( i \)
\( \alpha(\cdot), \beta(\cdot) \): Parameters whose values are shown in Table 3.

Estimation results of models. We estimated the route choice model for four travel purposes. For the work model, we estimated two types of models: one is the Work Model 1 which includes all elements of transfer time; and the other is the Work Model 2 which includes just the transfer time. For the School Model, the Leisure Model and the Business Model, we determined only one type of model including just the transfer time. Except the School Model, all models consist of two parts: one is for the users of aged less than sixty-five and the other is for the users of aged more than sixty-four.

The results of the calibration are shown in Table 4.1 and Table 4.2. Since the number

### Table 4.1 Estimation Results of the route choice model of work travel

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-train time (it)</td>
<td>-0.106</td>
<td>-4.89</td>
<td>-0.125</td>
<td>-4.79</td>
<td>-0.170</td>
<td>-4.92</td>
<td>-0.201</td>
<td>-4.18</td>
</tr>
<tr>
<td>Fare (f)</td>
<td>-0.0251</td>
<td>-2.54</td>
<td>-0.00311</td>
<td>-2.91</td>
<td>-0.00389</td>
<td>-2.23</td>
<td>-0.00480</td>
<td>-3.24</td>
</tr>
<tr>
<td>Generalized time of congestion ratio (cgt)</td>
<td>-0.000489</td>
<td>-1.75</td>
<td>-0.000161</td>
<td>-1.68</td>
<td>-0.000502</td>
<td>-1.79</td>
<td>-0.000620</td>
<td>-1.68</td>
</tr>
<tr>
<td>Transfer Time (tt)</td>
<td>-0.174</td>
<td>-1.22</td>
<td>-0.225</td>
<td>-1.63</td>
<td>-0.243</td>
<td>-6.72</td>
<td>-0.368</td>
<td>-4.42</td>
</tr>
<tr>
<td>Upstairs time (ut)</td>
<td>-0.161</td>
<td>-1.54</td>
<td>-0.224</td>
<td>-1.15</td>
<td>-0.146</td>
<td>-2.51</td>
<td>-0.213</td>
<td>-4.42</td>
</tr>
<tr>
<td>Downstairs time (dt)</td>
<td>-0.131</td>
<td>-1.68</td>
<td>-0.164</td>
<td>-1.89</td>
<td>-0.146</td>
<td>-2.51</td>
<td>-0.213</td>
<td>-4.42</td>
</tr>
<tr>
<td>Passage time (pt)</td>
<td>-0.0936</td>
<td>-1.01</td>
<td>-0.127</td>
<td>-1.34</td>
<td>-0.146</td>
<td>-2.51</td>
<td>-0.213</td>
<td>-4.42</td>
</tr>
</tbody>
</table>

**Basic statistics**

<table>
<thead>
<tr>
<th></th>
<th>Less than sixty-five</th>
<th>More than sixty-four</th>
<th>Less than sixty-five</th>
<th>More than sixty-four</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of samples</td>
<td>354</td>
<td>342</td>
<td>392</td>
<td>382</td>
</tr>
<tr>
<td>( \rho^2 )</td>
<td>0.172</td>
<td>0.184</td>
<td>0.197</td>
<td>0.184</td>
</tr>
</tbody>
</table>

**Time value (yen/min)**

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-train time (it)</td>
<td>42.0</td>
<td>40.1</td>
<td>43.7</td>
<td>42.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfer Time (tt)</td>
<td>62.6</td>
<td>76.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upstairs time (ut)</td>
<td>69.1</td>
<td>72.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Downstairs time (dt)</td>
<td>64.1</td>
<td>72.0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passage time (pt)</td>
<td>52.3</td>
<td>52.6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Escalator time (et)</td>
<td>37.3</td>
<td>40.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 4.2 Estimation Results of the route choice model of school, leisure and business travel

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-train time (it)</td>
<td>-0.124</td>
<td>-3.55</td>
<td>-0.0623</td>
<td>-2.76</td>
<td>-0.125</td>
<td>-4.79</td>
<td>-0.0845</td>
<td>-2.75</td>
</tr>
<tr>
<td>Fare (f)</td>
<td>-0.0117</td>
<td>-2.41</td>
<td>-0.00289</td>
<td>-2.99</td>
<td>-0.00311</td>
<td>-2.91</td>
<td>-0.00250</td>
<td>-3.52</td>
</tr>
<tr>
<td>Generalized time of congestion ratio (cgt)</td>
<td>-0.00153</td>
<td>-1.78</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Transfer Time (tt)</td>
<td>-0.174</td>
<td>-1.22</td>
<td>-0.206</td>
<td>-2.12</td>
<td>-0.000161</td>
<td>-1.68</td>
<td>-0.146</td>
<td>-2.51</td>
</tr>
</tbody>
</table>

