FUZZY TRAVEL BEHAVIOUR MODEL WITH SPATIAL INFORMATION TO EVALUATE PUBLIC TRANSPORT POLICY

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ABSTRACT

The public transport policy in local city is discussed in the study with fuzzy travel behaviour model. In terms of database, the person trip (PT) survey for urban area has been made every ten years. The database has been accumulated for over forty years concerning with activities and travel behaviour. It is often used to consider the future transport planning. Since the travel behaviour is reported with zone to zone in the trip survey, the spatial distribution cannot be specified precisely. The integration of travel behaviour model and geographic information system (GIS) is proposed. The algorithm to specify the activity spots of individual trip makers with spatial information of GIS. In travel behaviour modelling, the engineering data can be modified involving precise spatial information of trip maker. Even in the traditional modelling such as logit model, the advantage of combination between trip database and GIS information is to estimate the travel behaviour accurately. Furthermore, fuzzy logic based model with GIS information is proposed to estimate the travel behaviour in terms of description of human decision as well as accurate description of travel behaviour. In particular, the modal choice model can be proposed to estimate the impact of public transport policy to the urban traffic. The pricing policy and environmental taxes are mainly discussed for future transport planning in the local city. It is concluded that the impact of transport policy can be evaluated precisely with fuzzy logic based model with GIS information.

Keywords: GIS, fuzzy reasoning, travel behaviour, modal choice, person trip survey

INTRODUCTION

The mechanism of travel behaviour is usually analyzed by considering time budget and space constraint of trip maker. On the other hand, the large scale trip survey for urban area has been conducting in order to establish the more sophisticated transport planning model. The person trip survey has been recognised as an authorized trip survey for urban area in Japan. However, each trip is determined by zone to zone in the survey. It would be recommended the existing resource of the survey would be modified with proper spatial information. Therefore, the integration of travel behaviour model and geographic information system (GIS) is proposed in the study. The advantages of travel behaviour analysis with GIS can be summarized. Firstly, the precise travel patterns of trip maker can be illustrated with spatial information as a result of analysis. It corresponds to the spatial display of estimation results for travel patterns to evaluate the impact of transport policy. Secondly, the practical travel behaviour model can be created to describe the decision process of trip makers. It means that spatial information of GIS can be combined to the basic trip survey data to demonstrate trip patterns in urban area.

The travel behaviour model with fuzzy logic has been established by the authors (Akiyama, Okushima, and Izumi, 2006). The model includes the sequential estimation process of trips with purpose, travel modes and travel time and so forth. In the study, the activities of trip maker can be estimated simultaneously with trip purpose and duration. The original model been validated to estimate the trip patterns practically for urban area of Gifu city. The integrated model with GIS has been proposed to extend the estimation process in the original model. The integrated database is created combining with the trip survey database and geographic information. Therefore, the fuzzy travel behaviour model with the integrated database successfully estimates the travel patterns as well as activities of trip makers.

The graphical demonstration of travelling of specific group must be helpful to understand the dynamic change of daily trip pattern in the city. Therefore, it would be discussed that the integrated travel behaviour model with GIS would be able to estimate travel behaviour with dynamic spatial change. Comparing with the results from Logit model estimation, it is confirmed that the trip patterns are estimated effectively by the proposed model.

As an application of the integrated travel behaviour model with spatial information, public transport policy can be discussed with estimation of social benefit. The pricing for the public transport as well as environmental taxation for drivers would be evaluated as an effective transport policy to reduce the congestion in the urban area. The trip makers have to decide their trip making behaviour based on the conditions. The pricing policy has been evaluated especially considering mode choice behaviour using multi-agent formulation in future.

The public transport problems in local city is mentioned in Chapter 2 . It is an important issue in recent transport planning. In the society with large number of elderly people, the higher service level of public transport is required. In terms of environmental problem, the modal shift from car to public transport is recommended as well. In Chapter 3, The procedure of location specification of origin and destination of trips is proposed using spatial information. Furthermore, the development of integrated travel behaviour model is discussed. In Chapter 4, the mode choice model with GIS information is mentioned. In particular, the fuzzy logic based model with GIS information is proposed. The estimation results related to the public transport policy can be provided. In Chapter 5, case studies are mentioned in terms of public transport policy. It is summarized that the integration of trip survey and GIS information provides the advantage of travel behaviour analysis as well as evaluation of public transport policy.

PUBLIC TRANSPORT POLICY IN LOCAL CITY

In the study, the target area for travel behaviour analysis is Gifu city. The city has about 402,185 populations in 2009. It is regarded as a middle size local city. The city is located in Chukyo area, the third largest urban area of Japan. It locates at about 30 km north to Nagoya and about 150 km east from Osaka.

As the urban transport plan is usually created based on Person Trip Survey, the result of the survey is used in the study**.** The residential spots are widely spread even in the surrounding area of the city shown in **Figure 1**. In the PT survey, it is assumed that the city area consists of several zones. Figure 1 shows nine large size zones. Furthermore, the city area can be divided by 62 small size zones as well. Therefore, all individual trips are recorded as travels between zone and zone. Similarly, the activity location of trip maker can be determined as zone sized area.

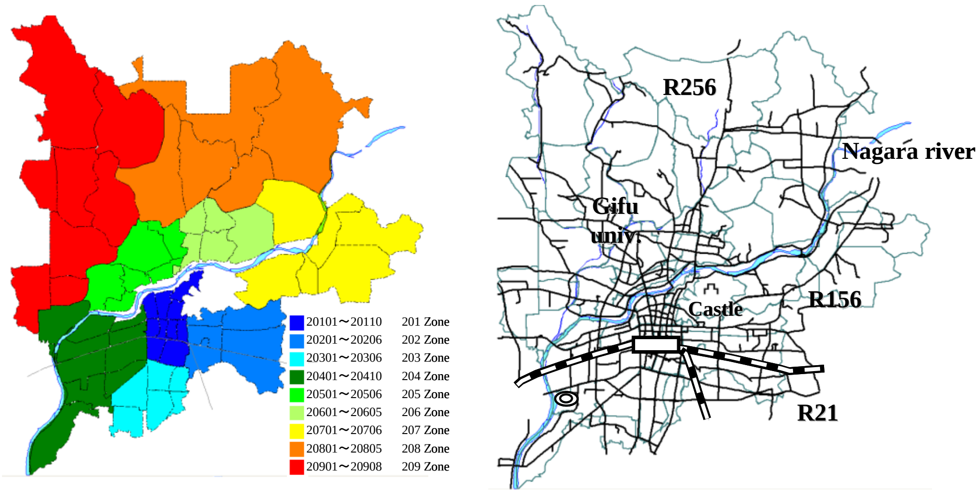

Figure 1 – Zoning and Road Network for Gifu City

The basic statistics of the city are summarized in **Table 1** corresponding to the PT database. It is obvious that the city is suburbanized rapidly because of recent large scale motorization. Even though the total number of population is decreased slowly, that of central zones is reduced rapidly.

Table 1 – Fundamental Statistics of Gifu City

Population	402,185	Schooling from the outside	11,772
[Centeral area]	74,531	Driving license holders	247,607
[Surrounding area]	162,653	Car owners	279,177
[Suburbun area]	165,001	Large size shops	64
Daytime population	426,865	Normal shops	7,585
Families	153,336	Commercial sales [yen]	18,918
Elderly person	73,492	Business sites	25,382
Commuters	279,224	Workers	185,614

The change of mode share can be observed from the trip survey database. The database can be accumulated from Chukyo Area Person Trip Survey data in every ten year. The trip data for Gifu city can be obtained. The tendency of mode share is illustrated in **Figure 2**. The share of public transport such as rail and bus is reduced year by year. On the other hand, the number of car trip is increased gradually.

