DEVELOPMENT OF TRAVEL-ACTIVITY SCHEDULING MODEL CONSIDERING TIME CONSTRAINT AND TEMPORAL TRANSFERABILITY TEST OF THE MODEL

S. KAWAKAMI[1),] T. ISOBE[2)]

1) Shogo KAWAKAMI
Department of Civil Engineering
Nagoya University
Nagoya, 464-01, Japan

2) Tomohiko ISOBE
Department of Civil Engineering
Nagoya University
Nagoya, 464-01, Japan

1. INTRODUCTION

It is important to study a decision process of human travel-activity scheduling behaviour in a day, since a day (24-hours) is the most basic cycle for human daily activities. Travel-activity schedules of office-workers, who have to work at their work places, have been investigated, in order to establish the behaviour theory for people who have to do their activities which are obligatory and fixed in time and space [(3) and (8)]. The studies on human travel-activity scheduling in the preceding works have been dealt with only the theory of time allocation to travel and activities.

This paper describes a method of representing travel-activity scheduling behaviour, considering the temporal continuity of activities and the connection of locations in which activities are performed. The data used in this study were obtained by person-trip surveys of Nagoya region in 1971 and 1981.

Furthermore, we try to examine the temporal transferability of the model between the two survey years: 1971 and 1981. Kostyniuk and Kitamura have investigated the temporal stability of the activity and travel patterns [(9)]. The result of their study shows that, "although activity scheduling exhibits qualitative similarities, many aspects of travel patterns of sample subgroups do not possess quantitative stability over time".

In contrast, this paper focuses the stability of the parameters of the travel demand model representing travel-activity scheduling behaviour.

In section 2, the basic concept which is necessary to develop the travel-activity scheduling model is given. In section 3, an operational model, in which human decision-making about behaviour is represented by way of the discrete choice model, is developed. To investigate a temporal transferability of the model, the coefficients of the models which are estimated using the two sets of data obtained in 1971 and 1981 from the residents in Nagoya City, are compared in section 4. Section 5 is a conclusion of this paper.

2. BASIC CONCEPT OF TRAVEL-ACTIVITY SCHEDULING MODEL [(6)]

2.1 Classification of travel-activity schedules

Travel-activity scheduling behaviour may be caused by multi-dimensional decision-making. However, it is difficult to develop a model in which all dimensions are represented satisfactorily. We use the concept of travel-activity patterns, so as to deal with the complex decision-making behaviour approximately. Thus it becomes possible to develop the operational model.

In this study the decision process of workers' scheduling behaviour in a weekday is represented as the process of participating in discretionary activities in addition to their obligatory schedules which are composed of at-home activities and work activities. The investigation from the data base of actual human behaviour will classify typical travel-activity patterns.

2.2 Data used in this study

We are going to use data obtained from home interview surveys which were conducted in 1971 and 1981, in Nagoya, Japan.

Since the study focuses specifically on the time allocation and the locational distribution by workers on non-work activities on weekdays, a set of screening criteria is to include in the sample only: those individuals who started from the home in the first place and returned the home in the end; who worked at their fixed work-places outside the home; and whose frequency of trips was less than 10, on the survey day. The data bases which were used in estimation contained samples of 22459 and 26387 workers in 1971 and 1981, respectively.

In these data bases, a type of activity is defined according to the purpose of the trip preceding that activity. Though the original data base divided trip purposes into 18 types, we divide into four types: "work activity", "non-work out-of-home activity", "at-home activity after temporary-returning-home" and "at-home activity after permanent-returning-home", in this workers' example.

2.3 Typical travel-activity patterns

Since a range of variations in a travel-activity schedule in a whole day is very wide, it is difficult to treat each of those as independent alternatives.

