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Study on Choice Model of Departure Time Based on Disutility of Going to City Centre Activity

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Abstract: This paper attempts to propose departure time choice model of travelers for going to city centre based on disutility that derived from three processes of going to a place for an activity. The first is leaving home process: process from leaving home or origin to arrival at the place or destination in city centre. The second is staying at the activity place: process from arrival at the destination to the leaving the place to return home. The third is returning home: process from leaving destination to arrival at home. The model was applied to the people who went to a city centre for daily shopping. By a goodness of fit test, it was revealed the proposed model was acceptable. The model is to be applied to develop a mode choice model in further studies.

Key Words: *Departure time, disutility, going to city centre activity*

1. INTRODUCTION

This paper proposes a departure time choice model of travelers who go to a city centre for a certain activity. Many previous studies have given attention to commuting trips as the consequence that the commuting periods are the most congested periods of the day in general. In recent years, however, non-work trips for the city centre such as shopping, recreation, and so on, become to induce more and more attention (Yoshida, A, *et* al., 1990) since they may provide more or less congestion and some kinds of environmental problems in the city centre.

As similar to the work trips, departure time choice models also provide a basis of considering the congestion for non-work trips. As commuters travel under explicit constraints in time, work start time and work end time, departure time from home and leaving time from the work place take account for the explicit constraints (Sumi, T., *et* al., 1990, Li, Q., *et* al, 2002, 2003). In contrast, non-work trips are not subject to explicit constraints in time. However, these trips are naturally under the constraint of one day life cycle, and departure time choices for non-work trips could be derived from the life cycle. A previous study proposed a model to consider the one day life cycle for non-work trips (Sumi, T., *et* al., 1994) and it was expanded to take account for more short time behavior (Sumi, T., *et* al., 1995), and for the travel with a series of plural destinations (Ooeda et al., 2005). The model provided a basis for taking account of excess-day travel (Ooeda et al., 1997) and also for taking account of the frequency of a non-work trip (Chen, W., et al., 2004, 2005).

The purpose of this paper is to expand and improve the previous model further in order to apply to persons of aged families and to find the different/identical features in comparison with families of different life stages.

2. MODELING FRAMEWORK

2.1 Pattern of going to city centre activity

Going to city centre activity of a person is an activity that begin from leaving home or origin, and traveling to destination in the city centre, doing his/her activity and ends by leaving the place to return to the origin. Generally, the activity can be patterned to three main processes in accordance with the places where decisions are made as shown in Figure 1. The first is leaving home process: process to decide the departure time from home, and the second process is stay process at activity place: process from arrival to destination place to leaving the place to return home. The third is returning home process: process to decide the arrival time at home.

The one day life cycle, which means the fact human activity level becomes low early in the morning and late at night, is mainly dealt with in the first and third processes. Two types of disutility, due to the earliness in morning and lateness at night, are assumed to express the variation of activity level as shown later. The second process to decide the stay time at the destination is to be related to the activity to be done in the city centre. In order to express the behavior to stay enough time at the destination, other two types of disutility are assumed. One is that due to the shortage of stay time for expressing the behavior to have enough stay time, and that due to the length of stay time to express the stay time is not extended if people feel it enough. All the types of disutility are defined as to have positive values and the disutility-minimizing logic is applied to the behavior.

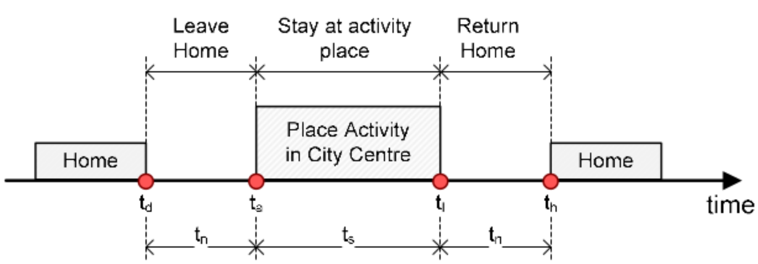


Figure 1 Pattern of going to city centre activity

2.2 Disutility of travel in a day

2.2.1 Disutility of leaving home process

Human activities are more or less reduced in the extremely early morning while people do not mind the earliness when the time of behavior becomes "enough late". Such a behavioral feature is expressed by the definition of disutility as shown by equation (1).

