Impact Analysis of Toll Policy for Expressway to Variable Traffic Demand for Local City with Integrated User Equilibrium Assignment Model

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Abstract: The reconfigure of expressway toll system is discussed from the view of economic effect to the local area recently. It is the purpose of the present study that the impact to the traffic demand and the traffic flow in the local city are estimated quantitatively for the proper evaluation of the toll policy. Therefore, the integrated user equilibrium assignment model is proposed for impact analysis of toll policy on expressway to local city. The demand function between the objective area and the outside area estimated considering with base site. The demand functions are integrated to the user equilibrium assignment model with variable demand. Finally, the traffic demand for the typical toll policies can be estimated and the impact to the traffic flow in the objective area can be analyzed with the proposed model.

Keywords: expressway toll, user equilibrium assignment, travel demand function, local city

1. INTRODUCTION

The reconfigure of expressway toll system is discussed from the view of economic effect to local cities recently. In particular, as toll policies might change the traffic demand of the expressway, not only the toll revenue but also the demand of the public transport is influenced. In the urban area of the Tokushima city and the surrounding cities in Japan are sensible to toll system at the expressway between the Kansai area and the Shikoku-island area. Actually, the traffic demand of the expressway and the streets increased with the special discount in the holiday. Therefore, it is necessary to evaluate the toll policy appropriately with the estimation of the traffic demand on the network of toll roads and streets.

On the other hand, the integrated user equilibrium assignment model has been formulated and applied for impact analysis of expressway toll policy in the previous researches (JSCE, 1998). For example, the traffic demand and the toll revenue in the case of the distance-based toll system on the urban expressway are estimated with the user equilibrium assignment model (Okushima & Akiyama, 2006). Also, the congestion pricing on the existing toll road in the urban area as the second-best is examined by user equilibrium assignment model with variable demand (Akiyama et. al., 2004). Furthermore, the integrated traffic equilibrium assignment model considering with trip chain has developed for the evaluation of the congestion pricing policy (Maruyama & Harata, 2006).

The traffic demand for the toll policy on the intercity expressway should be estimated with the integrated user equilibrium assignment model for the large area network. However, the traffic demand in the outside area as well as the traffic flow in the objective local area should be estimated integrally for the impact analysis of the toll policy on the intercity expressway.
The travel demand of visitors from the outside area is discussed for the revitalization of local cities. However, the travel demand is not classified under the activity base in the previous research (Hori & Okushima, 2012).

In the present study, it is aimed that the traffic demand and the traffic flow in the local city are estimated with the traffic assignment model for the proper evaluation of the toll policy. Therefore, the integrated equilibrium assignment model including not only the transport modal split models for residents but also the traffic demand functions for visitors is developed for impact analysis of toll policy on expressway to local city. The traffic demand function between the objective area and the outside area estimated considering with base site. The traffic demand functions are integrated to the user equilibrium assignment model with variable demand. Particularly, the calculation algorithm is proposed considering with round trip chain. Furthermore, the traffic flow in the objective area and the travel demand of visitors from the outside are estimated integrally with the proposed user equilibrium assignment model.

2. THE INTEGRATED USER EQUILIBRIUM ASSIGNMENT MODEL

The integrated user equilibrium assignment model with the traffic demand functions for visitors is constructed in the chapter.

2.1 Construction of the User Equilibrium Assignment Model with Variable Demand

The proposed equilibrium assignment model consists of not only the user equilibrium traffic assignment model but also the transport modal split model for the inner trip in the objective area and the traffic demand functions between the objective area and the outside area.

The market equilibrium flows on the network is equivalent to the user equilibrium in traffic assignment. The demand function is defined as follow,

\[ q_{rs} = D_{rs}(C^*_{rs}) \]

where,

\[ q_{rs} \]: Traffic demand for O-D pair r-s,

\[ C^*_{rs} \]: Minimum travel cost on the road network between O-D pair r-s,

\[ D_{rs}(\cdot) \]: Demand function for O-D pair r-s.

As private marginal benefit of trip from r to s is given by inverse demand function, \( D_{rs}^{-1}(q_{rs}) \), the following equation is established.

\[ C^*_{rs} = D_{rs}^{-1}(q_{rs}) \quad \text{for} \quad q_{rs} \geq 0 \]  \hspace{1cm} (2)

It is assumed that trip makers choose the route so as to minimize the trip cost as follows,

\[ C^*_{rs} = \min_k c^k_{rs} \]

\[ c^k_{rs} \]: Travel cost of path k on the road network between O-D pair r-s.