**Basic statistics**

<table>
<thead>
<tr>
<th></th>
<th>Less than sixty-five</th>
<th>Less than sixty-five</th>
<th>More than sixty-four</th>
<th>Less than sixty-five</th>
<th>More than sixty-four</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of samples</td>
<td>381</td>
<td>209</td>
<td>49</td>
<td>240</td>
<td>32</td>
</tr>
<tr>
<td>( \rho^2 )</td>
<td>0.159</td>
<td>0.140</td>
<td>0.163</td>
<td>0.115</td>
<td></td>
</tr>
</tbody>
</table>

**Time value (yen/min)**

<table>
<thead>
<tr>
<th>Variable name</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
<th>Coefficient estimated</th>
<th>t statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-train time (it)</td>
<td>10.6</td>
<td>21.6</td>
<td>20.9</td>
<td>33.8</td>
<td>32.4</td>
<td>71.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transfer Time (tt)</td>
<td>17.6</td>
<td>71.1</td>
<td>86.4</td>
<td>58.5</td>
<td>71.8</td>
<td>58.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
of samples of aged people in the Leisure Model and the Business Model are too small, we had better treat those results as just trials even though we estimated the coefficients statistically satisfactorily.

Because the value of time is essential for user's benefit calculation, we discuss the estimation results mainly concerning the time value of variables. We can find the following items:

- The Work Model 1 shows that the value of time for going upstairs is higher than the value for others in both the aged and the non-aged users. This means that the load of going upstairs is heavier than going downstairs or walking along passage.
- The Work Model 1 demonstrates that the value of time for going upstairs is closer to the value for going downstairs in the aged user's case than in non-aged user's case. As it is often pointed out, this means that walking downstairs burdens the aged persons as heavily as walking upstairs.
- The Work Model 2 shows that the value of in-train time for the aged users is less than that for the non-aged users whereas the value of transfer time for the aged users is more than that for the non-aged users.
- The Work Model and the School Model shows that the value of time for students is less than the value for working commuters.

The Leisure Model demonstrated that the value of transfer time for leisure travel is much larger than the value for other travel purposes.

**COST-BENEFIT ANALYSIS OF IMPROVING TRANSFER PROJECT**

We applied the developed model to a real railway project in the Tokyo Metropolitan Area and evaluate the project by cost-benefit analysis. Before the project evaluation, we analyzed the general features of transfer at stations in the Tokyo Metropolitan Area. After we understood the present problems, we selected a target project and apply the evaluation model to compute the benefit of improvement.

**Transfer of railway stations in Tokyo Metropolitan Area**

We focused on the rail network in the Tokyo Metropolitan Area. This is because the network is very dense and has serious problems of transfer not only at the terminal stations but at the suburban stations.

*Basic Features of Tokyo Metropolitan Area.* The Tokyo Metropolitan Area is defined as the area that includes Tokyo, Kanagawa Prefecture, Saitama Prefecture, Chiba Prefecture, and southern part of Ibaragi Prefecture, which is covered within a circle with the radius of about 50 km from the center of Tokyo as shown in Fig. 2. The Tokyo Metropolitan Area covers almost all area where the people commuting into the CBD live. This area has more than 34 million population in 1995, and this figure has increased in last fifteen years by 1% per year. In the central area of Tokyo, the night population has decreased in the last twenty years, while the working population has increased. On the other hand, in the suburban areas, both the night population and the work population have been increasing. This sub-urbanization phenomenon has increased the transport flow between the central zone and the suburban zones.
Because a network of highway and expressway has not yet been completed in the Tokyo Metropolitan Area, many people choose rail service to travel. In 1997, 55.8% of trips use railway or subway and only 32.8% of trips use automobile. The railway network in the Tokyo Metropolitan Area is shown in Fig.3. Total length of operated rail lines is 2,143.0km (1998) and it includes 270.4km of subway lines. This is around ten percent of the total railway length of Japan. Tram is running only for 17.2km long in CBD. Twenty-four railway companies are running and all of them are private operators. About 40% of the network is operated by JR East (East Japan Railway Company).
Transfer at railway stations in Tokyo Metropolitan Area. Fig.4 shows the distribution of transfer times of rail users per trip and day in the Tokyo Metropolitan Area. More than 80% of passengers change trains at least once. Commuters and students transfer at an average of more than three times. Fig.4 shows us that it is really necessary to improve transfer at stations as soon as possible. Table 5 is a time-series trend of average transfer times in the Tokyo Metropolitan Area. The average is almost constant, at 0.85 times per day for the last ten years. This means that the service level of transfer has not been improved so far. The average transfer time of students is longer than that of commuters. This may be because workers can get commuting allowance from their companies, thus they can choose a route which is more expensive but has less transfer.