$$D_1 = \begin{cases} -A(t_d - t_t) \ldots\ldots\ldots (t_d < t_t) \\ 0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (t_d \geq t_t) \end{cases} \tag{1}$$

where t_d and t_t are departure time from home and the time just when people become not to mind the earliness, i.e., the time corresponding to the threshold value of D_1. A linear function was adopted here just for simplification. Note that the upper portion of the right hand side of equation (1) gives always positive value since it considers the value of t_d less than t_t. The disutility D_1 is shown in the left portion of Figure 2. Thus, the disutility is given as a linear function monotonically decreasing with the increasing departure time, t_d.

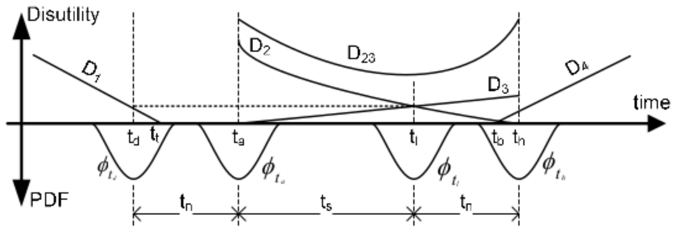


Figure 2 Types of disutility for going to city centre activity

2.2.2 Disutility of shortage of stay at city centre

As a person arrived at the destination achieves his/her travel purpose by staying there. Considering the diminishing law of utility, the utility as function of stay time, t_s, is assumed as shown by Figure 3, where stay time, t_s, is expressed as the time interval from arrival time, t_a , to leaving time, t_l. The utility function is expressed by a simple form as shown by equation (2). This definition never gives negative value of utilities derived from an activity.

$$U = 1 - e^{-\alpha t_s} \tag{2}$$

Where α is positive parameter.

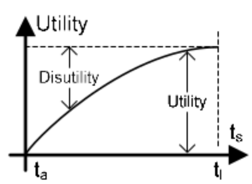


Figure 3 Utility of staying at city centre

Regarding the difference of utility derived from stay time, t_s, and the upper limit of utility, unity, as a disutility, the disutility due to the shortage of stay time, D_2 , is defined as follows:

$$D_2 = e^{-\alpha t_s} \tag{3}$$

As shown by Figure 3, utility monotonously increases as the stay time increases and people want to stay longer and longer. However, people do not stay no so long when they stay enough time in most cases, especially for "pure" daily shopping, people do not stay so long time at the destination. In order to take account of such behavior and consider the dispersion of "enough" judge and its individual difference, another disutility, D_3, is added to the above.

$$D_3 = \beta t_s \tag{4}$$

The parameter β is to have a positive value.

2.2.3 Disutility of returning home process
The reduction of human activities at late night can be similarly dealt with as that in early morning shown in section 2.2.1. Let the notations, t_h and t_b, express the arrival time at home and the time corresponding to the threshold value of the disutility due to late arrival time at home respectively, and the disutility due to the late arrival time at home, D_4, is given as follows:

$$D_4 = \begin{cases} B(t_h - t_b)\ldots\ldots\ldots(t_h > t_b) \\ 0\ldots\ldots\ldots\ldots\ldots\ldots\ldots(t_h \le t_b) \end{cases} \tag{5}$$

2.3 Formulation of departure time choice model

We regard that people decide their departure time from home considering the decision on leaving time from the destination and arrival time at home at a time. In other words, departure time is decided conditionally on the decision of leaving time from the destination and the arrival time at home. Thus, we formulate the departure time choice model as a two-step decision making as follows.