The travel cost for path k is calculated as the sum of travel cost for the links on the path k as follow,

\[ c^k_{rs} = \sum_a \delta^k_{a,rs} c_a(x_a) \]

where,

\[ x_a \]: Traffic flow volume for link a.
\( c_a(x_a) \): travel cost for link \( a \),

\( \delta_{a,rs}^k \): Dummy valuable of the link \( a \) on the path \( k \) for O-D pair \( r-s \).

The equivalent mathematics optimization problem for user equilibrium situation with variable demand has been formulated by Beckmann et al. (1956) as follow,

\[
\begin{align*}
\min Z &= \sum_a \int_0^{\infty} c_a(w)dw - \sum_{rs} \int_0^{\infty} D_{rs}^{-1}(w)dw \\
\text{subject to} \quad & q_{rs} = \sum_k f_{rs}^k \\
& f_{rs}^k \geq 0, \quad \forall k \in K_{rs} \\
& x_a = \sum_{rs} \sum_k \delta_{a,rs}^k f_{rs}^k \\
& q_{rs} \geq 0
\end{align*}
\]

where,

\( K_{rs} \): The set of all routes between O-D pair \( r-s \),

\( f_{rs}^k \): Traffic flow on the route \( k \).

Link cost is defined as the sum of toll and time cost as follow,

\[
c_a(x_a) = \xi \cdot t_a(x_a) + \pi_a
\]

where,

\( \pi_a \): Toll for link \( a \),

\( \xi \): Value of time.

The travel time \( t_a \) of link \( a \) is determined as the BPR function corresponding to free-flow travel time, link flow and traffic capacity.

\[
t_a(x_a) = t_a^0 \left[ 1 + \alpha \left( \frac{x_a}{Q_a} \right)^\beta \right]
\]

where,

\( t_a(x_a) \): Travel time functions for link \( a \),

\( t_a^0 \): Travel time for zero flow of link \( a \),

\( Q_a \): Traffic capacity for link \( a \).

The demand function can be defined according to O-D pair \( r-s \). The demand functions in the present study are described separately in the inside and the outside. Furthermore, the demand function can be defined according to the category of trip as well as the O-D pair \( r-s \) as follows,

\[
q_{rs,m} = D_{in,rs,m}\left( \frac{C_{rs}^m}{r} \right) \quad \text{if} \quad rs \in \Omega_{Area}
\]

\[
q_{rs,l} = D_{out,rs,l}\left( \frac{C_{rs}^l}{r} \right) \quad \text{if} \quad rs \notin \Omega_{Area}
\]

where,

\( \Omega_{Area} \): the set between origin-destination pair in the objective area,

\( D_{in,rs,m}(\cdot) \): The demand function in the objective area for category \( m \),

\( D_{out,rs,l}(\cdot) \): The demand function between the objective area and the outside area for category \( l \).

Therefore, the objective function of the equivalent mathematics optimization problem for
user equilibrium situation with variable demand can be formulated as follow,

\[
\min Z = \sum_{m,s,t} \int_{\Omega} c_a(w)dw - \sum_{m,s,t} \sum_{t}^{n_{rs}} D_{in,rs,m}^{-1}(w)dw - \sum_{m,s,t} \sum_{t}^{n_{rs}} D_{in,rs,m}^{-1}(w)dw
\] (14)

The demand for transport mode according to the purpose of trip has been observed with the person trip survey in the target area. Therefore, the transport modal split on the inside of the objective area is described with the binary logit model according to the purpose of trip in the present study as follow;

\[
D_{in,rs,m}^C = \frac{\bar{q}_{rs,m}}{1 + \exp(\theta_{rs,m} - V_{rs,m}^C)} \quad \text{if } rs \in \Omega_{Area}
\] (15)

\[
V_{rs,m}^C = \theta_{c,m} C_{rs}^* + \sum_j \theta_{j,m} h_{rs,j}
\] (16)

\[
V_{rs,m}^P = \theta_{c,m} C_{rs}^{Pub} + \sum_j \theta_{j,m} h_{rs,j}
\] (17)

where,

\( \bar{q}_{rs,m} \): Travel demand of purpose \( m \) between O-D pair \( r-s \) in the objective area,