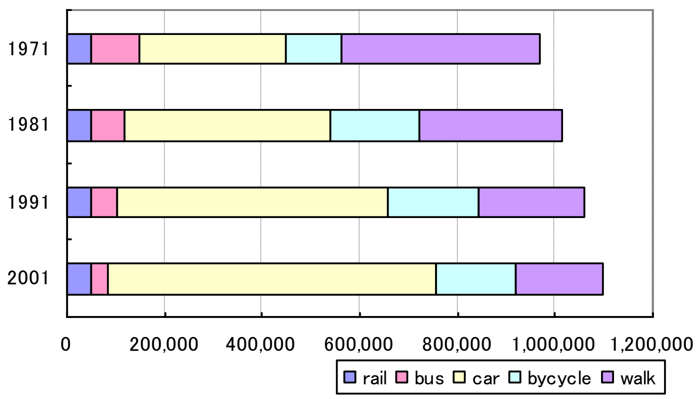

Figure 2 – Time Series Change of Modal share of Gifu City

THE TRIP DATABASE MODIFED WITH GIS INFORMATION

The Interaction between Trip and GIS Information

The integration between the travel behaviour database and spatial information of GIS is mentioned in the section. Furthermore, it is proposed that fuzzy travel behaviour model can be modified with accurate estimation using the spatial information. The outline of the database integration process can be illustrated in **Figure 3**.

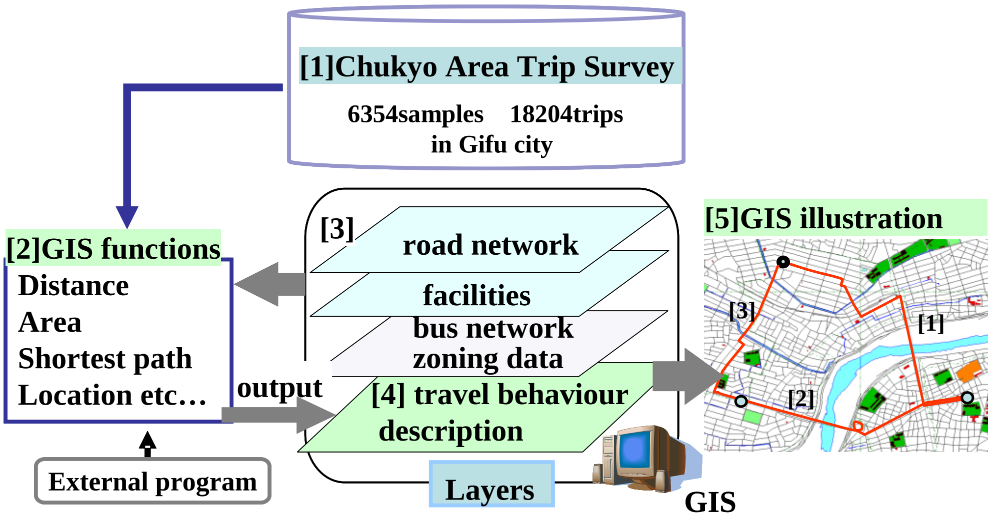

Figure 3 – The Outline of Travel Behaviour Database combing with Spatial Information

In the study, the Chukyo Area Person Trip Survey data is introduced as travel behaviour data. It consists of total 6,354 samples and 18,204 trips in Gifu city in 2001. These data can be used to calculation of GIS functions such as distance, area, shortest path, location algorithms etc. The GIS mainly adopts the layering system which includes layers of road network, facilities, bus network, zone etc. These layer data also given to GIS functions. After doing the analysis, the output also represented using the appropriated layers and graphically represented as shown in the **Figure 1**.
In the present study, the urban area of Gifu city has been selected as shown in **Figure 2**. It can be seen the analysis area and city structure from the figure. In that figure, the zoning details have been shown in the left side diagram using GIS. There are total 62 zones in the objective area. The right diagram in the figure shows the road network considered for the analysis. The network consists of the loop road and other trunk roads. Particularly, the central business district (CBD) area locates in the middle of city. The railway station of Japan Railway locates at city centre as well. Therefore, the traffic tends to concentrate in these zones. As the geometrical characteristics, the river Nagara crosses the city from east to west. Since the residential area locates mainly in northern part of the city, many commuting trips are observed on the bridges crossing the river.

The algorithm to use GIS information

The result of regional trip survey so-called "Person trip survey" should be an essential database of urban transport planning which has recorded the trips and activities of trip makers dynamically as well as spatially for the target city. Even though all the travel patterns are recorded in the PT database, there is a limitation of the detail analysis because the spatial activities are recognized only as zone size level shown in **Figure 1**. It means that the activity site of the trip makers cannot be pointed out from the PT database information (Akiyama, 2001).

Therefore, the technique of GIS can give spatial information to combine with the PT survey database.

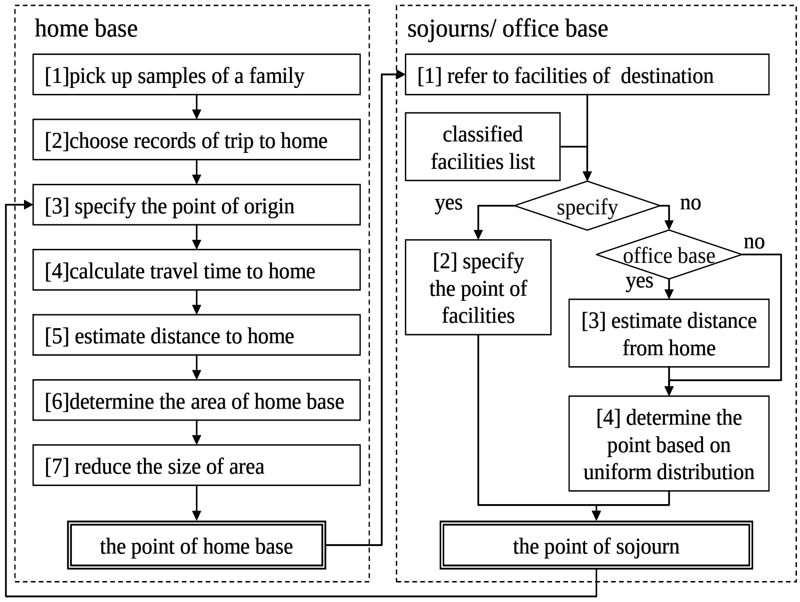

Figure 4 – The Algorithm of Spot Identification with GIS Information

The individual trip is recorded as zone to zone in original PT database. Therefore, the purpose of the algorithm is to specify the location of origin and destination with smaller size. The algorithm of sojourns estimation is shown in **Figure 4**. In the study, the estimation flows are specified according to the types of stop in travel patterns of trip makers.

The destinations for all trips are classified into three types such as home base, office base and the others. The essential idea of the algorithm is derived from the fact that family members come back to the single location of home. Another important fact is that large scale building of the city can be pointed spatially in GIS (Johnston, 1998). Therefore, the stop can be determined from the facilities recorded in PT database.

