DEVELOPMENT OF COMBINED MODAL SPLIT/ TRAFFIC ASSIGNMENT MODEL WITH FUZZY LOGIC

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Abstract: This study discusses a combined model of modal split and traffic assignment, in which the interaction between transit vehicles and the general traffic is modeled explicitly. In other presented integrated models, the logit model is often used. However, in some uncertain cases, the logit model cannot represent traffic choice behavior as precise as fuzzy model can. Therefore, fuzzy reasoning is applied in this combined model. This combined model provides more detailed descriptions for regarding urban traffic conditions.

Keywords: fuzzy mode choice, combined model, congestion pricing.

1. INTRODUCTION

In the field of traffic demand management, many types of transport policies have been proposed. Therefore, a precise evaluation method of an urban transport system should be required to produce the most efficient traffic conditions. In particular, the combined model as traffic assignment with modal choice could often be applied to estimate traffic flows in terms of user equilibrium condition. This study aims at developing combined model of traffic assignment and modal split that using fuzzy logic formulation. Since modal share and traffic flow on urban network can be estimated with integrated model, the impact of transport might be measured with traffic demand change. The logit-based modal choice model is usually introduced in standard formulation. However, the mixed mode trips may not be described properly with the single function model because many uncertain factors can be observed in real decision of trip maker. The main purpose of this study is developing the integrated traffic assignment model with modal choice using fuzzy logic representation. Fuzzy reasoning would be applied to produce the modal choice model in the study. The human perception in modal choice is rather easily described with fuzzy logic such as travel time. The integration between traffic assignment and fuzzy logic based modal choice model can be discussed. As fuzzy reasoning can be regarded as a highly non-linear model to describe human
decision, the calibration of the integrated model should be considered. The estimation algorithm is proposed with reference to the approximation method.

Firstly, for the purpose of representing the human perception as precisely as possible, the most specific feature of fuzzy logic – the fuzzy value, can be expected to be influential. Therefore, fuzzy reasoning would be applied to produce the modal choice model in this study. As many researches have been reported relating to the description of travel behavior using fuzzy logic, one more advantage feature of fuzzy logic – flexibility is also powerful point to consider among the many factors in the real mode decision. Human perception in modal choice is rather easily described by fuzzy logic such as travel time, travel cost, comport and so on. Realistic modal choice model can be created using fuzzy logic formulation.

Secondly, the integration between traffic assignment and fuzzy logic based on a modal choice model can be discussed. As fuzzy reasoning can be regarded as a highly non-linear model to describe human decisions, the calibration of the integrated model needs to be considered. The primitive integrated model with fuzzy logic can be discussed through this process. Furthermore, it should be mentioned that different types of fuzzy reasoning could be applied in the same model structure.

Thirdly, the practical application of the proposed model is mentioned. The scheme of congestion pricing is considered as an example of urban transport policy with consideration to the real network. Comparing it to the standard type of combined model can summarize the advantage of the proposed model in estimation. The applicability of fuzzy logic based model is provided with the evaluation results for the impact on congestion pricing policy. In particular, the value of time in human decision is discussed quite obviously.

Finally, it could be concluded that fuzzy logic based model provides precise estimation of urban traffic along with a description of human perception. As the impact of transport policy can be evaluated properly, it may provide efficient options for urban traffic demand management.

2. THE FORMULATION OF THE COMBINED MODEL WITH FUZZY LOGIC

2.1 The background of the combined modal split / traffic assignment model

This chapter discusses modal split and traffic assignment models, in which the interaction between transit vehicles and the general traffic is modeled explicitly. This section also analyzes a problem of determining simultaneously the equilibrium flows over an automobile network and a transit network. At this point it is still assumed that the transit links and the automobile links are independent of each other (in term of the effects of flow on travel time).

One of supposed solution for the combined model is that the basic network is augmented with virtual (dummy) links to represent several choice dimensions. Such augmented networks are referred as Super-network (Sheffi, 1985). In the study, the combined model is solved by directly using the below mathematical formulation.

In representation the network, the origin and destination centroid nodes are common to both the automobile and the transit networks.

