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VALUATION OF TRAVEL TIME SAVINGS FOR PRIVATE TRAVELS: EMPIRICAL ANALYSIS BASED ON THE TIME ALLOCATION MODEL

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Abstract

This paper aims to formulate the private travel behavior by an activity-based travel model and to valuate the travel-time savings of the private trip. The formulated model has a nested structure, consisting of two models: the one-day activity model and the weekly activity model, both of which are based on the constrained utility maximization. The former model allocates time and cost in a day under the given time and income, while the latter model determines the place and time of activity in a week by allocating time and cost. The weekly diary travel data is used for estimating the coefficients in the model. By applying the DeSerpa's definition of the value of travel time savings to this model, the authors valuate it by using the data of rail-users in the Tokyo Metropolitan Area.

Key words: Value of travel time savings; Activity-based travel model; Time allocation model; Private travel; Urban railway user
Topic Area: E3 Valuation of Internal and External Benefits / Costs

1. Introduction

Generally, the benefit stemming from the transportation investment mainly consists of the savings of the travel time and the travel cost. The travel time saving is the essential part of the user's benefit in the transportation investment, therefore, the measurement of the value of travel time saving (VTTS) has been an important issue in the public investment policy. Especially the valuation of VTTS for the leisure activity becomes gradually more important because the opportunity of people's leisure activity has increased in many countries.

There have been many practical and theoretical researches on the analysis of travel time savings since the economic theory about the time allocation was introduced in the 1960s. It was Becker (1965) who first showed an idea that the consumer's utility stems from the consumption of time, not from the goods consumed directly. After the Becker's work, several researches such as DeSerpa (1971), Evans (1972) and Small (1982) have developed the various time allocation models in which the consumer's utility is maximized under the constraints of available time and budget. Several different definitions of the VTTS have been proposed as well (Jara-Diaz, 2000). Especially DeSerpa's definition of VTTS is so important that it includes distinctively two types of value of time: a value of time as a resource and a value of time as a commodity.

From a viewpoint of empirical analysis of the VTTS, the disaggregate discrete choice model has been the most popular type of demand model which is used for estimating the VTTS. Train and McFadden (1978), for the choice of travel mode in a journey to workplace, showed that the conditional indirect utility function formulated in the discrete choice theory will give the value of time as the marginal substitution rate between travel time and travel cost. In the similar manner, Truong and Hensher (1985) and later discussions (Bates, 1987; Truong and Hensher, 1987) showed how the formulation of VTTS in Becker's model and DeSerpa's model is corresponding to the VTTS formulated by the discrete choice model. Although many behavioral VTTSs have been obtained from the discrete choice analyses, the empirical analysis on the measurement of VTTS based on the time allocation model has been quite limited (except Prasetyo et al., 2001, 2002, 2003). On the other hand, the development of activity-based approach to the travel demand analysis has been motivated since 1980s by the need to understand the consumer's travel behavior. As these models are intended neither to predict the future demand nor to appraise the transportation investment, the empirical results achieved from those analyses have not been considered as the ones to produce the acceptable forecasts. However, in this paper, the authors consider that the empirical analysis based on the time allocation model can be used for the discussion on the characteristics of the VTTS even from a practical point of view.

Therefore, this paper aims to formulate the non-work activities as the time allocation model by utilizing the activity-based travel model and to valuate the travel-time savings of the private travel. The rest of this paper is organized into three sections. The next section (Section 2) provides the mathematical formulation of two sub-models corresponding to a daily activity and a weekly activity. Section 3 presents the empirical results obtained using the 2001 Tokyo Metropolitan Area activity-travel survey data (see EAST JAPAN MARKETING & COMMUNICATIONS, INC., 2002) and shows the estimated value of travel time savings and discussions. The paper concludes in Section 4 with a summary of the important results and scope of the future research.

2. Time allocation model

2.1 Basic structure of the model

Activities, generally, can be grouped into two categories: mandatory and discretionary (Yamamoto and Kitamura, 1999). Mandatory activities are those in which an individual cannot choose to engage or not to engage by his/her idea, whereas discretionary activities are those in which an individual can choose to engage or not to engage. The amount of time and cost allocated to a mandatory activity are fixed because these activities must be engaged whereas the amount of time and cost allocated to a discretionary activity and its location can often be at the discretion of the individual.