Regard all the types of disutility are addible, and the sum of the types, D_{23}, is given as a function of stay time, t_s as follows.

$$D_{23}(t_s) = D_2(t_s) + D_3(t_s) \tag{6}$$

Then the maximum stay time of a person, t_{s0}, is given as an optimum stay time as follows.

$$\frac{dD_{23}}{dt_s}\Big|_{t_{s0}} = 0 \tag{7}$$

Note that there are following relations among the variables relating to time.

$$t_l = t_s + t_a \tag{8}$$

$$t_a = t_d + t_n \tag{9}$$

$$t_h = t_n + t_l \tag{10}$$

Total time consumption for the activity is less than the time interval from t_t and t_b, the person can choose the departure time from home and arrival time at home later than t_t and earlier than t_b, respectively, and total disutility for the travel for that activity is given as a constant value by equation (7), irrelevantly to the departure time choice. The distribution of departure time from home, $\varphi_{td1}{}^{P}(t)$, is given as an unit distribution as follows.

$$\phi_{td1}^{p}(t) = \frac{1}{t_{d0} - t_t}, \qquad (t_t < t_{d0}) \tag{11}$$

The notation t_{do} stands for a constant value given by the following equation.

$$t_{d0} = t_b - t_n - t_{s0} - t_n, \tag{12}$$

It is assumed that the going and returning travel times are equal.

In cases where a person cannot choose the departure time within the range [t_t, t_{do}], that is, the cases where $t_t \geq t_{do}$, the person decide the departure time taking account of the disutilities, D_1 and D_4, too.

Suppose a person who arrive at the destination at the time, t_a, he/she decides the leaving time, t_l, considering D_2, D_3, and D_4. This process can be regarded as a conditional decision making on arrival time at the destination, t_a, as follows.

$$D_{234}(t|t_a) = D_2(t|t_a) + D_3(t|t_a) + D_4(t|t_a) \tag{13}$$

$$\left.\frac{dD_{234}(t|t_a)}{dt}\right|_{t=t_l^*} = 0, \qquad (t_t \geq t_{d0}) \tag{14}$$

Equation (14) gives both the optimum leaving time, $t_l^*(t_a)$, and the minimum disutility, $D_{234}^*(t_a)$, as functions of arrival time, t_a, and the both can be converted into functions of departure time by applying Equation (9).

Thus, the total disutility is given as a function of departure time as follows.

$$D_{12345}(t_d) = D_{234}^*(t_d) + D_1(t_d) \tag{15}$$

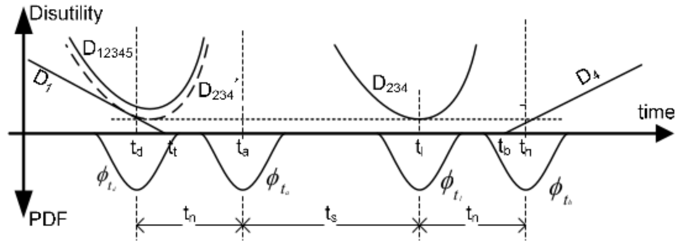


Figure 4 Constant value of utility in a time interval

As shown by Figure 4, the optimum departure time of a traveler is given as follows.

$$\left.\frac{dD_{12345}(t_d)}{dt_d}\right|_{t_d = t_{d2}} = 0, \qquad (t_t \geq t_{d0}) \tag{16}$$

Thus, the optimum departure and leaving times, t_{d2} and t_l^*, are decided at a time.

2.4 Dispersion of choice behavior

In the above arguments, we refer travel time as a constant. However, we have to consider a group of travelers and the distribution of travel time, so we shall regard every decision making is conditional on travel time hereafter.

Human behavior has always any dispersion, caused by individual and occasional differences. In order to express such differences, some parameters have to be defined as random variables. A parameter defined as a random variable can produce one dispersion of measurement. Define parameters, t_t and t_b as random variables in order to express the dispersions of departure time and leaving time choices, respectively. In addition, parameter α is defined as a random variable in order to express the dispersion of stay time.

Denote the PDF of these random variables as $\varphi_{tt}(t_t)$, and $\varphi_{tb}(t_b)$, respectively and assume their dispersions are independent to each other.