General formulation is well known as follows:

$$\min Z(x, x^{\text{tran}}, q^{\text{tran}}) = \sum_{a \in A} \int_{0}^{\infty} t_a(w)dw + \sum_{r \in R} \sum_{s \in S} \int_{0}^{\infty} \left( \frac{1}{\theta} \ln \frac{\omega}{q_{rs} - \omega} + C_{rs}^{\text{tran}} \right) d\omega$$

subject to
\[ \sum_k f_{krs}^r = q_{rs} - q_{rs}^{\text{tran}} \quad \forall r, s \]  
\[ f_{lrs}^r, f_{krs}^r \geq 0 \quad \forall k, l, r, s \]

where \( C_{rs}^{\text{tran}} \) is constant which captures the effects of all factors other than the travel time difference on the modal split.

### 2.2 The modal split model with fuzzy logic

#### 2.2.1 Fuzzy logic

The basic of fuzzy reasoning can be summarized as follows (Akiyama and Sasaki, 1988). Fuzzy reasoning is an application of fuzzy sets theory to ordinary reasoning. In the description of fuzzy reasoning, fuzzy relations should be considered. The fuzzy relation \( R \) between \( A \in X \) and \( B \in Y \) is a fuzzy subset on \( X \times Y \) defined as follows:

\[ R = \int_{X \times Y} \mu_{R}(x, y) / (x, y) \]  

The generalization of the concept of “relation” is defined on ordinary subsets. Considering fuzzy reasoning, the composition between \( A \) and \( R \) must be defined:

\[ A \circ R = \int_{Y} \sup_{y} [\mu_{A}(x) \wedge \mu_{R}(x, y)] / y \]  

Where \( R \) is the fuzzy logical relation between \( A \) and \( B \). In the fuzzy reasoning field, the implication such as “IF \( x \) is \( A \) then \( y \) is \( B \)” is described by \( \mu_{R}(x, y) \) as \( R \).

Therefore, \( R \) is conceived to be a human judgment result of state “\( y \) is \( B \)” from the condition “\( x \) is \( A \)” in the fuzzy circumstances. Once the structure of \( R \) is determined, the distribution that shows “\( y \) is \( B' \)” obtained from the input “\( x \) is \( A' \)” as follow:

\[ B' = \int_{Y} \sup_{y} [\mu_{A'}(x) \wedge \mu_{R}(x, y)] / y \]  

The fuzzy reasoning process is summarized that the value of truth for the premise of each rule is computed and applied to the conclusion part of each rule. As the process can be formulated in equation (2c), the fuzzy relation might have an important function to the reasoning. It corresponds that the implication rule should be determined by the definition of fuzzy relation in equation (2a).

The fundamental fuzzy control method is known as “min-max-gravity” method that Mamdani had proposed in the earlier studies in 1970’s. Since the “min-max-gravity” method is a primitive application of fuzzy reasoning to controller, many applications have been proposed in the practical fields.

In this study, the “min-max-gravity” method is applied for computing the mode shares.

#### 2.2.2 The modal split model with fuzzy logic

The purpose of modal split step is to determine the share of traffic of vehicle and Public transportation means in urban area. There are many formulations and methods were supposed to finding the share of mass transit and car on the network. One of the most well-known model that called “Logit model” is often used.
This is a sort of nonlinear function model that based on random utility theory. In this formulation, the share of mass transit between the OD pair (r-s) is determined by the general cost of mass transit \( C_{rs}^{\text{Transit}} \) and general cost of car \( C_{rs} \). In reality, the phenomena of mode choice are much more complicated. In the purpose of represent the human mode choice as precisely as possible, the fuzzy technique is applied. Particularly, the linguistic variables are really useful in representation human behavior in mode choice.

The travel time difference implies the difference of travel time of public transportation mean travel time from that of car in each OD pair. When the time difference changes, how the share changes? This is one of purposes of this model. In general fuzzy sets enable to model human oriented systems more realistically by allowing the use of linguistic descriptors, phrases, and modifiers (Zadeh, 1973). The travel time difference is recognized as a fuzzy number with subjective width in fuzzy traffic assignment models.

The outline of the triangular fuzzy number for each link travel time is illustrated in Figure 1. Figure 1 presents an example of a fuzzy number with a triangular membership function corresponding to the label “travel time difference is medium”.

![Figure 1. Description of fuzzy travel time difference](image)

\[
\Delta T = C_{rs}^{\text{Transit}} - C_{rs}
\]  

where \( \Delta T \) is the time difference on each OD pair, \( C_{rs}^{\text{Transit}} \) is mass transit travel time, \( C_{rs} \) is Car travel time are denoted.