It can be anticipated that the consumers' time allocation decision on work days and that on non-work days are not independent, and that the there are some relationships between two because of the limited amounts of time and cost available. Then, in this research, the time allocation model to discretionary leisure activities is formulated for the consumers' behavior of allocating their non-work time in a week. The non-work activity is categorized into three types: the in-home leisure activity, the after-work-time leisure activity, and the out-of-home leisure activity. First, the in-home leisure activity is defined as those engaged at home, including watching TV, playing a game, gardening, etc. No travel is required for the in-home leisure activity. Such activity engaged at home as taking bath, having dinner and sleeping in the bed is also considered as ones of the in-home activities, but these are defined in this research as the mandatory activities, in which individual cannot choose to engage or not engage. Next, the after-work-time leisure activity is defined as those engaged after finishing the working hour on a work day (in most cases it is likely to be a weekday), including drinking at pubs, having dinner at restaurants, going shopping, etc. The travel derived from the after-work-time activity should start from individual's workplace and should terminate at his/her home. Finally, the out-of-home leisure activity is defined as the activities on a non-work day. The travel for the out-of-home leisure activities should start from individual's home and terminate at his/her home.

The basic assumption of this paper is that the individual allocates his/her time and cost for discretionary activities to maximize his/her utility under the constraints of available time and budget. Then, it is considered that the consumers allocate their time to either the in-home activity or the after-work-time leisure activity on the work day while they allocate their time to either the in-home activity or the out-of-home leisure activity on the non-work day. It is assumed as well that while the one type of activities is engaged the other is never engaged.

The formulated model has a nested structure. It consists of two sub-models: the one-day activity sub-model and the weekly activity sub-model, both of which are formulated based on the constrained utility maximization theory. The former sub-model is the DeSerpa's type of time allocation model which allocates time and cost in a day under the time and the income available. The weekly activity model determines the frequency of engaging the leisure activities at the specific places in a given week by allocating time and cost under the constraints of time and budget available. Because the direct utility of a consumer is regarded as a function of the frequencies of visiting the specific place, the weekly activity model can be regarded as the classical economics model in which the direct utility is derived from the goods consumed directly. The expected time and cost at the specific place, which are used as one of input data in the weekly activity model are estimated by the estimation through the one-day activity model. The estimation method used in this paper is based on the idea of the Tobit model because the model includes the corresponding constraints, but it is different from the normal Tobit model because it uses the non-linear function for the model estimation.

2.2 One-day activity model

Suppose that the individual allocates fixed, positive amounts of time and cost of the discretionary activities to the in-home leisure activities and to the out-of-home leisure activities engaged at the place k on a given non-work day. In the same manner, suppose that the individual allocates fixed, positive amounts of time and cost of the discretionary activities to the in-home leisure activities and to the after-work-time leisure activities engaged at the place k on a given work day. Here, it is assumed that the individual can engage the out-of-home activities just once at the place k in the day. This assumption is also applied to the after-work-time leisure activities.

Let the utility of the individual of the given day be

$$U_{day}(Z_k, L_k, Z_{day}, L_{day}) \tag{1}$$

where Z_k is the amount of cost allocated to the out-of-home leisure activities or to the after-work-time leisure activities engaged at the place k; L_k is the amount of time allocated to the out-of-home leisure activities or to the after-work-time leisure activities engaged at the place k; Z_{day} is the amount of cost allocated to the in-home leisure activity; and L_{day} is the amount of time allocated to the in-home leisure activity. Then the individual's time allocation behavior as an optimization problem can be formulated as

$$\underset{Z_k, L_k, Z_{day}, L_{day}}{Maximize}\ U_{day}(Z_k, L_k, Z_{day}, L_{day}) \tag{2}$$

$$subject\ to \qquad Z_k + Z_{day} \le I_{day}, \quad L_k + L_{day} = T_{day}$$

$$Z_k > 0, \quad L_k > 0, \quad Z_{day} > 0, \quad L_{day} > 0$$

where I_{day} represents the total amount of income for discretionary activities in the day and T_{day} represents the total amount of time for discretionary activities in the day.