Regarding the parameters t_t and t_b as random variables, Equation (11) is rewritten into the following form.

$$\phi_{td1}(t|t_n) = \int_{-\infty}^{\infty}\int_{t_{b0}^{*}}^{\infty} \frac{1}{t_{d0}-s}\phi_{tb}(\tau)\phi_{tt}(s)d\tau ds, \qquad (t_t < t_{d0}) \tag{17}$$

Note that the value t_{b0}^{*} is the limit of t_b as to meet the requirement, $t_t<t_{d0}$. The distribution of arrival time at the destination for a give travel time, t_n, is given as follows.

$$\phi_{ta1}(t|t_n) = \phi_{td1}(t-t_n) \qquad (t_t < t_{d0}) \tag{18}$$

Considering the distribution of $\varphi_{tt}(t_t)$, and $\varphi_{tb}(t_b)$, the optimum departure time given by Equation (16) provides the distribution of departure time as follows.

$$\phi_{td2}(t|t_n) = \int \phi_{tb}(t_b)\left|\frac{dt_b}{dt_{d2}}\right|\phi_{tt}(s)d\tau ds, \qquad (t_t \geq t_{d0}) \tag{19}$$

The distribution of arrival time at the destination is again obtained as follows.

$$\phi_{ta2}(t|t_n) = \phi_{td2}(t-t_n) \qquad (t_t \geq t_{d0}) \tag{20}$$

Note that the distributions given by Equations (17), (18), (19), and (20), have the limited range of integrations derived from the restraints written in the parentheses, respectively, and they are not PDFs in normal sense. The PDFs of departure and arrival times, $\phi_{td}(t_d|t_n)$ and $\phi_{ta}(t_a|t_n)$ are given by the sums of Equations of (17) and (19), (18) and (20), respectively.

$$\phi_{td}(t_d|t_n) = \begin{cases} \phi_{td1}(t|t_n) \ldots\ldots\ldots\ldots (t_t < t_{d0}) \\ \phi_{td2}(t|t_n) \ldots\ldots\ldots\ldots (t_t \geq t_{d0}) \end{cases} \tag{21}$$

$$\phi_{ta}\left(t_a \middle| t_n\right) = \begin{cases} \phi_{ta1}\left(t \middle| t_n\right) \ldots\ldots\ldots\ldots (t_t < t_{d0}) \\ \phi_{ta2}\left(t \middle| t_n\right) \ldots\ldots\ldots\ldots (t_t \geq t_{d0}) \end{cases} \tag{22}$$

Denote the distribution of travel time, in the form of PDF, $\varphi_{tn}(t_n)$, and Equations (21) and (22) are expanded to take account of a human group with the distribution as follows.

$$\phi_{td}(t) = \int_0^\infty \phi_{td}(t|t_n)\phi_{tn}(t_n)dt_n \tag{23}$$

$$\phi_{ta}(t_a) = \int_0^\infty \phi_{ta}(t_a|t_n)\phi_{t_n}(t_n)dt_n \tag{24}$$

In addition to the above arguments, a complementary calculation is to be done. As shown later, this paper compares the arrival time distributions derived from above arguments to observed arrival time distributions. The distribution of observed arrival time clearly indicate the activity descend in the lunch time. When we consider the lunch time effect on the transportation, however, the model becomes much complicated and the applicability is significantly reduced. Therefore, the lunch time effect is taken into account as follows.

Denote lunch start time and lunch time duration as t_{LS} and t_{LD}, and the distributions of these two as $\varphi_{LS}(t)$ and $\varphi_{LD}(t)$, respectively. Probability of that a given arrival time is included in the lunch time, P_L, is obtained by the multiplication of the probability lunch has already started and the probability lunch is still continuing.

$$P_L(t_a) = \int^{t_a} \phi_{Ls}(\tau) \int_{t_a-\tau} \phi_{LD}(s)ds\,d\tau \tag{25}$$

If the arrival time is included in the lunch time, we assume simply that the trip is restrained. The distribution of arrival time is corrected as follows.

$$\phi_{t_a}^c(t_a) = \left\{1 - P_L(t_a)\right\}\phi_{t_a}(t_a) \Big/ \int \left\{1 - P_L(\tau)\right\} d\tau \tag{26}$$

3. APPLICATION OF MODEL

3.1 Calculation method to estimate parameters of the model

The above argument can be applied to all the travel behavior in a day. Concerning with the daily shopping, the duration of whole behavior, i.e., the time length from departure from home to arrival at home, is so short since the nearest destination is chosen and travelers are accustomed to buying goods in most cases. Therefore, we simplify the model to apply to this behavior by regarding that Equation (19) do not need to be applied and the travelers' behavior can be expressed enough by Equations (17) and (18). Thus, the parameters which used to express the travelers' behavior are only four, t_t, t_b, t_{LS} and t_{LD}.