\( q_{rs,m} \): Travel demand for car of purpose \( m \) in the objective area,

\( V_{rs,m}^C \): Deterministic components of utility for car,

\( V_{rs,m}^P \): Deterministic components of utility for public transport,

\( C_{rs}^* \): Minimum travel cost on the road network between O-D pair \( r-s \),

\( C_{rs,m}^{Pub} \): Travel cost of public transport between O-D pair \( r-s \),

\( h_{rs,j} \): Index of factor \( j \) between O-D pair \( r-s \),

\( \theta_{c,m} \): Coefficient parameter of travel cost for purpose \( m \),

\( \theta_{j,m} \): Coefficient parameter of factor \( k \) between O-D pair \( r-s \) for purpose \( m \).

Travel demand is measured by passenger car unit (PCU). Average number of person in a car is observed as 1.1 trips per vehicle with the person trip survey.

The inverse demand functions of purpose \( m \) between O-D pair \( r-s \) in the objective area can be described in reference to the previous researches (Sheffi, 1985) as follow,

\[
D_{in,rs,m}^{-1}(q_{rs,m}) = \frac{1}{\theta_{c,m}} \ln \frac{q_{rs,m}}{q_{rs,m} - q_{rs,m}} + \frac{V_{rs,m}^{Pub}}{\theta_{c,m}} \quad \text{if } rs \in \Omega_{Area}
\] (18)

On the other hand, traffic demand between the objective area and the outside area is estimated considering with trip chain in the study. In terms of the modeling, the user equilibrium assignment model considering with trip chain has been developed (Maruyama & Harata, 2006).

In the present research, it is assumed that the trip chain between the objective area and the outside area can be considered as a piston type only. Furthermore, traffic demand between OD pair \( r-s \) are assuming to be same as OD pair \( s-r \). Therefore, traffic demand for round trip according to the category \( l \) is determined with travel cost for round trip as follow,

\[
q_{rs,l} = q_{sr,l} = D_{out,rs,l}^{-1}(C_{rs}^* + C_{sr}^*) \quad \text{if } rs \not\in \Omega_{Area}
\] (19)

The traffic demand functions in the research are explained in the next section.

As the result, the objective function of the equivalent mathematics optimization problem for user equilibrium situation with variable demand in the present study can be formulated as follow,
\[
\min Z = \xi \sum_{m} \sum_{a} \int_{0}^{x_{m}} f_{a}(w)dw + \sum_{m} \sum_{r} \int_{0}^{\bar{q}_{r,m}} D_{out,r,m}^{-1}(w)dw
\]
\[
+ \sum_{r} \sum_{m} \int_{0}^{\bar{q}_{r,m}} \left( \frac{1}{\theta_{c,m}} \ln \left( \frac{w}{\bar{q}_{r,m}} \right) - w \right) dw - \sum_{r} \sum_{m} \hat{q}_{r,m} \frac{I_{r,\text{Pub}}}{\theta_{c,m}}
\]

where,
\[
\hat{q}_{r,m} : \text{Travel demand for public transport of purpose } m \text{ in the objective area.}
\]

2.2 Calculation Algorithm for the Equivalent Mathematics Optimization Problem

The flowchart of the calculation algorithm for the equivalent mathematics optimization problem in the present study is shown in the Figure 1.

![Flowchart](Figure 1. Flowchart for the estimation of the traffic demand and the traffic flow)

The calculation process is similar to the Frank-Wolfe algorithm for the user equilibrium assignment model with variable demands. The calculation steps for the proposed model can be described as follows;
[1] Update of the travel cost for links

The travel cost of link at the calculation cycle \( n \) is determined as follow,

\[
c_{a}^{[n]} = \xi \cdot t_{a}^{(x_{a}^{[n]})} + \pi_{a}
\]

where,

\( c_{a}^{[n]} \): Travel cost of link \( a \) at the calculation cycle \( n \),

\( x_{a}^{[n]} \): Flow volume of link \( a \) at the calculation cycle \( n \).