The left side of the figure indicates the outline of estimation for home base. According to the algorithm, the estimation process is summarized as follows:
1) Trips of family members can be investigated.
2) Trips to home for samples are engaged.
3) The point of origin is initially determined from facility information.
4) The OD travel time is recorded in PT database.
5) The spatial distance can be estimated with assuming the average speed of individual travel mode recorded in PT database as well.
6) The spatial range of home base is determined corresponding to the distance.
7) The size of estimated can be reduced with iteration of update the trip information for other family members.
If the area size of home base cannot be reduced, the estimation is shifted to the office base and sojourns. The essential point of the algorithm is that all family members in the survey

should terminate the trips at the same home base. It is quite primitive but important to investigate the trip data of family members simultaneously.

In the right side of the algorithm, the estimation of sojourns is mentioned. The essential algorithm is similar to that of office base.
1) The destination would be pointed referring to the facilities recorded in PT database.
2) If a particular facility can be specified, the spatial point of sojourn is determined precisely.
3) The distance from home base to office base should be estimated.
4) Determine the point among the same types of facilities with equivalent probability.

The essential point of the algorithm is that GIS should stores the spatial information for the specific building and facilities in the city. Therefore, particular spot is pointed out on the map according to the trip data without deterministic information. Similarly, the distribution of bus stops can be stored with coordinates in GIS. It is quite useful to measure the travel distance and travel time as engineering data.

For example, it is assumed that the purpose of trip is shopping and the facility is reported as a department store. Since the department stores generally exist with limited number, the location of department stores can be focused with rather high probability (Kitamura, 1984).
In the algorithm, it is iterated that the information of specified location is exchanged between the right and left estimations.
The areas of both ends of trip are specified for individual trip maker according to the recorded data of daily trip pattern. The size of area specified as home base can be reduced though the trip information of all family members. The procedure has been pictorially explained in **Figure 5**.

Initially, the border lines of home base location ranged with spatial data of family member A, B and C would be estimated as shown in the figure. Then the specified home base location for these family members has been identified by GIS with help of spatial information. Finally the origin of an individual or the starting location of the activity would be reduced from wider zone area to small and specific location as shown in the figure.

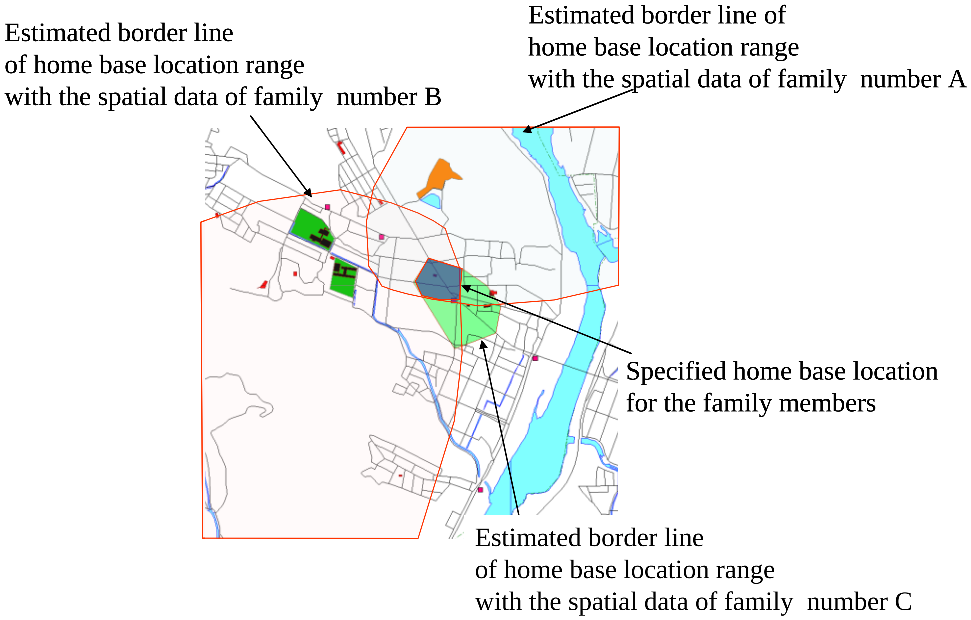

Figure 5 – Home Base Identification with Trip Patterns of Family Member

This process is considered as key element of GIS and by doing so, the accuracy in input data has been increased by defining the zones to specific points for travel behaviour modelling. This process would be carried out for all the samples and specific locations would be identified. After successfully identifying the locations for all the samples, this data would be used as an input for the travel behaviour model.

In the algorithm, the geographical database of GIS covers to specify the locations of City hall, public halls, kindergartens, schools, shopping centres, post offices, large scale park, hospitals and so forth. As facility type of trip end is reported in PT survey, the particular spot is often identified combining trip information such as travel time, zones, trip purpose and so forth.

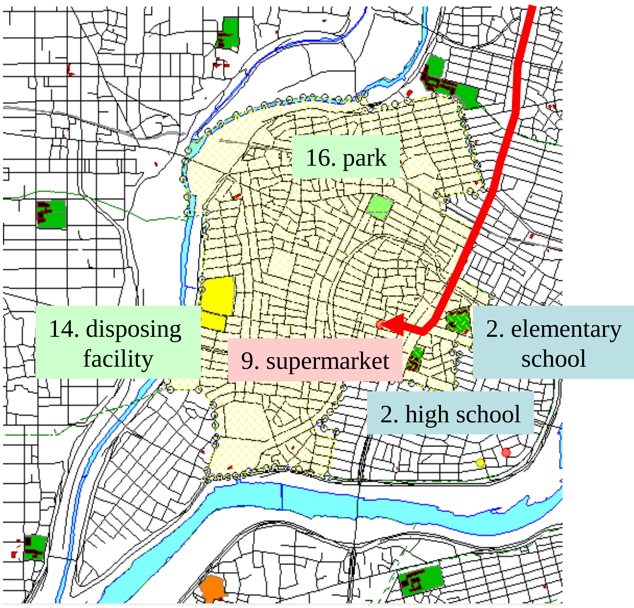

Figure 6 – The Specific Facilities Stored in GIS System

Performance of combination with GIS information

The spatial information accumulated in GIS is effectively applied in the research connecting to the PT database (Izumi, Okushim and Akiyama, 2004, 2005). The algorithm can be developed to specify the activities of trip makers spatial for a whole day in the city. According to the proposed algorithm, the dynamic behaviour of the trip makers in the area of the city can be easily observed. The algorithm would be applied extendedly to determine the sufferers in the earthquake. The proto type of the sufferers is determined as a person who might not come back home from the present position after the earthquake. The definition corresponds to the isolated peoples after the earthquake. The number of sufferer would be an essential index of disaster prevention planning for the city(Akiyama, Okushima and Guo, 2007, Guo, Okushima and Akiyama, 2008).

The essential facility information has been originally stored in GIS, which corresponds 593 for 20 categories. The reduction of trip end size for members in one family is iterated five times in the algorithm. The distance between the trip ends can be measured as the physical shortest path. The shortest path can be calculated through the searching algorithm in GIS (Li, 2002).

The average speed is assumed for each transport mode: car 25km/h, bicycle 12km/h, walk 4km/h. In the algorithm, the total travel time (TT) and total travel distance (TD) are summarized for each mode. The average speed of each mode is determined as follows: $\bar{v} = TD/TT$ (km/h). The gravity of the area is pointed easily in GIS (Akiyama, Okushima and Izumi, 2005). The dominated area is calculated through GIS function (Izumi, Okushima and Akiyama, 2004).