The unity in Equation (2) provides the scale for measuring every disutility in the model. The parameters in the proposed model are to be specified to reproduce the observed distribution of arrival time at a destination. There are 4 parameters, and higher order multiple integrations have to be made repeatedly. We have hardly effective methods other than the simulation techniques for such situations. Therefore, the following method was applied for this purpose.
(1) The four parameters are defined as random variables. Assuming their distributions as normal distributions, replace the parameters, t_t, t_b, t_{LS} and t_{LD} with average values and standard deviations, μ_{tt}, σ_{tt}, μ_{tb}, σ_{tb}, μ_{LS}, σ_{LS}, μ_{LD}, and σ_{LD}, respectively. The number of parameters to be specified substantially is 8. Give tentatively initial value for every parameter.
(2) Generate a set of sufficiently large numbers of random numerals using the average and standard deviation for above each parameter.
(3) Take one of the numerals from the set for every parameter of the four, and calculate the departure time and arrival time or those distributions by giving them as realized values along with the assumed values for other parameters for a certain value of travel time.
(4) Repeat the above procedure until the set of random values are all taken into account.
(5) Change the travel time to another value according to the observed distribution of travel time of the observed group. Repeat the steps (3) and (4) until the full range of travel time is covered.
(6) Weight the arrival time distributions by the share of travel time distribution. And superpose them so that the arrival time distribution of all members of the group is obtained.
(7) Compare the calculated distribution of arrival time with the observed one, and calculate the square difference between them.
(8) Change the assumed values of the parameters in an iterative manner to reduce the square difference. Some types of non-linear optimization programs may be available to reduce square difference.
(9) Stop the calculation when the variation of the parameters become enough small and regard the assumed values as the estimated values for the parameters.

Note that the above mentioned procedure is not the procedure to find mathematical solution of integral equations, but the procedure to find a set of numerals possibly regarded as the parameters, and the calculated values surely depend on the set of assumed initial values. Therefore we have to have some try-and-error process to find the possible parameter values.

3.2 Implementation of survey

A survey using questionnaire was done at two areas in and in the suburb of Fukuoka City, Japan. The two areas are Meinohama and Munakata, and they are located in the western part of the city and in the eastern suburb as shown in Figure 5. These areas were chosen for they had some differences to each other while both areas have considerable shopping centers in each area. The portion of young families among the residents of Meinohama is significantly large while aged population in Munakata is larger than that in Meinohama. Residents of Meinohama can easily reach the large scaled shopping center located at the CBD of Fukuoka by frequent subway and bus services, while people in Munakata much depend on private car usage. These circumstances provide good opportunity to test the applicability of the model. Table 1 shows the characteristics of the survey, and Table 2 shows the execution of the survey. Questionnaire sheets were delivered to all the housings in the selected areas by surveyors, and were collected by the postal service. The numbers of delivered sheets were 7,055 for Meinohama and 4,430 for Munakata, and 1,231 and 1,403 were available for the above mentioned calculation.

a. Meinohama Town b. Munakata Town

Figure 5 Location of survey

Table 1 Characteristic information in questionnaire

Category of attribute	Respondent attribute
Individually attribute	Sex, Age, Drivers license, Car ownership, Resident area, Family structure
Going to city centre attributes	Departure time from home, stay time at activity place, leave time from activity place
Trip attributes	Origin, Destination, Mode travel that used

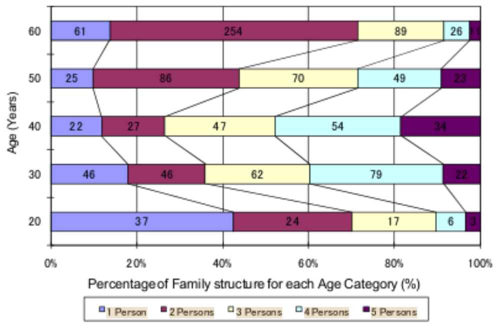
Table 2 Number of questionnaire

Location of survey (Town)	Meinohama	Munakata
Number of distribution (sheets)	7,055	4,430
Number of collection (sheets)	1,231	1,403
Collection rate (%)	17.4	32
Number of valid responses (sheets)	1,030	730
Valid response rate (%)	83.7	52