[2] Route search for minimum cost

Minimum travel cost the road network between OD pair \( r-s \) is estimated with the Dijkstra’s algorithm. As the result of route search, minimum travel cost is calculated as the sum of travel cost for the links on the minimum path as follow,

\[
c_{rs}^{[n]} = \sum_{\delta a,rs} c_{a}^{[n]} + \sum_{\delta rs a} c_{a}^{[n]}
\]

where,

\( c_{rs}^{[n]} \): Minimum travel cost between O-D pair \( r-s \) at the calculation cycle \( n \),

\( \delta a,rs \): Dummy valuable of the link \( a \) for O-D pair \( r-s \) at the calculation cycle \( n \).

[3] Modal split in the objective area

The auxiliary variable of traffic demand on the inside of the objective area is calculated with the binary logit model according to the purpose of trip as follow,

\[
v_{in,rs,m} = D_{in,rs,m} \left( c_{rs}^{[n]} \right) \quad \text{if} \quad rs \in \Omega_{area}
\]

where,

\( v_{in,rs,m} \): Auxiliary variable of traffic demand on the inside of the objective area for the purpose \( m \).

[4] Estimation of traffic demand between the objective area and the outside area

The auxiliary variable of traffic demand between the objective area and the outside area is calculated with the demand function as follow,

\[
v_{out,rs,l} = D_{out,rs,l} \left( c_{rs}^{[n]} \right) \quad \text{if} \quad rs \notin \Omega_{area}
\]

where,

\( v_{out,rs,l} \): Auxiliary variable of traffic demand for the category \( l \) between the objective area and the outside area.

[5] All or nothing flow assignment

The auxiliary variable of link flow is estimated with the minimum path and the auxiliary variable of traffic demand as follow,

\[
y_{a} = \sum_{rs \in \Omega_{area}} \sum_{m} \delta a,rs v_{in,rs,m} + \sum_{rs \in \Omega_{area}} \sum_{l} \delta a,rs v_{out,rs,l}
\]

[6] One-dimensional search of the objective function

The objective function is minimized with the optimum step size \( \lambda \) as follow,

\[
\min Z(\lambda) = \xi \sum_{a \in A} t_{a}^{(x_{a}^{[n]})} \pi_{a} - \sum_{rs \in \Omega_{area}} \sum_{l} \delta a,rs v_{out,rs,l}^{[n]} D_{out,rs,l}^{-1} (w)dw + \sum_{rs \in \Omega_{area}} \sum_{m} \delta a,rs v_{in,rs,m}^{[n]} V_{rs,m}^{Pub} \theta_{c,rs,m}
\]

subject to

\[
0 \leq \lambda \leq 1
\]
\[
\begin{align*}
X[n+1]_a &= X[n]_a + \lambda (y_a - X[n]_a) \\
D[n+1]_{rs} &= q[n]_{rs} + \lambda (v_{rs} - q[n]_{rs}) \\
\hat{q}[n+1]_{rs} &= \overline{q}_{rs} - q[n]_{rs}
\end{align*}
\] (28)

(29)

(30)

The traffic demand and the link flow can be estimated at the final calculation step, where the difference of calculation results for the former cycle to the convergence criterion.

### 3. APPLICATION OF THE PROPOSED TRAFFIC ASSIGNMENT MODEL

#### 3.1 The Traffic Demand Functions between the Objective Area and the Outside Area

The traffic demand function between the objective area and the outside area is described in the section. The base site of trip chain is focused on to estimate the traffic demand of visitor to the objective area.

The traffic demand between the objective area and the outside area is observed in the road traffic census survey in Japan (Ministry of Land, Infrastructure, Transport and Tourism, 1999). The mean absolute error of the traffic demand on the outward trip and on homeward trip is 2.06. It is equivalent to 11% of average number of trips. The correlation between the traffic demand on the outward trip and on homeward trip can be calculated as 0.995. Therefore, it is assumed the traffic demand can be estimated as round trip.

The objective area consists of 36 zones. The outside area consists of 4 zones in Tokushima prefecture as well as 45 zones in the other prefecture. The zone size in Tokushima prefecture is smaller than the others. Therefore, the trip chain in Tokushima prefecture is classified as the Group A. On the other hand, the trip chain of resident in the objective area for the other prefecture is classified as the Group B and the trip chain of visitor from the other prefecture to the objective area is classified as the Group C. The traffic demand functions are estimated by every group.