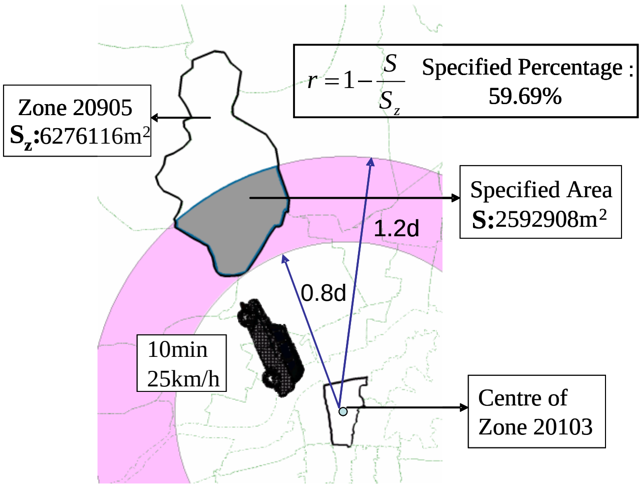

Figure 7 – The Specified Area for Reduction

Figure 7 shows the mechanism of size reduction for the trip end. The original zone is determined referring to the definition in PT survey as zone 20905 with the size of 6,276,116 m^2. According to the travel time information reported in the survey, the available area of trip end can be estimated with circular belt as shadowed in the Figure.

The intersection between the original zone and the estimated belt area can be regarded as the specified area for the trip end in the algorithm. The index of specified level for the trip end is formulated as: $r = 1 - S/S_z$, where S_z is the original zone area, S is the specified area in the algorithm. The index may indicate the reduction of zone size. Therefore, it reflects on the specific percentage of the original zone corresponding to the particular trip end.

Basically, the urban area is divided by zones in the person trip survey. Therefore, the location of trip end is reported as a small zone. It means that all trips should be indicated from zone to zone without any missing. The average zone size is 3,078,446 m^2. According to the algorithm proposed here, the average size of feasible area is measured by 816,867m^2 as 25 percent of the original zone. Therefore, it is obvious that the algorithm provide the precise spatial information of urban activities.

In the algorithm, the location of trip end can be determined from the specified facility information if the facility involves the database of GIS. Otherwise, the trip end is allocated randomly in the feasible travel area according to the average travel speed. Basically, two approaches should be applied separately corresponding to the condition of target trip end. As a check for the proposed method, the feasible area is determined independently for the trip end whose facility is already specified uniquely in the algorithm. It is known that 86.7 % of the specified facilities are involved in the area estimated with assuming the average travel speed. This reflects that the effective spatial specification can be formulated in the algorithm.

Figure 5 shows the distribution of specified level for all trip ends with indicating by the above index as 59.69%. In the case of the trip end as home base, the average of the index value is counted as 75.5%. The trip ends whose area is reduced by half of the original zone size are counted as over 84.1 percent.

On the other hand, the average of the index value is counted as 70.9% for the other type of trip ends with large variance. The accumulation of trip information for family members may provide the precisely specified location for home. It must be one of the important characteristics of the proposed algorithm for combining the PT trip information and GIS information.

The particular facilities are identified uniquely because GIS provides their specific spatial locations. The spatial database of GIS covers to specify the locations of City hall, public halls, kindergartens, schools, shopping centres, post offices, large scale park, hospitals and so forth. In the algorithm, 6,809 trip ends are specified to the unique points from the facility information reported in PT survey combining with GIS database. The algorism may provides the unique spatial spots for trip ends by 17.1 % (=6809/39,757).

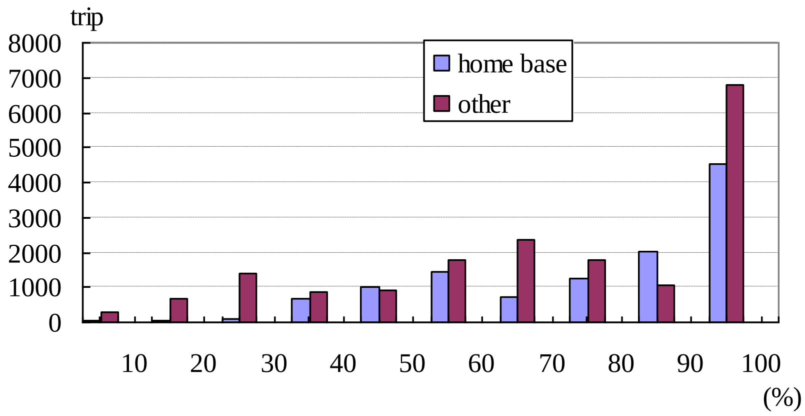

Figure 8 – The Percentage of Area Size Reduction

Data Modification with GIS Information

In terms of fundamental travel behaviour analysis, modal choice behaviour can be analyzed by logit model. Three travel modes are assumed in the analysis such as public transport, car and others. According to the motorization of local city, the share of public transport has been reduced. In terms of urban redevelopment, the activities in city centre are reduced because of low accessibility. Therefore, the higher level of service for public transport would be recommended in terms of transport policy.

Geographical information is handled in the algorithm to modify the trip survey database. The database concerning with individual trip is modified. Engineering data should be created to analyze the modal choice in the city. In particular, the essential factors for time and space are determined from the individual trip database such as travel time and travel distance. The original database is recorded on the basis of zone to zone trip. The distance between origin and destination is determined based on the centre of zones. It is assumed the origins of trip in a zone have the same zone centre. The destination of trip is determined with same manner. Therefore, the variation of individual trip distance cannot be represented.

The estimation results are summarized for logit model with and without spatial information as well as shown in Table 2. Logit model without GIS (Model 1) represents the logit model based on the ordinary database. On the other hand, Logit model with GIS (Model 2) represents the logit model with the modified database with spatial information.
Both logit models have the same structure in the utility function. The values of parameter tend to be similar. The proportion of car trips is over 50 % in observation. The values of parameter are influenced by the car dominated situation.

In logit model without GIS (Model 1), the values of parameters for travel time and travel cost are positive. It is not reasonable parameters in utility function for travel mode. Furthermore, three factors such as travel time, travel cost and access time to bus stop is determines as insignificant according to t-statistic (5 %).
On the other hand, all parameters of factors can be determined as significant in the logit model with GIS spatial information (Model 2).

Table 2 – The Parameters of Estimated Logit Models

	without GIS			with GIS		
	parameter	t-value		parameter	t-value	
travel time	0.002	2.047		-0.014	-9.770	*
travel cost	0.001	4.007		-0.001	-2.397	*
access time to bus stop (public transport)	-0.078	-1.583		-0.002	-2.007	*
bus arrival interval (public transport)	-0.038	-7.020	*	-0.055	-7.571	*
constant term (public transport)	-0.693	-3.476	*	-1.320	-7.358	*
number of vehicle (car)	0.538	7.874	*	0.642	8.914	*
female dummy(car)	-0.877	-6.458	*	-0.694	-4.991	*
driving license dummy(car)	4.307	21.598	*	4.460	20.900	*
young dummy(car)	-0.594	-4.026	*	-0.753	-4.979	*
elderly dummy(car)	-1.033	-3.377	*	-0.847	-2.719	*
constant term (car)	-3.062	-12.438	*	-4.048	-15.855	*
likelyhood ratio	0.500			0.569		

These results have been compared with observed data and estimation results.
From the Table 2, it can be observed that logit model (Model 1) would be able to estimate the decisions with about 79% accuracy.