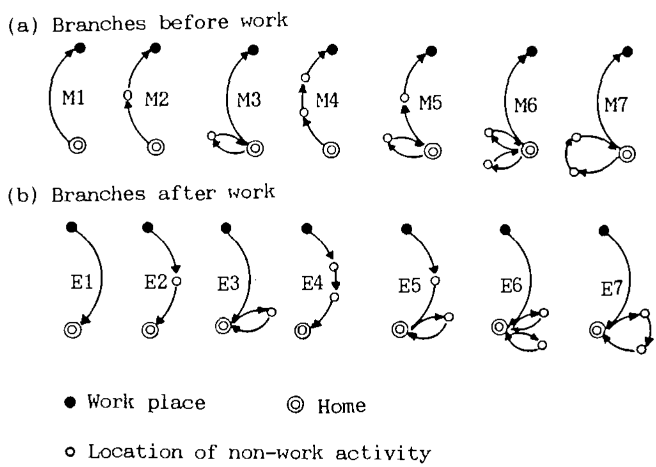

Figure 1. Typical travel-activity patterns for workers

Human daily behaviour consists of activities which are free/fixed in time and space; and which are discretionary/obligatory. In general, activities fixed in time and space have a priority of scheduling over those which are free in time/space. In addition, obligatory activities, even if free in time/space, have priority over discretionary ones.

Daily work activities are typical of workers' activity scheduling behaviour which are obligatory and fixed in time and space. Thus the existence of work activities allows us to divide workers' travel-activity schedules into two branches: before work and after work.

Consequently, considering each branch of a schedule, the number of alternative travel-activity patterns decreases, so that the model which represents workers' activity scheduling behaviour as a choice problem is developed. These typical patterns are illustrated in figure 1.

The observed scheduling behaviour of non-work activities, before/after work in a working day, are classified into 7 typical travel-activity patterns by the number of trips and activities and by frequency of temporary-returning-home. One of those patterns does not contain non-work out-of-home activity for either branch, and the others contain one or two non-work out-of-home activities.

3. FORMULATION OF TRAVEL-ACTIVITY PATTERN CHOICE MODEL [(6)]

3.1 Conceptual descriptions of travel-activity pattern choice model

Since the nature of the complex decision-making involved in daily activity scheduling has been so poorly understood, some researchers [e.g., Damm (3); Root and Recker (10); and Kitamura (8)] have tried to present various decision rules which are obviously suited for the task. A common concept in these preceding works is the analytical framework which is based on utility maximization. Further, development of the statistical models is due to this framework.

In this paper we will also develop the activity scheduling model according to the same framework as in the preceding works. However, a different characteristic of this paper from the preceding works is that the statistical choice model of location, at which people participate in discretionary activities, is added to the choice model of activity patterns.

In order to develop an operational model of activity scheduling, we consider a typical worker, who is faced with a decision about scheduling activities. He has some activities which are assumed to be obligatory. These obligatory activities take place at fixed sites such as his workplace or residence. Main factors in the decision process of travel-activity schedules are the types and the sequence of activities which workers participate in, and time allocation to discretionary activities.

The travel-activity pattern choice behaviour is, in this paper, divided into three stages: in the upper stage, the choice behaviour of travel-activity patterns without out-of-home activities besides work; in the middle stage, the choice behaviour of travel-activity patterns classified by their spatial connections; and in the lower stage, the choice behaviour of location of discretionary activities. These partial choice stages are illustrated in figure 2.

The lower choice stage, which is named as "level 3" in this paper, shows that the distribution of discretionary activity location affects the time allocation to activities by the trade-off relationship between travel time and activity duration under time constraint. Explanatory factors at this level are:

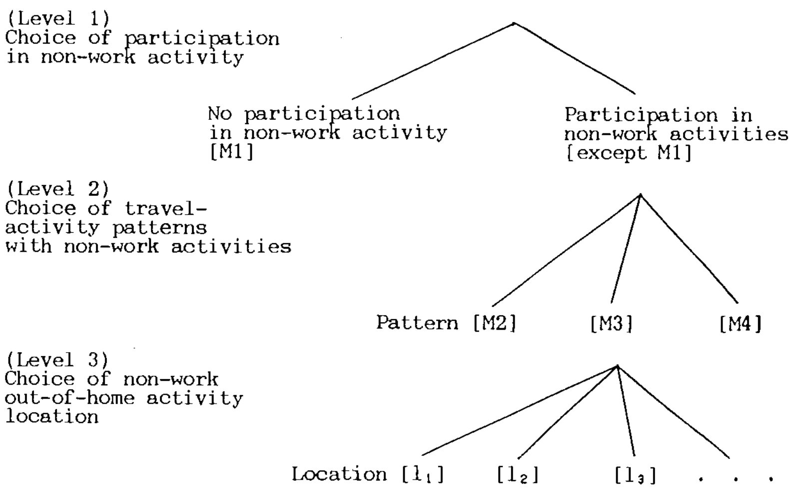

Figure 2. The choice hierarchy of travel-activity patterns (an example in the case of branch before work)

travel time, activity duration, and attractiveness measures of activity location.