The traffic demand functions are formulated with the gravity model based on the maximum utility theory in reference to the previous studies (Mun et al., 2005):

\[
D_{\text{out,rs,j}}(C_{rs} + C_{sr}) = d_{\text{j}}^\delta \cdot \alpha_i \cdot P_r \cdot P_s^{\beta_j} \cdot \exp(\gamma_j \cdot (C_{rs} + C_{sr}))
\] (31)

where,

- \(r\): base zone, \(s\): activity zone,
- \(\delta_r\): Dummy valuable of the base zone at the outside area in the prefecture,
- \(P_r\): Population of zone \(r\),
- \(P_s\): Population of zone \(s\),
- \(C_{rs}\): Travel cost between O-D pair r-s,
- \(d_{\text{j}}, \alpha_i, \beta_j, \gamma_j\): Parameters of the gravity model for group \(l\).

The parameter \(d_{\text{j}}\) of dummy valuable of the base zone at the outside area in the prefecture is estimated for the group A. However, it is fixed for the group B and the group C as 1.0. The population is observed with the database of the census in Japan (2000). Travel cost is defined as the sum of toll and time cost. The travel time between the objective area and the outside zone in the other prefecture is estimated with the National Integrated Transport Analysis System (NITAS) in Japan. The toll for the expressway is estimated with the national expressway information website. Moreover, the value of time is estimated by the base prefecture with the income approach. For example, the value of time in Tokushima prefecture is 47.7[yen/min].
The parameter of the gravity model is estimated with the non-linear regression analysis. The estimated parameters of traffic demand functions for each group are shown in the Table 1. All parameters are statistically significant. The proposed models are suitable to describe the traffic demand on the whole, since the coefficients of determination are enough.

Table 1. The estimated parameters of the traffic demand functions

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Group A Estimated</th>
<th>t-statistics</th>
<th>Group B Estimated</th>
<th>t-statistics</th>
<th>Group C Estimated</th>
<th>t-statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \alpha )</td>
<td>26.660</td>
<td>3.704</td>
<td>0.034</td>
<td>2.030</td>
<td>9.345</td>
<td>23.989</td>
</tr>
<tr>
<td>( \beta  )</td>
<td>2.744</td>
<td>15.714</td>
<td>2.376</td>
<td>18.405</td>
<td>0.738</td>
<td>22.776</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>-6.088</td>
<td>-10.318</td>
<td>-3.200</td>
<td>-26.000</td>
<td>-1.797</td>
<td>-67.528</td>
</tr>
<tr>
<td>( d )</td>
<td>7.939</td>
<td>5.830</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conditioned determination coefficient:
- Group A: 0.584
- Group B: 0.707
- Group C: 0.679

The traffic demand between the objective area and the outside area in Tokushima prefecture is estimated with the proposed model as shown in the Figure 2.

Figure 2. Estimation result of traffic demand between the objective area and the outside area in Tokushima prefecture
Similarly, the estimated traffic demand of resident in the objective area for the other prefecture is illustrated in the Figure 3.

![Figure 3. The estimated traffic demand of resident for the other prefecture](image)

Furthermore, the estimated traffic demand of visitor from the other prefecture to the objective area for is illustrated in the Figure 4.

![Figure 4. The estimated traffic demand of visitor from the other prefecture](image)

The RMS error is estimated as 694 in the group A, as 19 in the group B and as 28 in the group C, respectively. However, the estimated error can be found in some OD pairs between the outside zone in Tokushima prefecture and the neighbor zone in the objective area. It can be considered that the centroid node of the outside zone in Tokushima prefecture should be reallocated for the improvement of estimated accuracy.
3.2 Verification of the Estimation Result in Case of the Present Toll System

The integrated user equilibrium assignment model is verified with the estimation result in case of the present toll system.

The target network consists of 6752 links and 2751 nodes. The present toll system for the intercity expressway is the distance based toll system. The link flows in case of the present toll system are estimated with the integrated user equilibrium assignment model.

The estimated link flows are compared with the observed link flows in the database of the road traffic census survey in Japan (Ministry of Land, Infrastructure, Transport and Tourism, 1999) as shown in the Figure 5.