Let the utility of any activity be the sum of two utilities stemming from consumption of time and from consumption of cost corresponding to the activity. Then, following Fujii et al. (1999), let the total daily utility be the sum of in-home leisure activities and the out-of-home leisure activities for the non-work day, and let the total daily utility be the sum of in-home leisure activities and the after-home leisure activities for the work day. The total daily utility can be expressed as

$$U_{day}(Z_k, L_k, Z_{day}, L_{day}) = U_{Lk}(L_k) + U_{Zk}(Z_k) + U_{Ld}(L_{day}) + U_{Zd}(Z_{day}) \tag{3}$$

Let

$$U_{Lk}(L_k) = \alpha_{Lk} \ln(L_k) \tag{4a}$$

$$U_{Zk}(Z_k) = \alpha_{Zk} \ln(Z_k) \tag{4b}$$

$$U_{Ld}(L_{day}) = \alpha_{Ld} \ln(L_{day}) \tag{4c}$$

$$U_{Zd}(Z_{day}) = \alpha_{Zd} \ln(Z_{day}) \tag{4d}$$

be the functional form of each utility term. For $\alpha_{Lk}, \alpha_{Zk}, \alpha_{Ld}, \alpha_{Zd}$ in eq. (3), let

$$\alpha_{Lk} = \exp(AX_k + \varepsilon_L) \tag{5a}$$

$$\alpha_{Zk} = \exp(BX_k + \varepsilon_Z) \tag{5b}$$

$$\alpha_{Ld} = \exp(CY_n) \tag{5c}$$

$$\alpha_{Zd} = \exp(DY_n) \tag{5d}$$

where A, B, C, D represents the vectors of unknown parameters, X_k is a vector of exogenous variables corresponding to the place k, Y_n is a vector of exogenous variables corresponding to the individual attributes and ε_L and ε_Z are normal random components variating with a mean of 0 and a variance of σ_L, σ_Z respectively and without covariance between two error components. By applying the Kuhn-Tucker's theorem to the optimization problem of eq. (2), the first-order conditions are derived as

$$I_{day} - Z_k^{\ *} + Z_{day}^{\ *} = 0 \quad (\lambda_1 > 0) \tag{6a}$$

$$T_{day} - L_k^{\ *} + L_{day}^{\ *} = 0 \quad (\mu_1 > 0) \tag{6b}$$

$$Z_k^{\ *} > 0 \quad (\lambda_k = 0) \tag{6c}$$

$$L_k^{\ *} > 0 \quad (\mu_k = 0) \tag{6d}$$

$$Z_{day}^{\ *} > 0 \quad (\lambda_{day} = 0) \tag{6e}$$

$$L_{day}^{\ *} > 0 \quad (\mu_{day} = 0) \tag{6f}$$

$$\frac{\partial U_{day}(Z_k, L_k, Z_{day}, L_{day})}{\partial Z_k} = \frac{\partial U_{day}(Z_k, L_k, Z_{day}, L_{day})}{\partial Z_{day}} \tag{6g}$$

$$\frac{\partial U_{day}\left(Z_k, L_k, Z_{day}, L_{day}\right)}{\partial L_k} = \frac{\partial U\left(Z_k, L_k, Z_{day}, L_{day}\right)}{\partial L_{day}} \tag{6h}$$

where $\lambda_1, \mu_1, \lambda_k, \mu_k, \lambda_{day}, \mu_{day}$ are the Lagrange multipliers to budget constraint, time constraint, non-negative constraints of Z_k and L_k, and non-negative constraints of Z_{day} and L_{day} respectively. Then, the two equations corresponding to two error components are derived from the first order conditions and the assumptions of formulation of utility function as

$$\varepsilon_L = \ln(L_k^*) - \ln(L_{day}^*) + CY_n - AX_k \tag{7a}$$

$$\varepsilon_Z = \ln(Z_k^*) - \ln(Z_{day}^*) + DY_n - BX_k\,. \tag{7b}$$

Finally the following likelihood functions are derived due to the assumptions of these two error terms as a normal distribution

$$L_L = \frac{1}{\sigma_L \cdot L_k^*} \cdot \phi\left[\frac{\ln(L_k^*) - \ln(L_{day}^*) + CY_n - AX_k}{\sigma_L}\right] \tag{8a}$$

$$L_Z = \frac{1}{\sigma_Z \cdot Z_k^*} \cdot \phi\left[\frac{\ln(Z_k^*) - \ln(Z_{day}^*) + DY_n - BX_k}{\sigma_Z}\right] \tag{8b}$$

where $\phi(\cdot)$ represents a probability density function of the normal distribution. The unknown parameters are A, B, C, D and σ_L, σ_Z. They can be estimated by maximizing the following likelihood function:

$$LL_{day} = \sum_n \left(\ln L_L + \ln L_Z\right). \tag{9}$$

2.3 Weekly activity model

Suppose that an individual allocates his/her time and cost to the in-home activities and the out-of-home leisure activities by deciding the frequencies of visiting the place k for the out-of-home leisure activities on non-work days. In the same way, suppose that the individual allocates his/her time and cost to the in-home activities and the after-work-time leisure activities by deciding the frequencies of visiting the place k for the after-work-time leisure activities on work days. In this paper, it is assumed that the unit time and the unit cost allocated to each leisure activity are constant and it is assumed that individual can allocate time and cost by deciding the frequencies of engagement of each leisure activity.