Table 3 – The Fitness of Logit Model without GIS Information

	Logit Model without GIS	Public transport	Car	Others	Total
Observed	Public transport	6	19	186	211
Observed	Car	5	1118	39	1162
Observed	Others	13	245	627	885
Observed	Total	24	1382	852	2258
Fitness ratio		77.5%			

Table 4 – The Fitness of Logit Model with GIS Information

zc		Public transport	Car	Others	Total
Observed	Public transport	77	19	115	211
	Car	3	1126	33	1162
	Others	15	228	642	885
	Total	95	1373	790	2258
Fitness ratio			81.7%		

In the Table 3, it can be observed that logit model (Model 1) would be able to estimate the decisions with about 77.5 % accuracy. The trip database has been modified through the previous algorithm which specifies the origin and destination spots with small size. After introduction of spatial information in the input data for the logit model (Model 2), the accuracy is improved to about 81.7 %. Even though the logit model with the same structure is created, the accuracy of the model can be improved. It reflects that the travel behaviour can be described more properly with introducing the modified engineering data.

FUZZY TRAVEL BEHAVIOUR MODELLING

The travel behaviour modelling

After estimating the number of trips along with activities at each generation node, it is important to determine the mode of travel to the destination. Mode choice model estimates the mode for individual trips based on certain inputs.
In general, logit model is considered to determine the mode for a particular trip between origin and destination. In this study, fuzzy logic approach has been considered to estimate the mode choice behaviour of the individual.

In this study, four influencing variables are considered as input variables. They are: 1) travel time, 2) distance to bus stop, 3) frequency of bus service and 4) distance to destination. Based on the input, possibility of choosing the Public Transport, Car and other modes would be estimated using a set of rules. Fuzzy reasoning would be considered as appropriate technique because of the following reasons:

- All the above mentioned input variables are not crisp values and hence, they cannot be estimated exactly by an individual. In reality, there is a fuzziness involved in all of them.
- Every decision of driver (i.e. possibility of choosing a mode) has fuzziness and moreover human approximations are involved in it.
- The inference system between input and output possesses high non-linearity. The decision of trip maker can be described relatively easily.
- Rule base (IF.....THEN….. rules) with fuzzy reasoning has close resemblance of human knowledge and behaviour as they use linguistic terms and they are capable of handling complicated situations using certain rules.
- To handle such situations, the standard rule base would become so large and not applicable for some situations. In case of addition of any new input variable, this rule base becomes more complicate. On contrast, rule base with fuzzy reasoning simplifies the rules by making the variables into groups using linguistic terms.

By reviewing these factors, mode choice model has been proposed to consider fuzzy reasoning in this study. It is reported as well that fuzzy reasoning model can be applied combining with neural network to modal choice model (Petros and Haris). The decision tree model with fuzzy reasoning is introduced into rule-based models of discrete choice (Arentze, and Timmermans).

In the present study, it is proposed to consider only three fuzzy sets with triangular membership functions i.e. small, medium and large for each of input (except DLO, it has only two options. They are 'hold' and 'do not hold') and five fuzzy sets for output variables. They are very small, small, medium, large and very large. After creating the membership functions of all variables, appropriate fuzzy rule base (consists of 50 rules) has been formulated to estimate the possibility of choosing a mode. The inference rules have been presented in **Figure 9**.

The singleton fuzzy reasoning is applied to realize the above mentioned system in the study. The outline of the system is mentioned briefly. Let assume the fuzzy reasoning is considered with two input variables and an output variable.

As the knowledge of human reasoning is described by fuzzy reasoning rules, three rules are assumed as an example.

$$Rule-1 : IF \;\; x \; is \; A_1 \;\; and \;\; y \; is \; B_1 \;\; THEN \;\; z \; is \; c_1$$
$$Rule-2 : IF \;\; x \; is \; A_2 \;\; and \;\; y \; is \; B_2 \;\; THEN \;\; z \; is \; c_2$$
$$Rule-3 : IF \;\; x \; is \; A_3 \;\; and \;\; y \; is \; B_3 \;\; THEN \;\; z \; is \; c_3$$

where x and y are input variables and z is the output of reasoning.

The labels for input variables A_i, B_i are defined as fuzzy numbers. On the other hand, the label for output variable, c_i is defined as a crisp number.
If the values of input variable are determined for $(x, y)=(x_0, y_0)$, the compatibility of antecedent condition is determined as:

$$w_i = \mu_{A_i}(x_0) \times \mu_{B_i}(y_0)$$

Therefore, the conclusion as $z = c_i$ for Rule-i can be adopted by the degree of w_i. The reasoning result is derived as a sum of concluding values for all rules. That is,

$$z^* = \frac{\sum_{i=1}^{n} w_i \cdot c_i}{\sum_{i=1}^{n} w_i}.$$

This reasoning mechanism is regarded as a special case of min-max-gravity method in direct fuzzy reasoning.

In modal choice problem, input variables are regarded as explanatory factors for transport modes. The variables are summarized in Table 5. These factors are selected with referring to the logit model in the previous chapter.

The output variable is regarded as possibility of individual mode use. For example, POP stands for the possibility of public transport use. The possibility does not equivalent to the probability even though the value of index is determined between zero and one.

In singleton fuzzy reasoning process, the value of possibility is determined as five linguistic variables corresponding to the crisp number summarized in Table 5.

Table 5 – Variables in Fuzzy Logic based Model with GIS Information

TCP	travel cost for bus		Possibility	
BAL	access time to bus stop		very small	-1.0
UBF	bus arrival interval		small	-0.5
BRT	bus line hole time		medium	0.0
TCC	travel cost for car		large	0.5
NCH	number of vehicle		very large	1.0
AGE	age			
DST	travel distance			
DLO	driving license (crisp)			
POP	possiblity of public transport			
POC	possiblity of car			
POO	possiblity of others			

The value of possibility for each transport mode such as *POP*, *POC*, *POO* can be determined after the fuzzy reasoning process. It is assumed that the mode with highest possibility is chosen by the trip maker. The application method of possibility theory is summarized in terms of behaviour modelling (Kikuchi and Chakroborty, 2006).

In fuzzy reasoning model, the linguistic variables such as small, medium and large should be determined as membership functions.

Triangular Fuzzy Number (TFN) is applied to describe the decision of travel behaviour. Therefore, all linguistic labels for all variables are determined as a triangle or a trapezium. The membership function describes the fuzziness in human decision.

This corresponds to the linguistic variables in daily decisions of trip maker. For example, the travel time and travel cost for trip can be measured numerically as physical data. However, the definition of fuzzy number is required to describe human decision in reasoning.