When workers participate in non-work activities, their work hours and work-places being given, the middle choice stage, "level 2", represents which pattern is chosen by them to maximize their utility. Explanatory factors at this level are: total time of travel, total duration of activities, and the inclusive value from the choice model in "level 3".

The upper choice stage, "level 1", represents whether workers participate in non-work activities or not. Explanatory factors at this level are: working hours, socio-economic characteristics of workers, and the inclusive value from the choice model in level 2.

In addition, time factors (i.e., activity duration and travel time) are estimated with time allocation equations, because they depend on location of activities. Travel-activity scheduling behaviour of workers can be represented by the model structure in this section.

3.2 Choice model of location of non-work activities

Since the concept of locational choice of non-work activities is the same as that of destination choice in the disaggregate travel choice model [e.g., (1), (4) and (7)], we can adopt attractiveness of activity location and traffic impedance as explanatory factors for the the choice model of activity location.

In our model, duration of activities are added to the conventional measures, for example, population, economic measures, land use measures, and so on. Activity duration means time that people spend at an alternative location, and it is estimated by the time allocation equations.

Even if one travel-activity pattern contains two non-work activities, each location of non-work activity is regarded as an individual alternative, because we deal effectively with a small size sample. The parameters of the locational choice model of non-work activities are estimated using the pooled data across the various patterns.

We consider the interrelationships of choices made by an individual as a series of trips and activities. Then, trips around the location must be analyzed in order to explain locational choice behaviour. We introduce both trips to and from the location where workers are engaged in non-work activities into factors of the locational choice model. These travel time variables must be measured by the same rule, even though travel-activity patterns are various in number of non-work activities.

In the case that there are two non-work activities in a travel-activity pattern, the measuring rule must generalize as follows.

Suppose a triangle which connects an alternative location and the other two places which have already been decided (i.e., residence, workplace or the previous stops), as shown in figure 3. Then the sides which have the vertex that represents an alternative location indicate trajectory of travelling to or from the location, when workers go there. If the previous stops are the same, then the length of the side which connects two decided places may be regarded as zero.

According to the rule described above, it is possible to estimate travel time for all alternative locations.

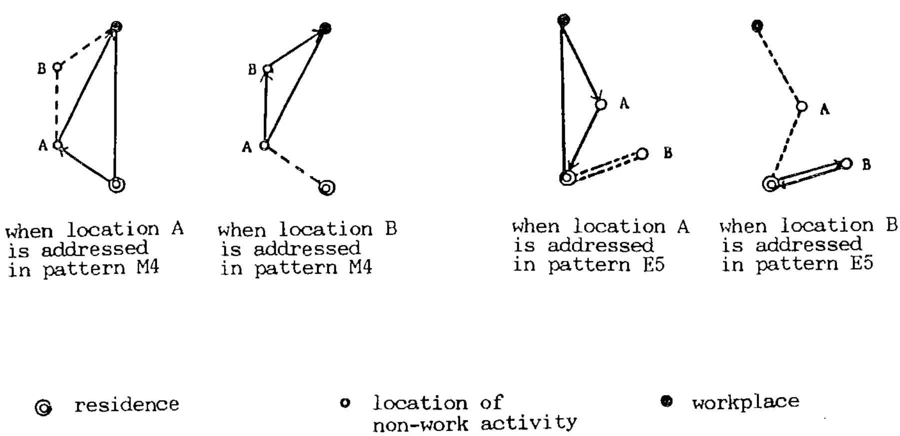

Figure 3. Triangle connecting alternative location with the fixed sites

3.3 Formulation of the travel-activity pattern choice model

Travel-activity scheduling behaviour is represented by choosing travel-activity patterns. The choice models of travel-activity patterns are formulated with the nested logit model, the structure of which consists of three stages as described in the section 3.(1).