Let the total utility of the individual in a given week be

$$U_{week}\left(\mathbf{N}^W, \mathbf{N}^H, L_{week}, Z_{week}\right) \tag{10}$$

where $\mathbf{N}^W, \mathbf{N}^H$ are the vectors of frequencies of visiting various places on work days and on non-work days respectively; L_{week} and Z_{week} are the time and the cost allocated to the in-home leisure activities respectively. The utility maximization problem with time and budget constraints are expresses as

$$\underset{\{\mathbf{N}^W, \mathbf{N}^H, L_{week}, Z_{week}\}}{Max} U_{week}\left(\mathbf{N}^W, \mathbf{N}^H, L_{week}, Z_{week}\right) \tag{11a}$$

subject to

$$\sum_k \left[N_k^W \left(\overline{Z_k}^{W*} + c_k^W - c_R \right) \right] + \sum_k \left[N_k^H \left(\overline{Z_k}^{H*} + c_k^H \right) \right] + Z_{week} \leq I_{week} \tag{11b}$$

$$\sum_k \left[N_k^W \left(\overline{L_k}^{W*} + t_k^W - t_R \right) \right] + \sum_k \left[N_k^H \left(\overline{L_k}^{H*} + t_k^H \right) \right] + L_{week} = T_{week} \tag{11c}$$

$$N_k^W \geq 0,\ N_k^H \geq 0 \quad (\forall k)\ ,\quad Z_{week} > 0,\ \ L_{week} > 0 \tag{11d}$$

where N_k^W, N_k^H are frequencies of visiting the place k on work days and on non-work day respectively, $\overline{Z_k}^{W*}, \overline{Z_k}^{H*}$ are the expected unit cost allocated to the leisure activities engaged at the place k on work day and on non-work day respectively, $\overline{L_k}^{W*}, \overline{L_k}^{H*}$ are the expected unit time allocated to the leisure activities engaged at the place k on work days and on non-work day respectively, c_k^W, c_k^H are the unit cost consumed in an engagement of activities on work days and on non-work day respectively, t_k^W, t_k^H are the unit time consumed in an engagement of activities on work days and on non-work day respectively, and I_{week}, T_{week} are the amount of income and time available in a week.

In the same way as the one-day activity model shown earlier, let the total weekly utility be the sum of the utilities stemming from three types of activities: the in-home leisure activities, the out-of-home leisure activities on non-work days and the after-work-time leisure activities on work days. Let the in-home leisure activities be the sum of the utilities stemming from the consumption of time and from the consumption of money, which are expressed as

$$U_{Lw}(L_{week}) = e^{GY_n} \ln(L_{week}) \tag{12a}$$

$$U_{Zw}(Z_{week}) = e^{HY_n} \ln(Z_{week}) \tag{12b}$$

where G, H are the vectors of unknown parameters and Y_n is a vector of individual attributes.

Let the utilities for the out-of-home leisure activities and for the after-work-time leisure activities be respectively

$$U_{Nk}^W(N_k^W) = \alpha_k^W \ln(N_k^W + 1) \tag{13a}$$

$$U_{Nk}^H(N_k^H) = \alpha_k^H \ln(N_k^H + 1) \tag{13b}$$

where α_k^W, α_k^H are the location factors which are assumed to be the following functional forms:

$$\alpha_k^W = \exp\left[E^W Y_n + F^W X_k + \beta_t^W (t_k^W - t_R) + \beta_c^W (c_k^W - c_R) + \varepsilon_{Nk}^W\right] \quad (14a)$$

$$\alpha_k^H = \exp\left[E^H Y_n + F^H X_k + \beta_t^H t_k^H + \beta_c^H c_k^H + \varepsilon_{Nk}^H\right] \quad (14b)$$

where E^W, E^H, F^W, F^H represent the vectors of unknown parameters, X_k is a vector of the exogenous variables corresponding to the place k, Y_n is a vector of individual attributes and $\varepsilon_k^W, \varepsilon_k^H$ are the error components, both of which follow the independent normal distribution variating with a mean of 0 and the variances of σ_N^W, σ_N^H respectively.