IF	NCH	is	very small	and	DLO	is	negative	THEN	POC	is	very small
IF	NCH	is	small	and	DLO	is	negative	THEN	POC	is	very small
IF	NCH	is	large	and	DLO	is	negative	THEN	POC	is	very small
IF	NCH	is	very small	and	DLO	is	positive	THEN	POC	is	large
IF	NCH	is	small	and	DLO	is	positive	THEN	POC	is	large
IF	NCH	is	large	and	DLO	is	positive	THEN	POP	is	very small
IF	BAL	is	small	and	UBF	is	small	THEN	POP	is	very large
IF	BAL	is	small	and	UBF	is	medium	THEN	POP	is	large
IF	BAL	is	small	and	UBF	is	large	THEN	POP	is	small
IF	BAL	is	medium	and	UBF	is	small	THEN	POP	is	very large
IF	BAL	is	medium	and	UBF	is	medium	THEN	POP	is	medium
IF	BAL	is	medium	and	UBF	is	large	THEN	POP	is	small
IF	BAL	is	large	and	UBF	is	small	THEN	POP	is	large
IF	BAL	is	large	and	UBF	is	medium	THEN	POP	is	medium
IF	BAL	is	large	and	UBF	is	large	THEN	POP	is	small
IF	TCP	is	large	and	UBF	is	small	THEN	POP	is	large
IF	TCP	is	large	and	UBF	is	medium	THEN	POP	is	medium
IF	TCP	is	medium	and	UBF	is	small	THEN	POP	is	large
IF	TCP	is	small	and	UBF	is	small	THEN	POP	is	very large
IF	TCP	is	very small	and	UBF	is	small	THEN	POP	is	very large
IF	TCP	is	very small	and	UBF	is	medium	THEN	POP	is	very large
IF	TCP	is	very small	and	UBF	is	large	THEN	POP	is	large
IF	TCP	is	very small	and	DST	is	large	THEN	POO	is	small
IF	TCC	is	large					THEN	POC	is	small
IF	TCC	is	very large					THEN	POC	is	very small
IF	BRT	is	small					THEN	POO	is	large
IF	BRT	is	large					THEN	POO	is	very small
IF	BAL	is	medium					THEN	POC	is	medium
IF	AGE	is	small	and	DLO	is	positive	THEN	POP	is	large
IF	AGE	is	medium	and	DLO	is	positive	THEN	POC	is	very large
IF	NCH	is	very large	and	DLO	is	positive	THEN	POC	is	very large
IF	NCH	is	large	and	DLO	is	positive	THEN	POC	is	large
IF	DST	is	very small					THEN	POO	is	very large
IF	DST	is	small					THEN	POO	is	large

Figure 9 – The Inference Rules of Fuzzy Reasoning

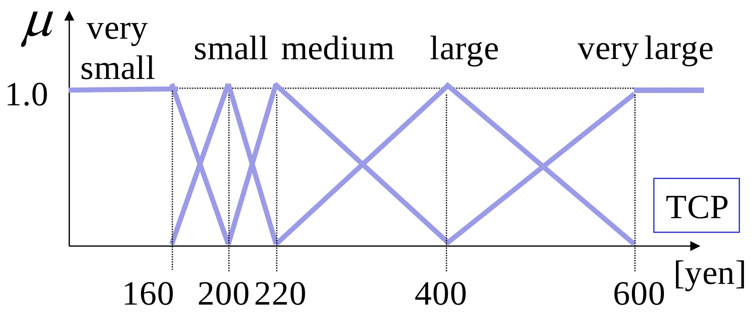

Figure 10 – Membership Functions of TCP

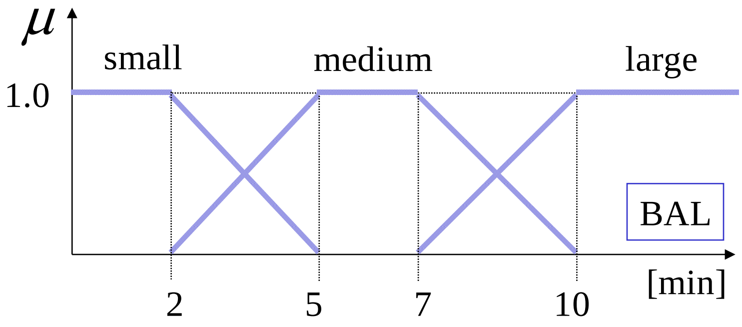

Figure 11 – Membership Functions for BAL

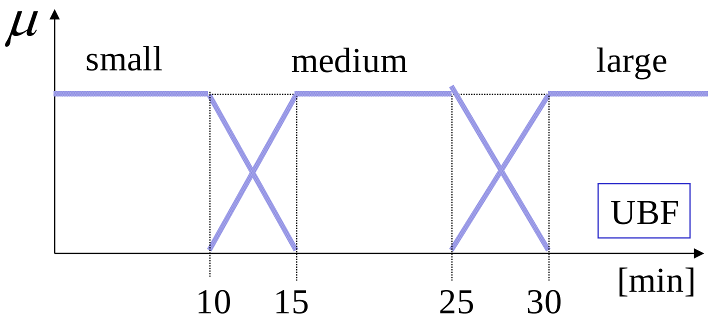

Figure 12 – Membership Functions for UBF

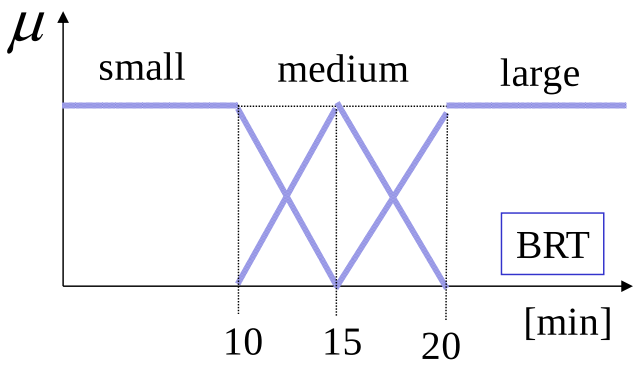

Figure 13 – Membership Functions for BRT

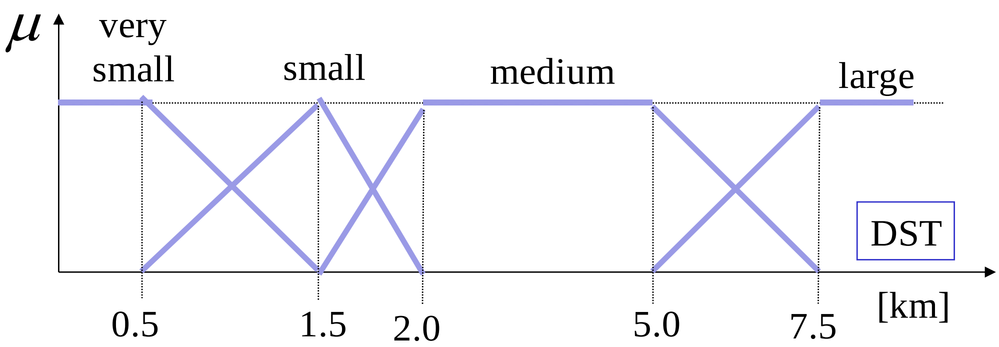

Figure 14 – Membership Functions for DST

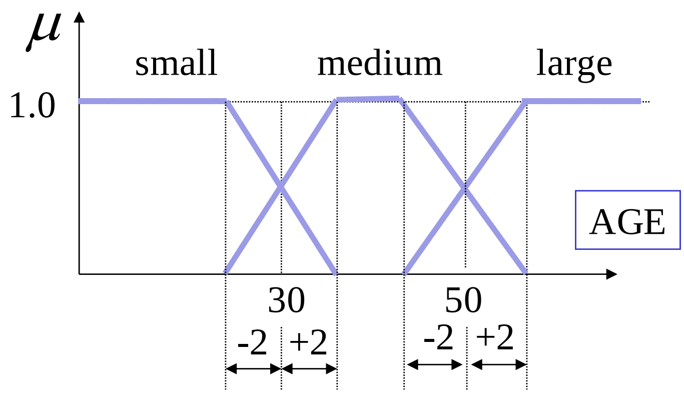

Figure 15 – Membership Functions for AGE

Performance of Fuzzy Travel Behaviour model

The proposed fuzzy logic model with spatial information can estimate the mode choice of trip makers. Table 3 summarizes the estimation results from the fuzzy logic based model with spatial information. The results can be compared with observed data. As fitness ratio is over 90 %, the rather proper estimation can be provided by the proposed model.

