Fuzzy Travel Behaviour Model with Route Choice Description

Takamasa AKIYAMA, Masashi OKUSHIMA and Madhu ERRAMPALLI

* Department of Civil Engineering, Gifu University,
1-1, Yanagido, Gifu 501-1193, JAPAN

e-mail: takamasa@cc.gifu-u.ac.jp, okushima@cc.gifu-u.ac.jp, k3812105@guedu.cc.gifu-u.ac.jp

Abstract — Application of travel behaviour model is highly desired to describe the daily trip pattern of the trip makers as an important analysis technique in urban transport planning. The model would describe the decision for purpose, mode, destination, and route for trips with considering the trip chaining of trip makers. In the study, soft computing approaches such as fuzzy reasoning, fuzzy neural network and so on would be applied to formulate the decision process to establish the fuzzy travel behaviour model. The trip patterns can be analyzed corresponding to the trip survey results for urban area. Furthermore, the effectiveness of traffic demand management can be discussed because the traffic flow analysis would be carried out with considering human fuzziness.

Keywords — Travel behaviour model, Daily trip pattern, Fuzzy reasoning, Soft computing approaches

I. INTRODUCTION

The influence of transport policy is generally observed in many different aspects. Therefore, the impact of transport policy should be evaluated in terms of aggregate traffic as well as travel patterns of individual trip makers [1]. The reduction of traffic congestion on the network can be evaluated with traffic flow analysis techniques to consider the user equilibrium situation of traffic. It reflects on the aggregate traffic flow on the network to know the overall impacts for urban transport. On the other hand, the impact of congestion to individual trip makers would be analyzed in the study. It is quite obvious that the daily travel pattern consists of sequential trips. Therefore, the distribution of travel pattern might indicate the range of influence with transport policy installation at individual level. It should be important because the travel pattern realizes the decision results of trip maker.

In terms of modelling, the travel behaviour model has been developed to simulate individual daily travel pattern with soft-computing approaches in the related studies by the authors [2]-[5]. Fuzzy logic should be an essential technique in soft-computing for these researches. It is reported that the overall description of travel pattern can be estimated with empirical data. Therefore, the reaction should be estimated independently with the assumption of road pricing installation. Firstly, the fuzzy logic based model estimates the change of the trips as an option of trip makers to transport policy. Secondly, the travel pattern is derived with the travel behaviour model with fuzzy logic. This estimation system with two stage estimation might be called as fuzzy travel behaviour model because the fuzzy logic formulation is applied in all stages in modelling. Therefore, the advantages of fuzzy logic might be realized in estimation of travel patterns [6].

The evaluation of road pricing policy can be realized with the particular assumption for urban area with established fuzzy travel behaviour model. The statistical analysis of road pricing can be easily realized. The reduction of traffic congestion might be measured as an aggregate level. On the other hand, the options of trip maker to the transport policy are classified quite obviously in the study. Therefore, the essential changes of travel patterns are summarized with example cases through the estimation of fuzzy travel behaviour model. It would be known from the observation that several alternative types of travel pattern might be realized in road pricing installation on the urban network.

II. THE FORMULATION OF TRAVEL BEHAVIOUR MODEL WITH FUZZY LOGIC

A. The Assumptions of Travel Behaviour Model

Travel behaviour from the first trip to the last in a day is estimated based on activities. The activities could be classified into two categories. The fixed activity is predetermined for an individual to be done within the daily
time budget. The working in office hours may be a typical example. It is a sort of enforced activity. The other category might be called as non-fixed activity. In the model, it is presumed that the characteristics of fixed activities such as location, starting time and duration are given. The travel behaviour in the unfixed time would be estimated. It means the travel behaviour in the fixed time is out of estimation. As for the type of non-fixed activities, they may be classified into four groups such as daily affair, non-daily affair, working and staying home. They are referred to the classification of the Person Trip Survey in Japan.

The structure of decision making process can be assumed as Figure 1. The model structure shows that a trip maker might decide a type of activity, duration time, a destination, and a travel mode sequentially. In the first stage, a trip maker on home base determines his commuting time. If the present time is closed to the commuting time, he should make a trip to the office. Otherwise, it can be known that the trip maker still has enough time to do the other activities than the office work. The activity at home as well as stopping some places before commuting are often observed corresponding to this pattern of trips. In the second stage, the trip maker decides the type of activity. It is the most important part of the model. The duration time of the activity, the location of activity as destination of trip, and the travel mode are determined as well in the stage. In the third stage, the trip maker considers the time to terminate the trip to home. The arrival time at home is given in the estimation of the model. If the time is almost in the termination period for the trip, he may go back to home and finish his activities. On the other hands, he may product some trips to the additional activities if he still has some time. In this case, the decision process for the next additional trip will be repeated from the first stage to the third stage.