We can express the nested logit choice probability as a product of marginal and conditional choice probabilities, each of which is a logit model [see, Ref. (2)]. For the example given, the choice probabilities of travel-activity patterns are formulated as the following equation.

$$P_n(ijl)=P_n(i)\cdot P_n(j|i)\cdot P_n(l|ij) \tag{1}$$

where,

$P_n(ijl)$: the simultaneous probability of choosing pattern i in level 1, pattern j in level 2 and location l in level 3;
$P_n(i)$: the probability of choosing pattern i in level 1;
$P_n(j|i)$: the probability of choosing pattern j in level 2;
$P_n(l|ij)$: the probability of choosing location l in level 3.

These choice probabilities are calculated with the nested logit model as follows:

$$P_n(i) = \frac{exp((V_i + S_i)\lambda_1)}{\sum_{i'} exp((V_{i'} + S_{i'})\lambda_1)} \tag{2}$$

$$P_n(j|i) = \frac{exp((V_j + S_j)\lambda_2)}{\sum_{j'} exp((V_{j'} + S_{j'})\lambda_2)} \tag{3}$$

$$P_n(l|ij) = \frac{exp((V_l)\lambda_3)}{\sum_{l'} exp((V_{l'})\lambda_3)} \tag{4}$$

and

$$S_i = (1/\lambda_2)\ ln \sum_j exp(\lambda_2 V_j) \tag{5}$$

$$S_j = (1/\lambda_3)\ ln \sum_l exp(\lambda_3 V_l) \tag{6}$$

where,

V_i: the systematic components of utility of travel-activity pattern i in level 1,
V_j: the systematic components of utility of travel-activity pattern j in level 2,
V_l: the systematic components of utility of location l in level 3;
S_i, S_j: the inclusive values determined by aggregating over utilities associated with choices in levels 2 and 3.

The inclusive value variable must be constructed within the theoretical framework used to formulate the model (in this case, it is a multinomial logit) [(5) and (11)].

The utility functions (V_i, V_j, V_l) are supposed as linear in the parameters in the example of the next section.

4. TEMPORAL TRANSFERABILITY TEST OF THE TRAVEL-ACTIVITY SCHEDULING MODEL

4.1 Comparison of data in two years

Average values which show characteristics of travel-activity scheduling behaviour in 1971 and 1981, are summarized in table 1. Ending time of work in 1981 is more later than that in 1971. Activity duration except business activity in 1981 is shortened than that in 1971. The number of activities in 1981 is also smaller than that in 1971.

Table 1. Comparison of data in two years

Factors	Years 1971	Years 1981
Starting time of the first trip	8:01	8:01
Starting time of work	8:32	8:33
Ending time of work	17:54	18:06
Arriving time of the last trip	18:48	18:54
Number of activities per person a day	0.3 (2.0)*	0.2 (1.6)*
Number of trips per person a day	2.3	2.2
Activity duration per one activity	65 min.	56 min.
Travel time per one trip	29 min.	30 min.
Sample size	22459	26387

Note: *Average value among workers who participated discretionary activities.

4.2 Estimated parameters

Parameters in the model are estimated using data of travel-activity scheduling in 1971 and 1981. The estimated results of parameters of the choice model of location of discretionary activity in level 3 are shown in table 2.

Sets of parameters are named as "71M", "71E", "81M" and "81E" in this paper. Here, "71" and "81" denote parameters estimated using data in 1971 and 1981, respectively, and "M" and "E" denote ones in the case of before and after work,

Table 2. Estimated results of the choice model of locations of discretionary activities

Explanatory Variables	Coefficients Estimate			
	71M	71E	81M	81E
Travel time to location	-0.0489 (-5.8)	-0.0443 (-21.3)	-0.0564 (-9.2)	-0.0586 (-27.2)
Travel time from location	-0.0390 (-4.3)	-0.0392 (-17.5)	-0.0246 (-4.4)	-0.0492 (-20.9)
Duration of non-work activity	0.00892 (4.2)	0.0106 (15.7)	0.0143 (5.8)	0.00903 (14.3)
Attractiveness measures				
Annual sales of restaurant business	24.8 (3.3)	47.9 (25.5)	16.2 (4.2)	30.5 (22.7)
Population of residents	4.00 (1.9)	5.20 (9.1)	2.33 (1.4)	3.05 (4.9)
Suburban dummy	4.11 (5.8)	3.52 (18.0)	2.99 (6.8)	3.73 (18.4)
Summary Statistics				
Number of observations	425	4377	611	4116
Number of cases	1416	20864	2601	22032
L(0)	-300.1	-4648.3	-555.3	-4906.9
L(c)	-1108.9	-11466.6	-1701.9	-11291.2
$L(\hat{\beta})$	-249.3	-3595.8	-464.0	-3581.8
$-2[L(0)-L(\hat{\beta})]$	101.5	2104.8	182.6	2650.3
$-2[L(c)-L(\hat{\beta})]$	1719.1	15741.5	2475.8	15418.9
ρ^2	0.174	0.227	0.164	0.270
$\bar{\rho}^2$	0.777	0.687	0.167	0.270
% right	81.8	70.5	76.1	72.7

Table 2. (cont.)