Fig.5 shows the present transfer time of rail commuters and students with rail season tickets. Most of transferring passengers are taking zero to three minutes, while about ten percent of transferring rail users are walking more than five minutes. Many rail users are inconvenienced by not only many times of transfer but also from the long walk for transfer.

Fig.6 shows a map of stations where more than 25,000 passengers transfer per day. As expected, most of them are located at the CBD or large terminal stations where suburban rail lines terminate. In addition, we can see many transfers at some suburban stations where a ring lines and suburban lines are crossing. Fig.7 shows a map of stations where passengers walk more than seven minutes to transfer. They are scattered both in the central area and in suburban areas. From these maps, we can find

Table 5 Trend of average transfer times in Tokyo Metropolitan Area

<table>
<thead>
<tr>
<th>year</th>
<th>1985</th>
<th>1990</th>
<th>1995</th>
</tr>
</thead>
<tbody>
<tr>
<td>commuters</td>
<td>0.82</td>
<td>0.84</td>
<td>0.81</td>
</tr>
<tr>
<td>students</td>
<td>0.91</td>
<td>0.89</td>
<td>0.98</td>
</tr>
<tr>
<td>total</td>
<td>0.84</td>
<td>0.85</td>
<td>0.85</td>
</tr>
</tbody>
</table>
that there are many stations where some improvement of transfer is needed.

Cost-Benefit Analysis by Application of the Model

In this paper, we selected a suburban station for case analysis. For the selected station, we developed an improvement plan considering the present geometric feature and physical constraint. Then, we apply the evaluation model to the project.

Improvement plan of the case project. First, we analyze transfer problems in the target stations and list up some possible countermeasures by observing the present situation around the station. Secondly, after taking account of constraints of geographical features, budget and possibility of affected people, we made two or three plans. Thirdly, based on the plans, we estimated the construction cost, running cost and maintenance cost based on similar projects. Then, we apply the evaluation model to evaluate the change of service level of transfer at the station and to compute the benefit of the project. Finally, we did the cost-benefit analysis on the project.

For the case analysis, we selected two stations located in the eastern suburban district of Tokyo. The two stations are station X (on the ground) and station Y (elevated). The railway line passing through station Y is a line connecting the central district and the suburban area, whereas the line passing through station X is a ring line. These two lines are operated by different operators. Because these stations are located far from each other, transferring passengers have to walk about 380m. In addition, since station Y is elevated, they need to walk upstairs or downstairs when transferring to and from station Y. According to the data of 1995, transfer volume is around 76,000 passengers per day. Although the elevated pedestrian deck is crossing over the road between two stations, many people are crossing the road illegally when transferring. This increases traffic accidents there and causes traffic jam in front of the stations.

Thus we suggest a plan shown in Fig. 8. This plan is to move the present station X to the new station Z just under station Y as an underground station. The reason why it is planned underground is because there is a road on the ground crossing under the station Y. By this improvement the distance of walking for transfer is expected to
We estimate the construction cost at around sixty billion yen. 

The computation result of the flow demand around the targeted stations is depicted in Fig. 9 and Fig. 10. By the improvement, the transferring passengers between two

Table 6 Expected improvement of transfer by the planned project

<table>
<thead>
<tr>
<th>Transfer elements</th>
<th>without case</th>
<th>with case</th>
</tr>
</thead>
<tbody>
<tr>
<td>walk along level pavement</td>
<td>377.1 m</td>
<td>50.0 m</td>
</tr>
<tr>
<td>Escalator (up)</td>
<td>5.0 m</td>
<td>22.5 m</td>
</tr>
<tr>
<td>walking downstairs</td>
<td>32 steps</td>
<td>0 steps</td>
</tr>
<tr>
<td>transfer time (peak time)</td>
<td>370 seconds</td>
<td>137 seconds</td>
</tr>
<tr>
<td>transfer time (off-peak time)</td>
<td>361 seconds</td>
<td>135 seconds</td>
</tr>
</tbody>
</table>