As mentioned earlier, when attempting to represent a mode choice model that considers about human behavior, the fuzzy reasoning is applied. Here are three simple rules that used in this model:

**Rule 1:** If \( \Delta T \) is big, then \( P_{\text{Transit}} \) is big.

**Rule 2:** If \( \Delta T \) is medium, then \( P_{\text{Transit}} \) is medium.

**Rule 3:** If \( \Delta T \) is small, then \( P_{\text{Transit}} \) is small.

![Figure 2. Rules set](image)
Here, in each OD pair, the value of the linguistic variable “big”, “medium” and “small” will be defined. Each membership function of linguistic variable is summarized in figure 3.

![Membership function](image1)

Figure 3. Membership function

Each OD pair has a range of travel time difference, the ranges of some representative OD pairs is listed in table 2. Figure 3 shows us the membership function of an OD pair and (-30, 30) is the range of travel time difference for the objective OD pair. In this description, the travel time difference is a crisp value. This is also the medium rule in fuzzy rule sets that supposed in this model.

![Share of Mass Transit](image2)

Figure 4. The share of mass transit

Figure 4 presents the change of mass transit’s share and the time difference in one OD pair, assume that the range of travel time difference is (-20, 20). The results obtained from both models, logit mode choice model and Fuzzy mode choice model are shown in the figure, the share of mass transit share computed by logit mode choice model changes rapidly when the absolute value of travel time difference is small, in contrast to that computed by Fuzzy mode choice model. In logic model, when the time difference of one OD pair approximates to the range limit of that OD pair, the share of the model that have longer travel time becomes 0. Abstract to that of fuzzy model, although the time difference of one OD pair approximates to the maximum value of the time difference, the share of the mode that have longer travel time still appreciable. This result is near the reality than that of logic model.

In this step of the study, the modal split model is based on the time difference only, this do not describe the reality of human daily mode choice closely. In the next step of study, the modal split model should be improved. Some other uncertain factors will be taken into account.

This study proposes a combined traffic assignment model with fuzzy mode choice model and compare to combined traffic assignment model with logit mode choice model.
3 THE ANALYSIS OF URBAN NETWORK WITH THE COMBINED MODEL

3.1 Representation of the urban network

In this study, the urban network of Gifu city is chosen as target network. There are 34 nodes, 100 links, 20 zones in the network. The river Nagara cross the city as figured. The target network is figured in figure 5. There are many nodes in the same zone, but each zone has only one generative node as shown in table 1. The zone number 2 is the Yanagase area. The center area concludes zone number 1, 2, 5, 6.

Table 1. Zone and Centroid

<table>
<thead>
<tr>
<th>Zone</th>
<th>Centroid</th>
<th>Zone</th>
<th>Centroid</th>
<th>Zone</th>
<th>Centroid</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>8</td>
<td>23</td>
<td>15</td>
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<td>21</td>
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<td>2</td>
<td>10</td>
<td>18</td>
<td>17</td>
<td>29</td>
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<td>18</td>
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<td>7</td>
<td>19</td>
<td>14</td>
<td>26</td>
<td></td>
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</tr>
</tbody>
</table>

The data of OD volume that used in this application is the CHUKYO area person trip survey in 1999. The traffic volume is the medium traffic volume of weekdays.

Figure 5. The objective network – the urban network of Gifu city
3.2 Construction of the modal split model with fuzzy logic

For each OD pair, the time different ($\Delta T$) between mass transit travel time and car travel time of iteration number $n$ will be calculated by the combine modal in loop number $n-1$, until the UE condition is met. For each OD pair, the range is defined before hand, and they are listed in table 3. Because it becomes too long to list the ranges of all the OD pairs in the network, in the table, only some representative OD pairs generated from origin zone 1, 11 are listed.

Table 2. Zone pairs and ranges

<table>
<thead>
<tr>
<th>Origin Zone</th>
<th>Destination Zone</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>40</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>40</td>
</tr>
<tr>
<td>...</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>11</td>
<td>7</td>
<td>60</td>
</tr>
<tr>
<td>11</td>
<td>8</td>
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<td>11</td>
<td>9</td>
<td>30</td>
</tr>
<tr>
<td>11</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>

As mentioned above, shares of Car and mass transit will be estimated by modal split with fuzzy reasoning, in this section, the “Min – Max – Gravity” method is applied. The method is simply represented as figure 6. For example, in this figure, the range of one OD pair is defined as 20 minutes, the time different is 6 minutes, the share of Car is 63% and share of mass transit is 27%.