B. The Estimation Process of Travel Behaviour

It is assumed that the basic elements in travel behaviour are determined as route choice, departure time and modes (Ozawa & Akiyama, 2002). As a road pricing is generally intend to change the transport policy in long term, trip makers have to manage the basic elements of travel behaviour such as commuting mode and commuting route etc. On the other hand, the decision of trip makers in short term is repeated to reflect on the daily change of traffic condition. As the road pricing scheme is introduced as a transport policy, the trip maker make decisions with different conditions. In the former study, these two steps of decision making of trip makers are separated to describe the model as “Reaction Model” and “Travel Behaviour Description Model” respectively (Ozawa et al. 2003a, 2003b). However, a travel mode, travel route and departure time are decided in long term as well as in short term. It is desirable that two steps of decision making is integrated as the only one travel behaviour model. In this study, the decision making process of trip makers is described as the integrated model with application of the transportation policy and daily change of traffic condition.

Figure 1. Structure of decision making process

The structure of sequential decision making process can be assumed as Figure 2. The model structure shows that a trip maker might decide a type of activity, duration time, a destination, and a travel mode sequentially (Kitamura, 1984a, b). In the first stage, a trip maker at home base should determine his commuting time. If the present time is closed to the regular departure time for commuting, he should start a trip to the office. Otherwise, it can be known that the trip maker still has enough time to do the other activities than the office work. The activity at home as well as stopping some places before commuting are often observed corresponding to this pattern of trips. In the second stage, the trip maker decides the type of activity. It is the most important part of the model. The duration time of the activity, the location of activity as destination of trip, and the travel mode are determined as well in the stage. In the third stage, the trip maker considers the time to terminate the trip to home. The arrival time at home is given in the estimation of the model. If the time is almost in the termination period for the trip, he may go back to home and finish his activities. On the other hands, he may product some trips to the additional activities if he still has some allowance of time. In this case, the decision process for the next additional trip will be repeated from the first stage to the third stage.
C. Route Choice Model

The route choice model is formulated with fuzzy reasoning. It is assumed that a trip maker may choose the original route through the central area as well as a detour route. The detour route here should be a composed route to summarize all other reasonable routes from the original route. The structure of the route choice model is shown in Figure 3. The route choice model consists of two step estimation. The first step is the estimation of value of time because the perception of trip maker can be described by fuzzy logic particularly in the time evaluation. The second step is the decision of the route choice by the level of utility for each route with fuzzy value of time. It might be regarded as sequential usage of two fuzzy reasoning models.

The explanatory variables of first step are personal factors of trip maker such as sexuality, occupation and age. The estimated variable is the value of time. The value of time and age are expressed with linguistic variables (Small, Medium and Large). The triangular fuzzy numbers are used to describe human fuzziness about value of time. The inference rules for value of time are summarized in Figure 4. The perceived travel time and travel cost in addition to fuzzy value of time are the explanatory variable in the second step. The magnitude of choice is determined as an index of utility for each alternative route. The index is scored between 0 and 100 to demonstrate the level of utility. It is assumed that the route with highest value of utility should be selected by the individual trip maker. Figure 5 summarizes the rule base for the inference in this stage.

<table>
<thead>
<tr>
<th>Rule</th>
<th>IF TCG is</th>
<th>THEN UTL is</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule - 1</td>
<td>very small</td>
<td>very large</td>
</tr>
<tr>
<td>Rule - 2</td>
<td>small</td>
<td>large</td>
</tr>
<tr>
<td>Rule - 3</td>
<td>medium</td>
<td>medium</td>
</tr>
<tr>
<td>Rule - 4</td>
<td>large</td>
<td>small</td>
</tr>
<tr>
<td>Rule - 5</td>
<td>very large</td>
<td>very small</td>
</tr>
</tbody>
</table>

**Figure 3** The route choice model with fuzzy value of time

**Figure 4** The fuzzy inference rules for value of time estimation
Human fuzziness on value of time, generalized travel cost, age and level of utility are illustrated with triangular fuzzy numbers. Each linguistic variable can be formulated as membership functions. The value of minimum, median and maximum of triangular fuzzy numbers are estimated as a parameter of membership functions. The membership function for age is shown in Figure 6.