*Application of the evaluation model.* We applied the evaluation model to this project. We used the whole rail network of the Tokyo Metropolitan Area for computation. After calculating the rail flow demand, we evaluated the user's benefit and the operator's net profit. We calculated the rail flow demand for both "without" and "with". For the OD matrix, we used the Tokyo Metropolitan Transport Census (1995) for commuters and students, whereas we used the Person Trip Survey in Tokyo Metropolitan Area (1988) for leisure and business travels after the modification of the difference of the surveyed year. The evaluation model requires an iterative calculation by inputting the transfer flow from the route choice sub-model into the transfer flow sub-model. Moreover the congestion ratio will also change for each iteration. We computed the rail flow demand by the following steps:

First step: we set initial values of transfer time and congestion ratio for all transfers and railway lines.

Second step: we compute the transfer time by the transfer flow sub-model for all transfers and input them into the route choice sub-model.

Third step: if the output of the rail route choice sub-model satisfies a given criteria, we go forward to the fourth step. If it does not satisfy, we go back to the first step.

Fourth step: we compute the user's benefit and the operator's net profit.

The expected improvement of transfer by the planned project is shown in Table 6. We applied the evaluation model to this project. We used the whole rail network of the Tokyo Metropolitan Area for computation. After calculating the rail flow demand, we evaluated the user's benefit and the operator's net profit. We calculated the rail flow demand for both "without" and "with". For the OD matrix, we used the Tokyo Metropolitan Transport Census (1995) for commuters and students, whereas we used the Person Trip Survey in Tokyo Metropolitan Area (1988) for leisure and business travels after the modification of the difference of the surveyed year. The evaluation model requires an iterative calculation by inputting the transfer flow from the route choice sub-model into the transfer flow sub-model. Moreover, the congestion ratio will also change for each iteration. We computed the rail flow demand by the following steps:

First step: we set initial values of transfer time and congestion ratio for all transfers and railway lines.

Second step: we compute the transfer time by the transfer flow sub-model for all transfers and input them into the route choice sub-model.

Third step: if the output of the rail route choice sub-model satisfies a given criteria, we go forward to the fourth step. If it does not satisfy, we go back to the first step.

Fourth step: we compute the user's benefit and the operator's net profit.

The computation result of the flow demand around the targeted stations is depicted in Fig. 9 and Fig. 10. By the improvement, the transferring passengers between two
stations increase by about sixty-four percent. Because the transfer level of service is improved, the demand passing through station Y increases by about eight percent.

Consequently, we calculated the daily user's benefit and is shown in Table 7. The benefit of improving transfer time accounts for more than 90 percent of the total user's benefit. On the other hand, there is an increase in total fare, because passengers changing routes have to pay additional initial fare when transferring into the different operator's service. We also computed the operator's net profit to be 698,000 yen/day.

Cost-benefit analysis. Finally, we analyzed the economic efficiency by cost-benefit analysis. As in many previous studies noted, for example Prest and Turvey(1965), we need to determine several values and assumptions for the analysis. In this paper, we assume the followings:

1. Evaluating period: we assume two cases: thirty years and fifty years.
2. Taxes: we exclude the consumption tax in construction, maintenance and running cost.
3. Social discount rate: we use 4% due to the recent average risk-free long-term rate in Japan.
4. Project life: we assume that the service life of devices attached to structures like escalator to be 15 years and the service life of structures to be 32 years. We assume that the devices and the structure are reinstalled at the end of its service life.
5. Present year: we regard the present year to be 1995 for converting the benefit and the cost into present value.
6. Remaining value of last year of evaluating period: The remaining value of facilities after the depreciation is counted into benefit.
7. Technical external effect: we ignore the impact on environment.

<table>
<thead>
<tr>
<th></th>
<th>Benefit by time saving</th>
<th>Benefit by easing in-train congestion</th>
<th>Benefit by cost saving</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>in-train time</td>
<td>transfer time</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Non-aged users</td>
<td>142.3</td>
<td>1817.0</td>
<td>36.1</td>
<td>-46.9</td>
</tr>
<tr>
<td>Aged users</td>
<td>6.1</td>
<td>140.7</td>
<td>1.7</td>
<td>-1.3</td>
</tr>
<tr>
<td>Total</td>
<td>148.4</td>
<td>1957.7</td>
<td>37.8</td>
<td>-48.2</td>
</tr>
</tbody>
</table>

* unit: ten thousands yen
In addition, we assume that the change of travel demand by the project occurs immediately and that the future travel demand to be equal to the present demand till the end of evaluating period. Investment criteria. Used:
1. Net Present Value (NPV): select the project where the present value of benefit exceeds the present value of cost.
2. Cost-Benefit Ratio (CBR): select the project where the ratio of the present value of benefit to the present value of cost exceeds unity.
3. Economic Internal Rate of Return (EIRR): select the project where the economic internal rate of return exceeds the rate of social discount.
The result of evaluation is shown in Table 8. All criteria indicate that the project is viable.