Note: L(0) is log-likelihood when all parameters are zero;
L(c) is log-likelihood without explanatory variables;
$L(\hat{\beta})$ is log-likelihood with the variables presented;
Numbers in parentheses are t-statistics which indicate the significance of the difference from 0;
% right is a measure of goodness of fit;
ρ^2 is a likelihood ratio index which is defined as

$$\rho^2 = 1 - L(\hat{\beta})/L(0);$$

$\bar{\rho}^2$ is a likelihood ratio index which is defined as

$$\rho^2 = 1 - \frac{L(\hat{\beta}) \;/ \sum_{n=1} (J_n - 1) - K}{L(0) \;/ \sum_{n=1} (J_n - 1),}$$

where, J_n refers to the number of alternatives faced by individual n and K is the total number of variables in the model.

respectively.

In order to be able to compare between the coefficients in 1971 and 1981, the same sets of explanatory variables in both years are used.

The study area is the Nagoya region in Japan. We defined 16 sub-areas within the city boundary and one suburban area as alternative location.

The estimated parameters show the following implications. The coefficients for travel time variables are negative in all cases. This means that a location for which people must spend more time to travel, is less chosen, as the same manner that the traditional trip-distribution models and destination choice models have represented.

Two types of variables, "travel time to location" and "travel time from location", are introduced in this model. The latter represents future dependency of destination choice, such as Kitamura's work in which a series of travel choices is considered [(7)]. Comparing these two variables, the absolute value of the coefficient of the former is greater than that of the latter, in each case. In other words, the former is primary to the latter.

Secondly, let us discuss the coefficients of variables of attractiveness measures of each location. The results show that three variables seem also effective in explaining locational choice behaviour. These are "annual sales of restaurant business", "population of residents" and "suburban dummy". Although we have tried to introduce other statistical variables, we were not able to find better variables.

All but "population of residents" are significant at the 0.01 level. The fact that the coefficients are all positive indicates that a worker chooses an activity location where he can feel higher attractiveness than the other location.

As an additional attractiveness measure, "duration of non-work activity" is used to explain the locational choice behaviour in this model. This variable indicates that duration spent in non-work activity at the chosen location changes according to time spent in travel to reach and leave there under the time budget constraint. The values of durations are estimated for each travel-activity pattern with the equations. (The description of methods and results of estimating durations are omitted in this paper.)

The results show that the coefficients of those are positive and significant at the 0.01 level in cases of the branches both before and after work.

There are some differences between the variables of time spent in travel and non-work activities, even if they are included in the same group of time factors. The signs of these two factors are opposite to each other. The absolute values of the coefficients of activity-duration variables are smaller than those of travel-time variables.

Hence, it seems that people would rather spend their hours in non-work out-of-home activities at their preferable location than spend it in travelling.

Further, the results represent the following. Since there are inter-relations between travel time and activity duration, saving travel time causes a rise in utility for people, through the selection of more attractive location or the increase of time spent in non-work activities.

4.3 Comparison of coefficients

Comparisons of coefficients between "71M" and "81M"; and between "71E" and "81E", are described in this section.

The statistic for the the asymptotic t test of equality of individual coefficients between two different years is calculated by the following equation:

$$t = \frac{|\beta_{71} - \beta_{81}|}{\sqrt{(\beta_{71}/t_{71})^2+(\beta_{81}/t_{81})^2}} \tag{7}$$

where,

t : asymptotic t-statistics for coefficient difference between two years;
β_{71}, β_{81} : individual coefficients in 1971 and 1981, respectively;
t_{71}, t_{81} : t-statistics for β_{71}, β_{81}, respectively.