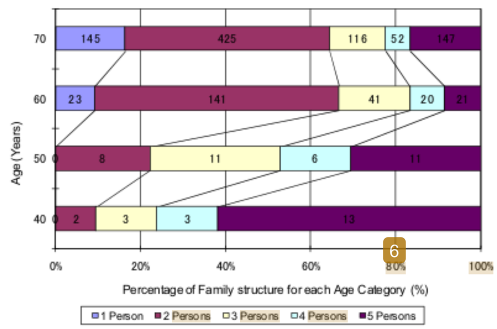
3.3 Results of survey

Figure 6a and Figure 6b show the relations between the distributions of family size and the generation. The notation "age" in the figures means generation of the representative person of a family. As shown by the figures, there are young families in Meinohama, while no young families of 20 and 30 years old could be available in Munakata. In contrast, there was no respondent over 70 years old in Meinohama, but there were many families in Munakata.

Figure 7 shows frequency of daily shopping activity in a week for each category of family structure of respondents in Meinohama and Munakata. The figure shows that the category of two persons as family size had larger trip frequencies for daily shopping in a week than those in other categories. The dominant frequencies in Meinohama and Munakata were 3 times and twice a week, respectively.

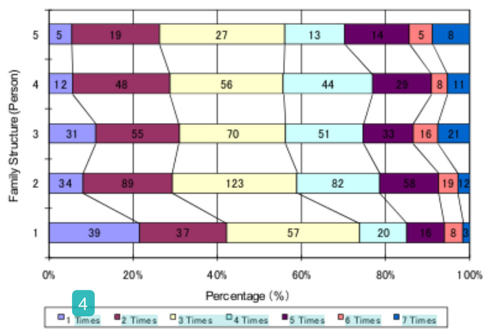


a. Meinohama

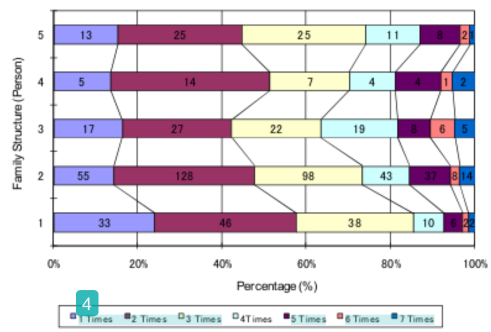


b. Munakata

Figure 6 Characteristic of age and family structure

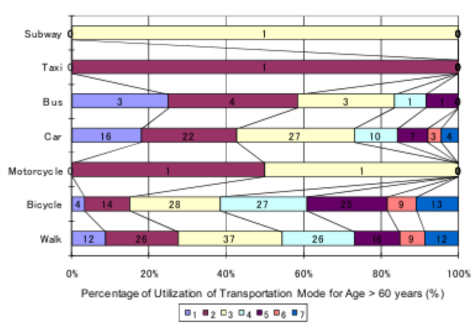


a. Meinohama

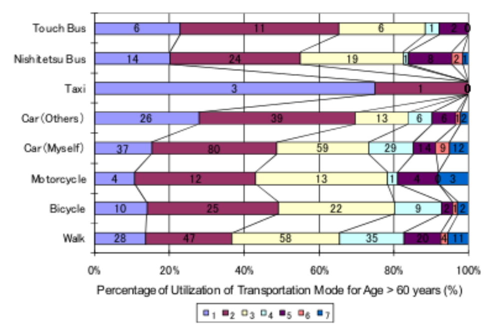


b. Munakata

Figure 7 Characteristic of number of trip.