Table 6 – The Fitness of Fuzzy Logic based Model with GIS Information

FR Model with GIS		Public transport	Car	Others	Total
Observed	Public transport	176	20	15	211
	Car	21	1098	43	1162
	Others	15	71	799	885
	Total	212	1189	857	2258
Fitness ratio			91.8%		

It is already analyzed that the Model 1 represents the results related to logit model and model 2 is logit model with spatial information. The results are summarized in Table 3 and Table 4. On the contrary, the performance of fuzzy logic based model with spatial information (Model 3) can be mentioned with comparing the results in those tables. It is known that that the fuzzy logic model with spatial information (Model 3) is estimating the decisions with an accuracy of about 92%. From the results, it can be clearly seen the superiority of Model 3 to the logit based models. The fuzzy logic with spatial information in estimating the mode choice behaviour compared to other traditional approaches.
Therefore, the fuzzy logic with spatial information model (Model 3) has been implemented to estimate the individual decisions related to mode choice in the conducted analysis.

THE EVALUATION OF PUBLIC TRANSPORT PLOLICY

The Impact Assessment of Transport Policy

The proper values of estimation should be required to determine the public transport policy in future. It is also required that the present situation of urban transport should be described with high accuracy because it shows the original situation of transport without transport policy. The present proportion of modes can be estimated properly by fuzzy logic based model.

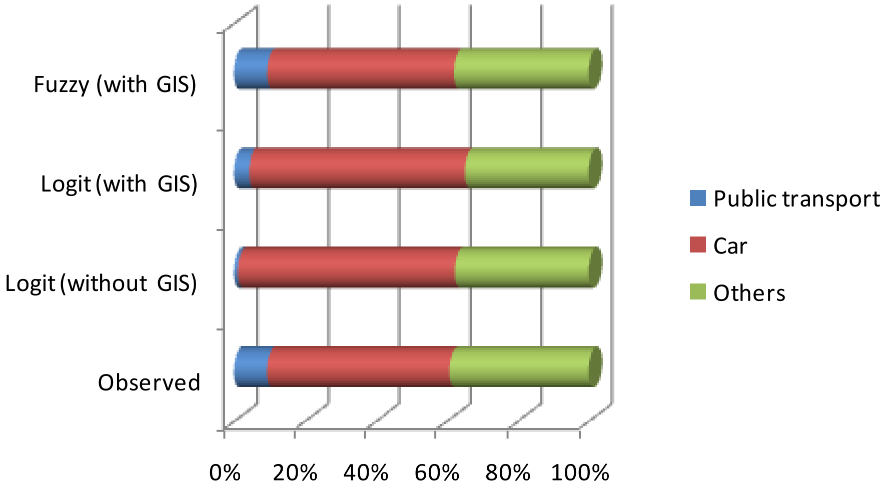

Figure 16 – Estimated Proportion of Transport Modes

In the present bus fare system, the uniform fare as 200 yen is applied in the route inside of central area of the city. On the other hand, the distance based fare is applied for the long distance journey. If a user changes routes for making a particular trip between the origin to the destination, the fare for each route should be paid. It takes at least two times of 200 yen (400 yen). The discount of two times riding is applied as 80 yen in this case. The day time discount rate is determined as well between 10:00 to 16:00. Similarly, the other types of discount fare are applied. These discount fare can be relatively easily introduced by electronic pay card system.

Even though several discount schemes are applied in the present bus system, the different types of bus fare would be required to promote the public transport use.
It is assumed the bus fare system is updated for reduction of charge for trip makers. It corresponds to for example, introduction of zone based fare system in future.
Assuming the bus fare is reduced by 5 % to 20 %, the share of public transport is estimated by three different models.

Even in the example, logit models with and without GIS information estimate few amount of change of public transport use. On the other hand, the fuzzy logic based model with GIS information estimates gradual increase for the public transport use.

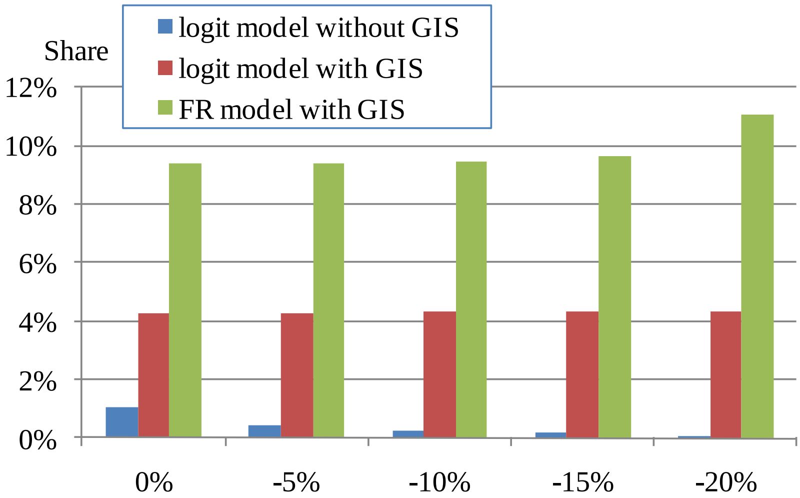

Figure 17 – The Share of Bus with Change of Bus Fare

Another public transport policy is discussed. In the bus system, the waiting time at bus stop should be important factors in service level of bus system. The waiting time is directly related with the frequency of bus service. It is assumed that the interval of bus arriving time can be reduced in proportion to the frequency of bus service. The share of bus is estimated by the fuzzy logic based modal choice model. The bus arrival time is assumed to reduce by 5 % to 20 %. It is observed that the share of bus use may not be increased in proportion to the arrival time. The share of bus use cannot be increased even though the bus arrival time is reduced by less than 20 %.

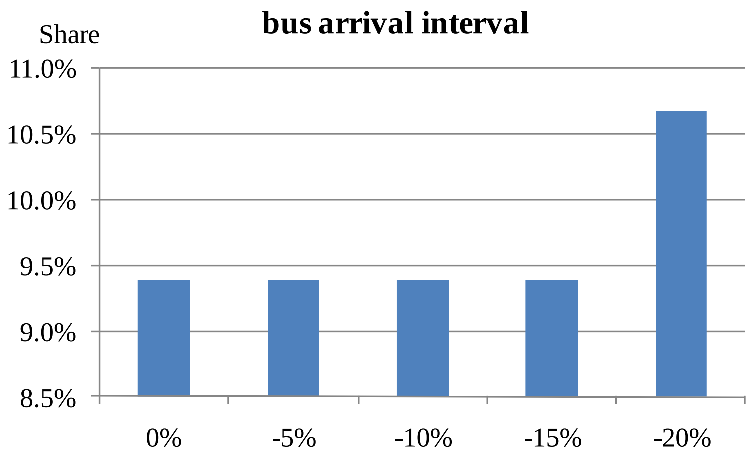

Figure 18 – The Share of Bus with Change of Bus Arrival Time

Recently the global environment problem becomes serious in transport. The modal shift from car to public transport would be recommended. It is realized that the hybrid vehicle is promoted by the tax reduction to reduce the emission of CO_2. The number of vehicles may not be reduced in the policy even though the number of petrol cars is reduced. On the other hand, the environment taxes are directly charged to the petrol cars.

According to the increase of cat travel cost, the share of public transport is expected to increase. The share of public transport is estimated corresponding to the increase of car travel cost by environment taxes.