![Figure 6. The “Min – Max- Gravity” method](image-url)

3.3 Estimation results by applying the proposed model

The results of travel flows and travel times on the network computed by the proposed combined model are figured in figure 7, 8. Because there are so many OD pairs (400) on the network, therefore only the travel flows and travel times that have the generative node in the two centers zone 1,2 are listed here.

In almost areas, specially in the center of Gifu, the traffic congestion often occurs, the vehicle users are more than that of mass transit.
The results were already checked and the network met the User Equilibrium condition. The figure 9 shows the change of vehicle share as iteration grows. The program automatically stops as the convergence met.

![Figure 9. Vehicle share on computing progress](image)

### 3.4 Evaluation of the combined model with fuzzy logic

Table 3 Evaluation of the Modal Split with Fuzzy reasoning model

<table>
<thead>
<tr>
<th>O</th>
<th>D</th>
<th>Original data</th>
<th>Car share by Fuzzy</th>
<th>Car share by Logit</th>
<th>Evaluation by Fuzzy</th>
<th>Evaluation by Logit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>0.668</td>
<td>0.425</td>
<td>0.502</td>
<td>-36%</td>
<td>-25%</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>0.711</td>
<td>0.438</td>
<td>0.498</td>
<td>-38%</td>
<td>-30%</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>0.803</td>
<td>0.459</td>
<td>0.494</td>
<td>-43%</td>
<td>-38%</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>0.790</td>
<td>0.453</td>
<td>0.378</td>
<td>-43%</td>
<td>-52%</td>
</tr>
<tr>
<td>11</td>
<td>7</td>
<td>0.533</td>
<td>0.471</td>
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<td></td>
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<td>11</td>
<td>8</td>
<td>0.543</td>
<td>0.473</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>9</td>
<td>0.978</td>
<td>0.543</td>
<td>0.483</td>
<td>-44%</td>
<td>-51%</td>
</tr>
<tr>
<td>11</td>
<td>10</td>
<td>0.899</td>
<td>0.395</td>
<td>0.335</td>
<td>-56%</td>
<td>-63%</td>
</tr>
</tbody>
</table>

The shares of mass transit and car on each OD pairs are listed in table 3. In the table, it may become too long to list all share in this paper, only the shares of some representative OD pairs are listed. As we can observe from the table, the shares that were computed by modal choice model with fuzzy reasoning are closer to the real shares (original data) on the network than that calculated by the logit model. In almost OD pairs, the proposed model with fuzzy logic is leading to the better results. For example, in OD pair...
(11, -9) the share of car that calculated by fuzzy mode choice model is 0.543 compare to that of logit model choice model is 0.483. This is evaluated by compare to 0.978 (the real mode share of the OD pair). The result computed by fuzzy mode share model is near the real data than that of logit mode share model, -44% compare to -51%.

As we can observe in the figures 4, the figure describes the share of mass transit that obtained from ‘The combined modal split/ traffic assignment model’ in both ways, ‘with logit model “and ‘with Fuzzy logic model’. Comparison of the proposed model to the normal combined modal split/ traffic assignment modal:

Normal combined modal split and traffic assignment model: in figure 4, the share line of the logit formulation is strictly symmetrical. The shares of mass transit (so does that of vehicle) are changing symmetrically and strictly in mathematical way. The share of mass transit in case of $\Delta T = \{-20,-15,-10,-5\}$ equals those of vehicle in case of $\Delta T = \{-20,-15,-10,-5\}$. In reality, the share of mode is changing complicatedly due to many certain factors and uncertain factors. By reference to the real data of all modes’ share, it can be assumed that the mode share is not symmetrical. This proves that the shares of transportation means in the combined MS/TA model that calculated by logit formula do not describe the human modal choice naturally and the share is changing unnaturally.

The results in table 3 show that results of the modal choice rates calculated by logit formulation are not close to the reality as that of fuzzy logic.

The combined of modal split with fuzzy logic model and traffic assignment model: the share line of the fuzzy logic model in figure 4 is dissymmetrical, the shares of mass transit (so does that of vehicle) are changing naturally. The shares of car in case that $\Delta T$ changing from (-5 , -10) is almost the same, this describe the human psychology in making daily modal choice decision. This can be explained as: In general, people tend to use their own car than public transports. If the travel time by using public transports is a little shorter than that by using their own car, for example, -5 minutes or 10 minutes, in human psychology, they feel almost the same, and may be, this explains why even the $\Delta T$ is different from -5 to -10, the modal choice rates are almost the same. The modal choice rates are rather close to the reality and this was showed by the data in the table 3.