![Figure 5. Verification of the Estimation Result of the link flows](image)

The RMS error is estimated as 9554 and the correlation is estimated as 0.892. As the p-value is calculated as 0.21 in the result of the two-sample Kolmogorov-Smirnov test, the estimation result of the link flows is validated statistically. However, the estimated error is larger than ten thousand vehicles in some links on the Route 192 in the central area of Tokushima city. Therefore, the zone size and the allocation of the centroid nodes should be reconsidered around the Route 192 corresponding to the road network for the improvement of the estimated accuracy.

4. IMPACT ANALYSIS OF TOLL POLICY FOR EXPRESSWAY

Impact of the toll policy to the target city is analyzed with the integrated user equilibrium assignment model in the chapter. The no-toll system and the distance based toll system with the upper bound are focused on as the typical toll policy for expressway. The upper bound such as 2,000 yen is introduced into the current toll system.

4.1 Evaluation of the Toll Policies with the Social Benefit
The traffic demands and the link flows in case of the no-toll system as well as in case of the upper bound toll system are estimated with the integrated user equilibrium assignment model.

The current toll system for the intercity expressway is the distance based toll system. The basic amount of rate on the current toll system is calculated as the sum of the on-ramp charge 150 yen and the product of the unit price 24.6 yen/km and the traffic distance on the expressway. However, the toll system for routes including sections passing over the straits is different from the basis toll system. For example, the amount of toll for the Kobe-Awaji-Naruto expressway had been set at 5,450 yen for the traffic distance 89 km. It is considerably higher than the basic toll.

The level of the current rate in Japan is higher than other countries. The unit price of the distance based toll for passenger car is less than 10 yen/km in not only eastern Asia such as China or Korea but also southern Europe such as Italy or Portugal. Moreover, the highways except high occupancy toll lane are available free for passenger car in the United States. The distance based toll for only heavy freight vehicle is applied on the autobahn in German.

The no-toll system and the upper bound toll system are regarded as discount toll for the present toll system. Since the travel costs with these toll systems are decreased, it is expected that the traffic demands are increased. These discount toll system were proposed by the Japanese government to break off the stagnation of economic activities by the promotion of the travel between the cities. The discount of the toll for the long-distance travel with the upper bound toll system is expected to promote the traffic between the cities of the wide area. The upper bound toll is set to 2000 yen at the maximum in reference to the suggestion of the Japanese government. The estimated traffic demands in the objective area as well as between the objective area and the outside area are summarized in the Table 2.

### Table 2. Estimation result of the traffic demand

<table>
<thead>
<tr>
<th>Traffic demand between the objective area and the outside area</th>
<th>Present toll system</th>
<th>No-toll</th>
<th>Maximum 2000 yen</th>
</tr>
</thead>
<tbody>
<tr>
<td>[A] From the objective area to the inside the prefecture</td>
<td>55,847</td>
<td>67,363</td>
<td>61,441</td>
</tr>
<tr>
<td></td>
<td>(+11,516)</td>
<td>(+5,594)</td>
<td></td>
</tr>
<tr>
<td>[B] From the objective area to the outside area</td>
<td>8,270</td>
<td>92,422</td>
<td>40,689</td>
</tr>
<tr>
<td></td>
<td>(+84,152)</td>
<td>(+32,419)</td>
<td></td>
</tr>
<tr>
<td>[C] From the outside area to the objective area</td>
<td>14,256</td>
<td>53,567</td>
<td>34,304</td>
</tr>
<tr>
<td></td>
<td>(+39,311)</td>
<td>(+20,048)</td>
<td></td>
</tr>
<tr>
<td>[D] subtotal=(A)+(B)+(C)</td>
<td>78,373</td>
<td>213,352</td>
<td>136,434</td>
</tr>
<tr>
<td></td>
<td>(+134,979)</td>
<td>(+58,061)</td>
<td></td>
</tr>
</tbody>
</table>

The estimated traffic demands in the objective area with the toll policies are the almost same as the present toll system. On the other hand, the increase of [D] the traffic demand between the objective area and the outside area is estimated as 135 thousand vehicles with the no-toll, and as 58 thousand vehicles with the upper bound toll. Considering with base site, [B] the traffic demand of resident from the objective area to the outside area is increased in 84 thousand vehicles with the no-toll and 39 thousand vehicles with the upper bound toll. On the contrary, the increase of [C] the traffic demand of visitor from the outside area to the objective area is estimated as 39 thousand vehicles with the no-toll and 20 thousand vehicles with the upper bound toll. However, the increase of the traffic demand from the outside area is almost...
equivalent to half of the increase to the outside area.