The share of bus use is gradually increased as travel cost of cars increases by 5 % to 20 %. The car travel cost is measured in proportion to the travel distance. The variation of car travel cost seems to be relatively large comparing to the fare of bus.

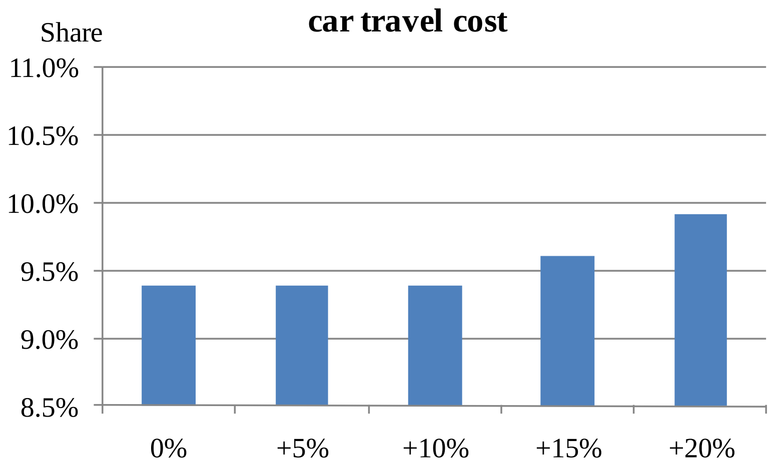

Figure 19 – The Share of Bus with Change of Car Travel Cost

The share public transport is increased sensitively comparing to the case of bus fare discount policy. However, the increased percentage is not so large.

The spatial impacts of public transport policy

The share of modes according to the public transport policy has been discussed in the previous section. The spatial distribution of trip makers can be obtained rather easily because the fuzzy logic model with GIS information estimates the change of transport modes spatially as well. As the fitness ratio is over 90 % in estimation of individual trip mode, the spatial distribution can be available to demonstrate.

In terms of pricing policy in urban transport planning, the reduction of bus fare and environmental taxation would be discussed in the study.

Figure 20 illustrates the increase of the share of public transport by large size zone according to the 20 % reduction of bus fare. This corresponds to the last case in the first example of public transport policy.
The impact of modal share change is observed larger in the west and east zones surrounding the central zone.

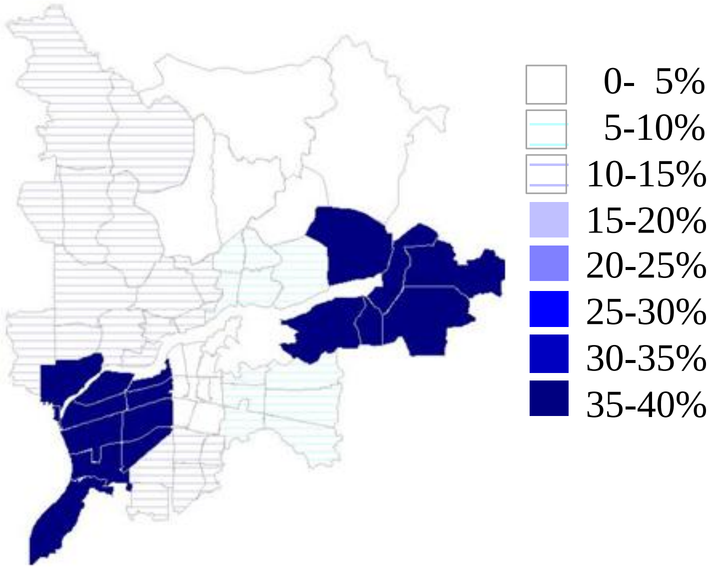

Figure 20 – The Spatial Distribution of Share of Bus with Change of Bus Fare

According to the spatial elasticity of public transport, the revision of bus network should be recommended with connecting to the bus fare system.

In the next analysis, it is assumed that travel cost of car increases by 20 % because of environment tax application. This correspond the last case of the third example. The figure shows the spatial distribution of change of public transport. Even though 20 % extra charge for the car use is assumed, the share of public transport does not increase so much. It is observed numerically as a few percent for each zone.

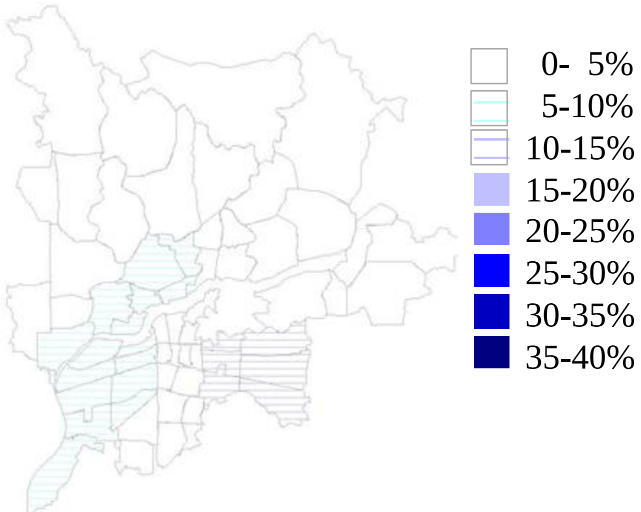

Figure 21 – The spatial Distribution of Share of Bus with Change of Car Travel Cost

CONCLUDING REMARKS

The regional trip survey data has been accumulated for over forty years. Even though the database would be applied essentially to establish the transport plan in urban area, the travel behaviour can be estimated with zone based level. Therefore, the accurate description of individual trip makers might be limited. On the contrary, the geographic information system (GIS) may provide the detail spatial position to determine the daily trip pattern on the urban area. Therefore, the integration of travel behaviour model and GIS has the advantage to estimate the travel behaviour precisely and illustrate the travel patterns on the urban area.

The following findings of the research can be summarized:

1) The function of GIS provides the analytical advantages to demonstrate trip patterns as well as to provide the precise estimation mechanism of travel behaviour. In particular, the spot of trip ends can be determined quite accurately with GIS information. The algorithm is proposed to generate the integrated trip database utilized for the individual travel pattern estimation. It corresponds that the revised engineering data is created significantly to the travel behaviour estimation. Therefore, the integration might be recommended to provide the spatial information to revise the travel behaviour model traditionally formulated with zone based database.

2) The accurate estimation of travel behaviour model is validated with the empirical study of urban transport problem in Gifu city. The elements of individual trip pattern can be estimated on the basis of integrated database with precise geometrical positions. Therefore, the daily trip patterns and activities are analyzed quite effectively to discuss the transport policy. The impact of public transport policy can be evaluated in the view of individual travel behaviour as well as overall traffic flow on the urban areas. The geographic demonstration would be utilized to discuss the impact of traffic flow on the network rather instantly.

3) It is summarized that the proposed integrated model is applied to evaluate urban transport policy. The impact of transport policy can be illustrated obviously including the change of individual travel behaviours. Therefore, the mechanism can be applied to develop the multi-agent simulation for artificial urban transport system. The day to day decision mechanism of individual trip makers can be formulated additionally to the integrated model. Even the primitive simulation of different groups of trip makers in artificial society is proposed, the emergence of urban transport system might be observed. It is expected that the advanced type of transport policy based on the autonomy of trip makers can be provided.

For further studies, the computer demonstration system of individual trip makers would be developed to discuss the dynamic transport demographic on the target urban area. The integration of fuzzy travel behaviour model and GIS might provide an initial stage of the comprehensive transport planning system.

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