Discussions. From the results of the preceding case analysis, we could find some important aspects about transfer improvement projects. First of all, we found that we can expect significant user’s benefit by such project. The most remarkable feature is that most of the benefit is attributed to the reduction of transfer time. Two reasons for this feature can be considered: one is because the volume of passengers transferring at stations is huge, thus the reduction of transfer time even by a small amount can account for nearly all of the entire benefit; another is because of the unavailability of alternative route all commuters are held captive which explains the high impact of the project. Secondly, we can expect a positive operator’s net profit from the project. In order to analyze the distribution of profit, we additionally computed each operator's net profit. We found that the operator of railway passing station Y incurs much of the net profit, whereas the operator of station W losses its profit. Still the net profit exceeds zero. Therefore, if we propose rail operators to undergo the project, we may not be able to achieve a consensus. Thirdly, we can expect high economic efficiency in the transfer improvement project. This is because of much social benefit due to factors mentioned above and of quite low construction and maintenance cost as well. Though the cost depends on various conditions of the site, the transfer improvement could be much cheaper than the construction of a new railway line. However, in general, a station with significant transfer is a major station, thus the area around the station is highly developed in many cases. This might increase project cost. Fourthly, we need to discuss some political issues related to railway investment: who should pay for the cost of the transfer improvement project? We can calculate the user's benefit generated in any prefecture or any zone. In the case analysis, we found that most of the benefit comes from the users residing in suburban area, which is farther from the center of Tokyo than the improved station. This means that many of the beneficiaries do not reside around the improved station. Therefore, if we use the tax revenue for the project, we need to consider the variation of burden among areas. Of course, we could expect the railway operators to partially shoulder the cost of the transfer improvement project, however, it might be difficult for them to say for the project to tackle. One of the reasons is a consensus problem as we mentioned,
especially, that there is a conventional and tacit rule in Japan that the cost of the project should be paid or organized by the project proposer. Under this convention, no operator would propose the project. Another reason is the investment risk for railway operators. Even though an operator might earn the net profit by the project, the cost may be too large for private company to pay compared to its financial scale. Fifthly, we should consider the impact on the local people around the improved station. When the stations are located apart from each other, many shops usually open business. If we would improve the transfer by such as the case project, they may lose their potential customers. Actually, some transfer improvement projects in the Tokyo Metropolitan Area have been opposed by many sectors, especially shop owners. For achieving a consensus, we should add on to transfer improvement projects, for example including a revitalization of station surroundings.

We can find many difficulties in realizing the project, even if the social benefit is high and the rail operator's total net profit is positive. To proceed with more improvement of transfer at railway stations, we need to discuss the following:

- Development of a plan-led system for the public transport planning: we should construct a systematic transport planning system in which an macro level plan covers an arrangement of welfare or benefit among areas, people, sectors, etc. In the system, the railway plan should also be set and its impact should be considered by the macro level plan.

- Better decision process for consensus-building: we should improve the decision making process in which there is more opportunity for related stakeholders to say more and discuss more openly.

- Introduction of a new payment system: we should discuss, first of all, who are beneficiaries and who are losers in the project. Based on this discussion, we need to seek an appropriate way to redistribute the benefits. For example, it might be possible to install pricing gates at transfer station for transferring passengers by applying a new smart technology.

**CONCLUSIONS**

We suggested the socio-economic evaluation model for improving transfer at railway stations. Then we applied the model to simulate the effect of a transfer improvement project in the Tokyo Metropolitan Area. We successfully evaluated the project by the cost-benefit analysis. Finally, we discussed some issues of the transfer improvement project based on the result of case analysis. From a viewpoint of realization, there may be some difficulties. We need to discuss more how those difficulties can be overcome. Finally, it should be noted that the proposed model covers only railway user's behavior. However, if evaluating the impact of modal shift from automobile to railway, we just add a modal split model to the route choice model. Therefore it can be applied in practical use by improving this component of the model.
APPENDIXES

The observed data and the formulas of the transfer flow model are shown as from Fig.A-1 to Fig.A-4.

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REFERENCES