Figure 6 The membership functions for Age

The parameter of the membership functions of value of time, generalized travel cost and level of utility are estimated by using the GA (Genetic Algorithm). It is commonly known that GA provides the rather precise approximation to the ill-defined optimization problem such as fuzzy logic estimation. The total number of route choice model samples is counted as 1456, of which 437 samples (30%) are used for model calibration. The fitness rate is measured as 85.6%. The forms of the optimized membership functions are illustrated in Figure 7 to Figure 9 respectively. It is shown from the Figure 7 that the “medium” in generalized travel cost has the wide left spread and the narrow right spread. It is known that the change of perception of generalized travel cost is more sensitive under 1,000 yen than over 1,000yen.

III. APPLICATION OF TRAVEL BEHAVIOUR MODEL WITH FUZZY LOGIC

A. The Performance of the Travel Behaviour Model

The performance of the model should be investigated particularly aiming at precise description of individual trip pattern. Therefore, it would be confirmed that present trip patterns can be estimated correctly by the proposed travel behaviour model. The following procedure is introduced to investigate the performance of the model in terms of replication for travel patterns of trip makers.

The individual trip patterns can be estimated through the sequential procedure. The outline of the procedure is summarized in Figure 5. As the personal data and initial conditions for a trip maker are obtained from the empirical survey database, the travel behaviour model provides the estimation of daily trip pattern through the following sequential process:

[Step 1] According to the personal factors and elements of fixed activities for individual trip maker, the varied factors at the decision-making stage (their present locations, the present time, starting time for work, etc.) and the content of proceeded trips (the number of trips, mode of commuting trip, etc.) are provided into the model.

[Step 2] The elements of travel behaviour can be estimated according to the procedure of estimation step by step.

[Step 3] The decision about "the terminal trip" should be done to finish all daily travel of trip maker.

[Step 4] If "the terminal trip" is not derived from the estimation at the step [3], the updated trip condition at the next decision making time is provided into the model. And return to the step [2].

[Step 5] If "the terminal trip" is derived from the estimation at the step [3], the estimation should be stopped and the daily trip pattern for the trip maker might be observed.

[Step 6] The impacts of transport policy may be evaluated in
terms of time and space in trip patterns for trip makers. The daily travel pattern can be generated with above procedure trip by trip. Totally, 8,443 samples are used to confirm the model performance. The distribution of trip patterns is observed from the replication for the samples. The result is summarized in Table 1 with reference to the original distribution of travel mode share.

Table 1 Summary of the model estimation

<table>
<thead>
<tr>
<th>Mode of trip</th>
<th>Replication</th>
<th>Original</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass Transit</td>
<td>4446 (17.8%)</td>
<td>2300 (10.0%)</td>
</tr>
<tr>
<td>Car</td>
<td>11738 (46.9%)</td>
<td>12447 (54.3%)</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>8831 (35.3%)</td>
<td>10043 (43.8%)</td>
</tr>
<tr>
<td>Bike etc</td>
<td>25,015</td>
<td>24,790</td>
</tr>
</tbody>
</table>

The overall mode share might be similarly distributed. However, the share of mass transit in replication is rather larger than the original values by 93%. This result might connect to the smaller values in replication for pedestrian and bike. On the contrary, the share of car in replication is little larger than the original value by 6%. The fact shows that the share of car to the other modes can be estimated properly. The replication result of trip generation of each purpose is summarized as well with reference to the original distribution in Table 2.

Table 2 Statistics of trip purpose in estimation

<table>
<thead>
<tr>
<th>Trip purpose</th>
<th>coming home</th>
<th>commuting</th>
<th>temporary coming home</th>
<th>daily affair</th>
<th>non-daily affair</th>
<th>work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replication</td>
<td>7,705</td>
<td>6,023</td>
<td>2,143</td>
<td>3,929</td>
<td>820</td>
<td>4,395</td>
</tr>
<tr>
<td>Original</td>
<td>8,443</td>
<td>5,835</td>
<td>1,846</td>
<td>3,514</td>
<td>1,513</td>
<td>3,639</td>
</tr>
</tbody>
</table>

The total volume of trip generation might be similarly estimated. The difference of the number of trips is counted as 225 with error of 1%. The number of coming home trips is estimated smaller by 738 trips. The fact reflects on the smaller estimation for the number of trip pattern with home based trips. It might cause of over estimation of duration time at home. Even though the trip maker is estimated to come back to home in a day time, he cannot create another visit without enough time allowance. Therefore, the number of stops of the trip pattern tends to be reduced. As the result of this underestimation of trips after the staying home activity, the trips of non-daily affair and coming home are estimated smaller than the original in number. This observation may show the direction for modification of estimation process. In term of overall estimation, totally 4993 trip patterns are replicated correctly. The fitness ratio can be calculated as 59.1% (4993/8443). It may not be sufficient results in terms of trip pattern estimation. However, it is observed from the distribution of estimation that the trip patterns seem to be estimated within the small difference of trip pattern. There are many errors that a particular type of trip pattern is estimated incorrectly to the trips in the same zone. It would be recommended from the observation that the category of trip pattern should be considered more realistically.