4 THE APPLICATION OF THE COMBINED MODEL WITH FUZZY LOGIC

4.1 The outline of congestion as a transport policy.

Congestion pricing has been discussed as a practical traffic management on urban transport networks, for example, in United Kingdom (The Greater London), in Norway, in Singapore, in Korea (Seoul). Congestion charging is a way of ensuring that those using valuable and congested road space make a financial contribution.

It encourages the use of other modes of transport and is also intended to ensure that, for those who have to use the roads, journey times are quicker and more reliable. The government requires drivers to pay a congestion toll per day if they wish to continue driving into the area applying the congestion pricing during the scheme’s hours of operation.

The application of congestion pricing as a transport policy has some key priorities that is listed as: Reducing traffic congestion, overcoming the backlog of investment on the underground, making radical improvements to bus services across the city, better integration of the national rail system with city’s other transport systems, making the distribution of goods and services in the city more reliable,
sustainable and efficient, increasing the overall capacity of city's transport system, improving journey
time reliability for car users, supporting local transport initiatives, improving the accessibility of city's
transport system, bringing forward new integration initiatives…etc.

Traffic congestion is defined as an external diseconomy on the network in transport economics. It has
been proposed that congestion pricing would be applicable to reduce traffic on the network. This
system calls for a congestion toll to the links on the overall network. However, link-based charging may
not be realized practically because of technical problems. Therefore, cordon congestion pricing should
be considered. The optimal combination of cordon tolls would be determined in order to maximize
social benefit. As the set of cordon congestion tolls is obtained, the evaluation of congestion pricing can
be done in terms of social benefit analysis as well as reduction in traffic congestion.

4.2 The technical consideration in estimation

The traffic assignment can be connected to congestion pricing theoretically. The market equilibrium
flows on the network is equivalent to the user equilibrium (UE) in traffic assignment. The travel cost is
measured by the link performance function \( t_a(w) \). The demand function is defined as \( q_{rs} = D_{rs}(c_{rs}) \).

\[
\min Z_{UE} = \sum_{a \in A} \int_0^{x_a} t_a(w) dw - \sum_{r \in R} \sum_{s \in S} p_{rs}^{\max} \left( \frac{1}{\theta} \ln \left( \frac{w}{q_{rs} - w} \right) + c_{rs}^{\max} \right)dw + \sum_{a \in A} \sigma x_a C 
\]

subject to

\[
\sum_{k \in K} \int_0^{x_a} f_k^{rs} = q_{rs}, \quad \forall r \in R, s \in S \tag{5b}
\]

\[
f_k^{rs} \geq 0, \quad \forall k \in K_{rs}, r \in R, s \in S \tag{5c}
\]

\[
x_a = \sum_{r \in R} \sum_{s \in S} \delta a.k f_k^{rs}, \quad \forall a \in A \tag{5d}
\]

\[
q_{rs} \geq 0, \quad \forall r \in R, s \in S \tag{5e}
\]

\[
\sigma = 1 / 0 \quad \text{Exit/ not exit toll gate for Congestion charging}
\]

where \( x_a \) is flow in link \( a \), link \( a \) is a link in the set \( A \), \( t_a(x_a) \) is link cost function in link \( a \), \( R \) is the
origin node set, \( S \) is destination node set, \( f_k^{rs} \) is flow on path \( k \) that consists OD pair \( rs \). \( \delta \) is
assumed as 1 if link \( a \) belongs to path \( k \) that consist OD pair \( rs \), and 0 otherwise. \( C \) is Congestion toll.

In the formulation 5, the second item is replaced by fuzzy modal split model.

Although, this study does not prove the uniqueness of the solution of the function 5 yet, the reliability of
the solution can be proved by reference to the figure 4, the share of mass transit and also the car that
calculated by the normal logit model and fuzzy model. In normal combined MS/TA Model, the curve
of the share is strictly symmetrical. It figures the shares of mass transit (also that of vehicle) are changing
symmetrically and strictly in mathematical way, (Figure 4). In the combined MS/TA with fuzzy logic, the
changing of the shares (mass transit and vehicle) are dissymmetrical, the value of time in human decision
is represented more precisely.
This formulation is a modal split and traffic assignment integrated model with UE principle. It corresponds to the market equilibrium according to the average cost (AC). Next, the modal split and traffic assignment integrated model can also be applied to compute all the travel times, travel flows of all links and all paths of a target urban network- Gifu city urban network as shown in figure 5.