a. Meinohama

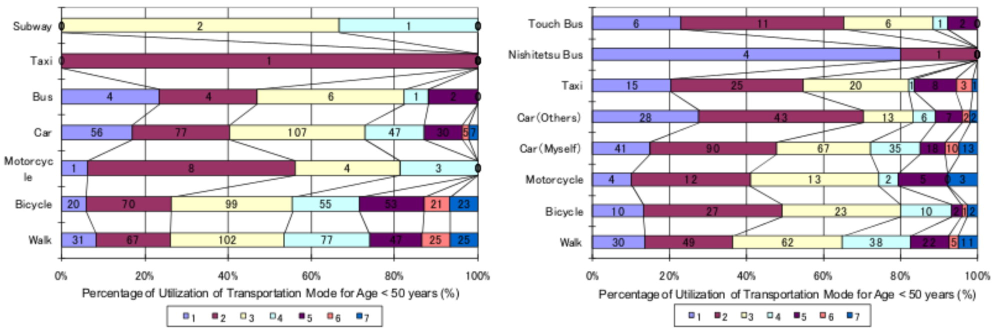


b. Munakata

Figure 8 Characteristic of mode transit utilization of age > 60 years category

Figure 8 and Figure 9 show the portions of travel modes for daily shopping of families generation 60s and those less than 50s, respectively. "Touch Bus" for Munakata residents in the figures is a bus service provided by the local government but by any private companies. It was revealed that all the available modes were used and the variation of modes depends on the local conditions.

As shown by the above arguments on the survey results, we classified the respondents in Meinohana into 2 categories of age, i.e., generation 50s and less, and that over 60s. We also categorize the family size into two, 1-2 persons, and 3 and more. On the other hand, the respondents of the generation under 50s were few in Munakata, only the respondents over 60s are taken into account for the comparison with those in Meinohama. The classification of the family size for Munakata respondents is the same as that for Meinohama respondents.



a. Meinohama b. Munakata

Figure 9 Characteristic of mode transit utilization of age < 50 years category

3.4 Results of calculation

The estimated parameters for each category of the respondents are shown in Table 3 along with the statistics showing the minimized square difference values, R_{Min}, and fitness of the calculated and observed arrival time distributions, χ^2 and KS.

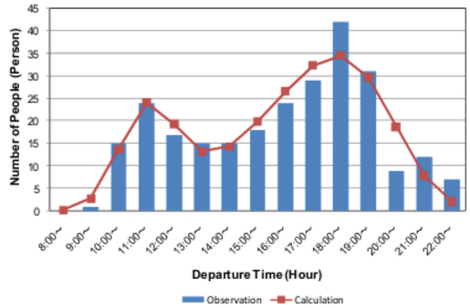
Table 3 Result Calculation of Parameter

Attribute of Category		Parameter Model								Number of data	R_{Min}	Significant level of test	
No. Family Members (People)	Age (years)	μ_{tt}	σ_{tt}	μ_{tb}	σ_{tb}	μ_{LS}	σ_{LS}	μ_{LD}	σ_{LD}			χ^2 (%)	KS (%)
1 – 2*	< 50	10.5	0.80	20.5	1.55	11.5	1.30	4.0	2.45	259	104.4	5	20
> 3*	< 50	11.0	0.35	18.0	2.20	12.0	0.25	3.5	2.50	421	825.0	1	20
1 – 2*	> 60	10.5	0.40	16.5	2.80	12.5	0.15	2.0	0.80	236	111.5	5	20
> 3*	> 60	10.5	0.65	17.5	0.60	12.5	0.15	3.5	2.30	93	42.9	5	20
1 – 2**	> 60	10.5	0.35	16.5	1.95	12.5	0.15	2.5	1.40	474	863.2	-	20
> 3**	> 60	10.0	0.40	17.0	2.55	12.5	0.60	2.0	0.95	167	45.8	5	20

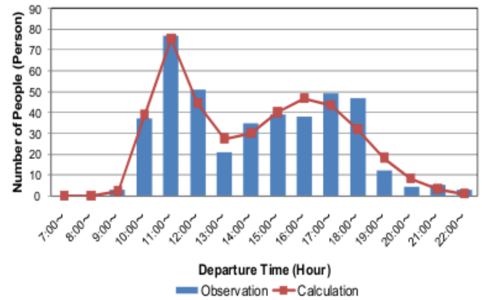
Note: * Meinohama town, **Munakata town

The arrival time distributions obtained from the calculation are shown in Figures 10 and 11. It was revealed that the calculation reproduced the observed distributions well though the Chi-square tests gave small values of goodness of fit for some categories. On the other hand, the significant levels of goodness of fit by *Kolmogorov-Shirinov* (*K-S*) test reached 20% for all categories.