B. The Impact Analysis of the Transport Policy

The impacts of travel pattern should be analyzed from the estimation in the case of road pricing installation. The initial condition for the estimation model should be determined according to the above assumption of road pricing. The travel cost for car is composed of monetary cost and travel time in the travel behaviour model. Therefore, the monetary cost is assumed to increase by value of congestion toll in every estimation step. All other elements of initial condition should be fixed as original values in estimation.

It is confirmed in the previous chapter that the change of the daily trip pattern can be estimated by fuzzy travel behaviour model. The aggregate level of traffic can be evaluated with considering several statistics. However, the impact of road pricing should expand to the other trips of individuals because the alternative trip production may influence the time and space budget of trip maker. Therefore, the change of travel pattern should be mentioned as an indirect impact of road pricing. The estimation process of trip pattern is designed with following stages:

[Step1]: The value of road pricing is installed into the travel behaviour model as initial conditions. It corresponds to the cordon line toll for road pricing in entering the target area to reduce the congestion.

[Step2]: The individual reaction to the road pricing as raising travel cost is determined through each estimation process. The sequential decision for the options of travel to road pricing is assumed such as (1) influenced by road pricing, (2) change of travel route, (3) change of departure time, (4) change of travel mode, (5) pay for the congestion toll.

[Step3]: The travel pattern in road pricing is estimated by the fuzzy travel behaviour model with the updated condition of the change in influenced trip. The daily trip pattern should be regarded as the chain from the first trip to the last trip. Therefore, the choice of the public transport for the first trip may give some effect to the later connected trips. The impact to trip pattern can be derived as a result of sequential estimation of trip by the fuzzy travel behaviour model.

C. The Impacts of Road Pricing in Traffic Flow

The change of travel behaviour can be estimated sequentially referring to the assumption of road pricing. Figure 10 summarizes the result of estimation for the change of the daily trip pattern with road pricing.
According to the time and space condition of road pricing, 40,610 trip makers are classified as influenced individuals. It reflects that they originally have the first trip strongly concerning with the road pricing. The samples with shift of departure time are counted as 5,971 in the second stage of estimation. Therefore, 34,639 (=40,610 - 5,971) samples correspond to the individuals considering the other options to road pricing. These samples can be divided into 25,684 samples for alternative mode and 8,955 samples for the other options in the third stage estimation. It means that 8,955 samples are nominated into the next stage estimation. The samples can be classified into two groups as 1,870 samples on the original route (path 1) and 7,085 samples on the alternative route (path 2) in the fourth stage estimation. Therefore, 8,955 samples are no change of options in the fourth stage estimation. It is known from the summary in Figure 15 that over 63% (=25,684/40,610) of individual drivers might change the daily first trip mode from car to public transport with road pricing.

IV. CONCLUDING REMARKS

The fuzzy travel behaviour model is designed with the sequential estimation process to describe the travel pattern in road pricing installation. In particular, the options of trip maker are determined to summarize the reactions to transport policy. Since the perception of trip maker can be formulated with fuzzy logic, the decision of individual trip maker might be easily analyzed through the estimation process. In particular, the fuzzy value of time is proposed to describe perceived cost of trip maker realistically. Another advantage of fuzzy logic formulation is realized as well in the process of model calibration. The membership function has an important role to define the characteristics of linguistic variables in mode choice and route choice. According to the formulation, the parameters in membership function are determined through estimation process of genetic algorithm. The further studies would be recommended to summarize the knowledge for practical application of road pricing. Firstly, the impacts of future transport policy may not be evaluated quite properly because the empirical data in future updated conditions cannot be obtained. Therefore, it may be recommended that knowledge from the real observations in the other areas or the result of stated preference survey could be accumulated. Secondly, the connection between the first trip and the other trips may not be investigated precisely even though the essential difficulty in estimation lies in time and space budget of trip maker. The interactive model structure between time and space would be reconsidered. Thirdly, the derived knowledge in formulation of fuzzy reasoning might not be sufficiently applied to reveal the decision mechanism of trip makers. Since there are many fuzzy and uncertain factors in decision of trip makers, the knowledge describing with linguistic description might provide the powerful information to real transport policy.

REFERENCE