The application of this test for the models in two different years are given in table 3. Table 3 shows the comparison between "71M" and "81M", and between "71E" and "81E". From table 3 we find that all the t tests are insignificant at the 0.05 level in the case before work, while only two coefficients among six are insignificant in the case after work.
This is occurred by reason that average values of characteristics in 1971 and 1981 are in the case after work as shown in table 1.

Table 3 shows the results from a simple comparison between parameters two years. Insignificancy means that there are less sample so as to confirm the significant difference, and does not mean that the difference is not serious. Then, it is necessary to investigate different points of various conditions between two years.

Attractiveness measures play the role of the indicators to represent relative measures within the study area. Especially, when applying the logit model to the calibration of parameters, only the relative differences among alternative attractiveness measures are effective. The relative differences of the values of explanatory variables from the minimum value among all alternatives, which are weighted by the sample subgroup chosen each alternative, are compared. Then, "Annual sales of restaurant business" and "population of residents" in 1981 increase 1.52 times and 1.60 times as large as those in 1971, respectively.

Table 3. Asymptotic t test for coefficient differences between parameters in 1971 and 1981

Explanatory Variables	Asymptotic t-statistics between 71M and 81M	Asymptotic t-statistics between 71E and 81E
Travel time to location	0.72	4.79**
Travel time from location	1.35*	3.07**
Duration of non-work activity	1.65*	1.69*
Attractiveness measures		
Annual sales of restaurant business	1.02	7.56**
Population of residents	0.62	2.54**
Suburban Dummy	1.35*	0.73

Note: *significant at the 0.10 level; **significant at the 0.05 level.

Next, the coefficients for travel time and activity duration are compared. In the case after work, the absolute values of coefficients of travel time increased, while the absolute values of coefficients of activity duration decreased. It seems that those variations are caused by changing the value of time under the time budget constraint.

In the same manner as attractiveness measures, the relative differences of the values of time factors are compared. Then, "travel time to location", "travel time from location" and "duration of non-work activity" increased 0.732 times, 1.17 times and 0.462 times, respectively, in the case before work; and increased 0.905 times, 0.789 times and 1.04 times, respectively, in the case after work.

When the coefficients in 1971 are modified in the way of dividing by the increasing rates, then these become similar to ones in 1981. The modified coefficients (71M' and 71E') are shown in table 4.

Further, in order to compare statistically these coefficients, t test by equation (7) is applied. The results are also given in table 4. In the case after work, 4 pairs of coefficients are significantly different at the 0.05 level, without modifying coefficients, while only one pair of coefficients is significantly different with modifying coefficients.

Therefore, if the coefficients in 1971 are modified as above, these coefficients are approximate to those in 1981, and the activity location choice in 1981 is able to be forecasted using them.

5. Conclusion

The travel-activity scheduling model which is developed in this paper is based on the essential elements of human behaviour, and treats travel demand totally, being different with the partial travel demand sub-models such as the modal choice model or the destination choice model.

Table 4. Modified coefficients of the choice model of locations of discretionary activities

Explanatory Variables	Modified Coefficients Estimate				Asymptotic t-statistics	
	71M'	71E'	81M	81E	between 71M' & 81M	between 71E & 81E
Travel time to location	-0.0669 (-10.8)	-0.0489 (-26.0)	-0.0564 (-9.2)	-0.0586 (-27.2)	1.20	3.39**
Travel time from location	-0.0335 (-3.2)	-0.0496 (-28.1)	-0.0246 (-4.4)	-0.0492 (-20.9)	0.75	0.14
Duration of non-work activity	0.0193 (19.7)	0.0102 (14.6)	0.0143 (5.8)	0.00903 (14.3)	1.88*	1.24
Attractiveness measures						
Annual sales of restaurant business	16.3 (1.4)	31.5 (3.9)	16.2 (4.2)	30.5 (22.7)	0.01	0.12
Population of residents	2.50 (0.7)	3.25 (3.6)	2.33 (1.4)	3.05 (4.9)	0.04	0.18

Note: *significant at the 0.10 level; **significant at the 0.05 level.

Therefore many of the parameters of the travel-activity scheduling model developed in this paper are stable, in spite that the decade between 1971 and 1981 includes the oil crises in 1973 and 1978.

In order to confirm the forecasting ability of the developed model as a travel demand model, spatial transferability test is necessary. For example, a comparison between regions which are various in size of population, degree of improvement of transportation facilities, and so on, have to be studied for a future research.

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