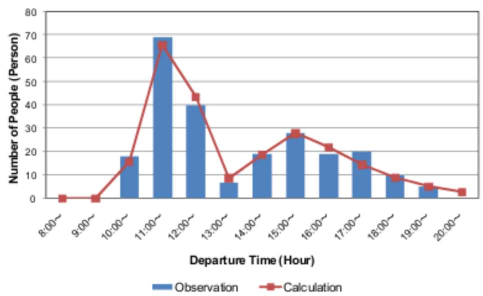
Comparing the specified values of parameters among the categories, we can find that the values for younger families appeal slightly different from other categories, while aged families may be regarded to behave similarly in spite of quite different conditions of their environment. We can expect considerable detective ability of the model to measure the human property in daily travel.



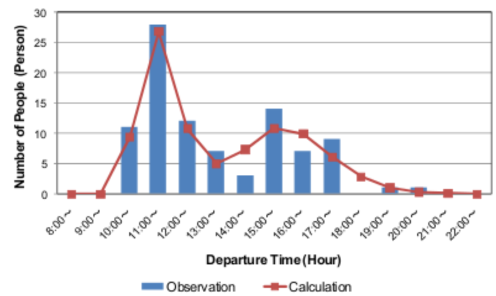
a. No. Family Member 1 - 2 persons; Age < 50 years



b. No. Family Member > 3 persons; Age < 50 years

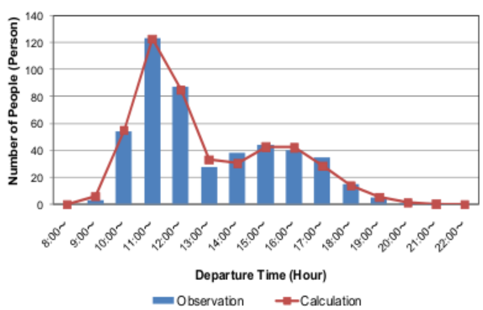


c. No. Family Member 1 - 2 persons; Age > 60 years

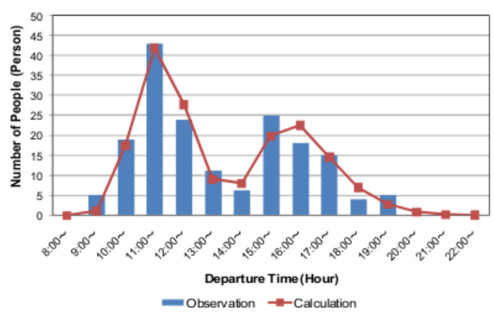


d. No. Family Member > 3 persons; Age > 60 years

Figure 10 Comparison between the calculation and the observation value of people`s departure time in Meinohama Town



a. No. Family Member 1 - 2 persons; Age > 60 years



b. No. Family Member > 3 persons; Age > 60 years

Figure 11 Comparison between the calculation and the observation value of people`s departure time in Munakata Town

4. DISCUSSIONS AND CONCLUSIONS

In this paper, the authors have proposed a model to describe the departure time decision for daily shopping travel. The model consists of departure time consideration process, staying time consideration process, and returning home consideration process. Four types of disutility, such as disutility related to earliness of departure from home, disutility related to shortage of stay at activity place, and length of the stay at the activity place, and disutility related to lateness of arrival time at home, were assumed to describe the three processes However, the model was simplified to apply to the daily shopping travel considering the feature of the travel, i.e., short duration of total behavior.

The proposed model was applied to the daily shopping activity in two areas in and in the suburb of Fukuoka city, Meinohama and Munakata, and it was revealed that the model and estimated parameters provided acceptable reproducibility of departure time choices. However, concerning with the lunch time effect in daily life cycle, the model adopted a very simple way. Since this type of behavior can be observed in some cases, the model could be revised and expanded in the future.

The calculated results also suggest that the behavioral property of younger generations is different from that of older generations, and the older generations behave similarly regardless of the difference of boundary conditions of their travel.

The model with estimated parameters is to be tested further by applying to other situations, and we can expect that the model provides a basis to find more advanced and expanded models such as mode or/and destination choice models, and so on.

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