The objective function in case of integrated model with SO principle is:

$$\min Z_{SO} = \sum_{a \in A} x_a R_a - \sum_{r \in R} \sum_{s \in S} q_{rs}^{mass} \left( \frac{1}{\theta} \ln \left( \frac{w}{q_{rs}^0} - w \right) + c_{rs}^{mass} \right) dw + \sum_{a \in A} x_a R_a$$

(6)

Link cost can be determined from BPR function as (JSCE, 1998):

$$t_a(x_a) = t_a^0 \left[ 1 + 0.15 \left( \frac{x}{Q_c} \right)^4 \right]$$

(7)

In this paper, congestion pricing is considered in these 2 cases; narrow area cordon congestion pricing (case 1), wide area cordon congestion pricing (case 2). In case 1, only zone number 1 is applied the congestion charging system. Zone 1 is the center area in the Gifu city, (Figure 10). In case 2, a wider area that consists zone number 1,2,5,6 is applied the congestion charging system. This area is the downtown area in the Gifu city (figure 10). The congestion charges in each case are: 250 yen, 500 yen and 1000 yen. This means that there will be $2 \otimes 3 = 6$ cases for calculation. All these 6 cases are calculated by “Combined modal split / traffic assignment with fuzzy logic”.

All the results of travel time, travel flow, of all links, can be computed. Then some other involved features of economic effect may be accrued, such as social benefit, social net benefit, social surplus, user surplus, number of car users, number of mass transit users, increase of mass transit income and so on, after a congestion pricing application has been computed and analyzed.

Figure 10. Cordon Congestion Pricing, Narrow Area – Wide area
4.3  Estimation results on the urban transport network

The results obtained after application the combined model modal split/traffic assignment to the network in case of road pricing are listed as following. When the toll of the road pricing charge is changed, the social benefit, social surplus benefit, government revenue, mass transit users, social cost... change. The following figures show some of those items.

When the congestion charge system is applied, the drivers who have to make a trip through the area have to pay the congestion charge, when the area become wider, the number of driver who has to pay for the toll also increases. Almost they tend to avoid the paying. This leads the number of vehicle users decrease and mass transit users increase.

The social cost in the case of “Narrow area Cordon Congestion Pricing” and in the case of “Wide area Cordon Congestion Pricing” are shown as figure 12. The wider the congestion charge area is, the higher social cost is.

The cordon congestion pricing system is proposed as a combined optimization problem in this study. It might be the practical application of the congestion pricing for an urban transport network. The congestion pricing on urban transport network can be formulated via a combined model of modal split and traffic assignment. The cordon congestion pricing system may work well to ease traffic congestion in central area of a city.

By application of congestion pricing, the number of car users decreases, and the mass transit users increases. The income coming from congestion pricing should be used not only to improve vehicle networks services but also public network services. This could be a positive solution on environmental problems.

5. CONCLUDING REMARK

In this study, modal split model with fuzzy logit is provided and applied into the combined model modal split/traffic assignment model.

Firstly, by using the linguistic variables, the human psychology in making daily modal choice decision can be represented more efficiently. Realistic modal choice model can be created using fuzzy logic formulation. The results of the fuzzy modal choice model are rather close to the reality. It could be concluded that fuzzy logic based model provides precise estimation of urban traffic along with a description of human perception.

Secondly, a combined modal split/traffic assignment model with fuzzy logic has been formulated in this study. This model is applied into an objective urban network that has a same size with the real network. The results obtained in this study shows that the created model could represent the reality well.

Thirdly, the cordon congestion charging can be considered in this combined model. The values of tolls in congestion charging are changed and social cost, government revenue are estimated. The applicability of fuzzy logic based model is provided with the evaluation results for the impact on congestion pricing policy.

The next step of the study, in purpose of taking into account many uncertain factors, the modal split by fuzzy reasoning could be improved or change to suite to the real condition in network by improvement or change of the fuzzy rule sets.

Figure 13. Government revenue – Tolls

The cordon congestion pricing system is proposed as a combined optimization problem in this study. It might be the practical application of the congestion pricing for an urban transport network. The congestion pricing on urban transport network can be formulated via a combined model of modal split and traffic assignment. The cordon congestion pricing system may work well to ease traffic congestion in central area of a city.

By application of congestion pricing, the number of car users decreases, and the mass transit users increases. The income coming from congestion pricing should be used not only to improve vehicle networks services but also public network services. This could be a positive solution on environmental problems.

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