The evaluation indexes as the estimation result are summarized in the Table 3. The total travel time with the no-toll is larger than with the present toll for 306 thousand hours, and for 123 thousand hours with the upper bound toll according to the increase of the traffic demand.

<table>
<thead>
<tr>
<th>Expressway toll</th>
<th>Present toll system</th>
<th>No-toll</th>
<th>Maximum 2000 yen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic demand (hundred)</td>
<td>5,231</td>
<td>6,575</td>
<td>5,810</td>
</tr>
<tr>
<td>Travel time (hundred)</td>
<td>1,945</td>
<td>5,003</td>
<td>3,179</td>
</tr>
<tr>
<td>User benefit (ten-thousand-yen)</td>
<td>—</td>
<td>44,191</td>
<td>14,154</td>
</tr>
<tr>
<td>Social benefit (ten-thousand-yen)</td>
<td>—</td>
<td>36,829</td>
<td>22,735</td>
</tr>
<tr>
<td>Fare receipts (ten-thousand-yen)</td>
<td>7,362</td>
<td>0</td>
<td>15,942</td>
</tr>
</tbody>
</table>

On the other hand, these toll policies have some advantages for present toll system from the viewpoint of not only the user benefit but also the social benefit. The user benefit includes the decrease of toll payment. The social benefit is calculated as the sum of the user benefit and the increase of toll payment. The user benefit of the resident to the other prefectures is significantly increased with the toll policies. Furthermore, the amount of the toll in case of the upper bound toll is larger than the present toll system. Therefore, it is suggested that the relevant toll discount is effective for the management of the expressway. However, the estimation result depends on the demand functions. Therefore, it should be verified comparing with the traffic demand on the social experiment for the toll policy.

4.2 Impact Analysis with the Regional Index

The impact of the toll policy for the intercity expressway is analyzed with the regional index. The increase of the estimated link flow with the no-toll is illustrated corresponding to the road network in the Figure 6.

In case of the no-toll system, the link flows are significantly increased not only on the expressways but also on the trunk streets according to the toll discount. It can be found that the increase of the traffic demand for the expressway influences to the link flows on the trunk street for the access to the expressway.
Moreover, the increase of the estimated link flow with the upper bound toll is illustrated in the Figure 7. Though the link flows on the expressways and on the trunk streets in case of the upper bound toll system are increased, these are smaller than in case of the no-toll system.

Furthermore, the traffic demand is analyzed according to the travel cost of each OD pair.
The distribution for the difference of the traffic demand comparing with the case of the present toll is illustrated corresponding to the difference of the travel cost in the Figure 8. The difference of the traffic demand is larger on the range of travel cost from -4,000 yen to -8,000 yen with the no-toll, and from -2,000 yen to -6,000 yen with the upper bound toll. The OD pairs through the Kobe-Awaji-Naruto Expressway are included in the remarkable range.

5. Concluding Remarks

In the present study, the user equilibrium assignment model with variable demand is developed for impact analysis of toll policy for intercity expressway to local city. The summary of findings of the study is as follows:
1) The traffic demand between the objective area and the outside area are described as round trip considering with base site in the traffic demand function as the gravity model. The parameters of the traffic demand functions are estimated with the road traffic census survey. It is verified that the proposed traffic demand functions can be applied to the estimation.
2) The proposed traffic demand functions are integrated to the user equilibrium assignment model. The calculation algorithm for the equivalent mathematics optimization problem is developed based on the Frank-Wolfe algorithm. The error of the estimated links flow in case of the present toll system with the integrated traffic assignment model is less than
10 thousands vehicles compared with the observed link flows as well as the correlation is high. Therefore, the integrated model can be applied to estimate the traffic demand and the link flows on the real road network which includes the intercity expressways.

3) The traffic demands and the link flows with typical toll policies on the intercity expressway can be estimated with the integrated user equilibrium assignment model. Moreover, the impact to the traffic flow in the objective area can be analyzed with the proposed model. The total travel time with the discount toll is larger than the present toll according to the increase of the traffic demand. On the other hand, it is suggested that the relevant toll discount is effective for the management of the expressway.

For further study, the travel time on the link in the outside area should be estimated adequately and the centroid nodes in the prefecture should be reallocated for the improvement of estimated accuracy.

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