The expected unit time and unit cost consumed are estimated by using the one-day activity model. The optimization conditions of the one-day activity model are shown as

$$\frac{e^{AX_k+\varepsilon_L}}{L_k^*} = \frac{e^{CY_n}}{T_{day} - L_k^*} \quad (15a)$$

$$\frac{e^{BX_k+\varepsilon_Z}}{Z_k^*} = \frac{e^{DY_n}}{I_{day} - Z_k^*}. \quad (15b)$$

Then, the optimal unit time and unit cost allocated for the out-of-home leisure activities and the after-work-time leisure activities are derived as

$$L_k^* = \frac{e^{AX_k+\varepsilon_L}}{e^{AX_k+\varepsilon_L} + e^{CY_n}} \cdot T_{day} \quad (16a)$$

$$Z_k^* = \frac{e^{BX_k+\varepsilon_Z}}{e^{BX_k+\varepsilon_Z} + e^{DY_n}} \cdot I_{day}. \quad (16b)$$

Therefore, the expected unit time and the expected unit cost are shown as

$$\overline{L_k^*} = \int_{-\infty}^{\infty} \left[L_k^*(\varepsilon_L) \cdot f(\varepsilon_L)\right] d\varepsilon_L = T_{day} \cdot H_1 \quad (17a)$$

$$\overline{Z_k^*} = \int_{-\infty}^{\infty} \left[Z_k^*(\varepsilon_Z) \cdot f(\varepsilon_Z)\right] d\varepsilon_Z = I_{day} \cdot H_2 \quad (17b)$$

where H_1 and H_2 are expressed as

$$H_1 = E\left(\frac{e^{AX_k+\varepsilon_L}}{e^{AX_k+\varepsilon_L} + e^{CY_n}}\right) = \int_{-\infty}^{\infty}\left[\left(\frac{e^{AX_k+\varepsilon_L}}{e^{AX_k+\varepsilon_L} + e^{CY_n}}\right) \cdot f(\varepsilon_L)\right] d\varepsilon_L \quad (18a)$$

$$H_2 = E\left(\frac{e^{BX_k+\varepsilon_Z}}{e^{BX_k+\varepsilon_Z} + e^{DY_n}}\right) = \int_{-\infty}^{\infty}\left[\left(\frac{e^{BX_k+\varepsilon_Z}}{e^{BX_k+\varepsilon_Z} + e^{DY_n}}\right) \cdot g(\varepsilon_Z)\right] d\varepsilon_Z \quad (18b)$$

where $f(\varepsilon_L)$ and $g(\varepsilon_Z)$ are the probability density functions of the error terms ε_L and ε_Z respectively.

Finally, the first-order condition for the problem in eq.(11) is derived from the Kuhn-Tucker's theorem as

$$\frac{\partial U_{week}\left(\mathbf{N}_k^W, \mathbf{N}_k^H, Z_{week}, L_{week}\right)}{\partial N_k^W} - \lambda_2\left(\overline{Z_k^{W*}} + c_k^W - c_R\right) - \mu_2\left(\overline{L_k^{W*}} + t_k^W - t_R\right)$$

$$= -\lambda_{Nk}^{W} \begin{cases} = 0 & (N_k^W > 0) \\ < 0 & (N_k^W = 0) \end{cases} \qquad (\forall k) \tag{19a}$$

$$\frac{\partial U_{week}\left(\mathbf{N}_k^W, \mathbf{N}_k^H, Z_{week}, L_{week}\right)}{\partial N_k^H} - \lambda_2\left(\overline{Z_k{}^{H*}} + c_k^H\right) - \mu_2\left(\overline{L_k{}^{H*}} + t_k^H\right)$$

$$= -\lambda_{Nk}^{H} \begin{cases} = 0 & (N_k^H > 0) \\ < 0 & (N_k^H = 0) \end{cases} \qquad (\forall k) \tag{19b}$$

$$\frac{\partial U_{week}\left(\mathbf{N}_k^W, \mathbf{N}_k^H, Z_{week}, L_{week}\right)}{\partial Z_{week}} - \lambda_2 = 0 \tag{19c}$$

$$\frac{\partial U_{week}\left(\mathbf{N}_k^W, \mathbf{N}_k^H, Z_{week}, L_{week}\right)}{\partial L_{week}} - \mu_2 = 0\,. \tag{19d}$$

By applying the specific utility function to the above first-order conditions, the likelihood function is derived as

$$L_{Nk}^{W} \begin{cases} = \dfrac{1}{\sigma_N^W \cdot \left(N_k^{W*} + 1\right)} \cdot \phi\left[\dfrac{\ln(N_k^{W*} + 1) + \ln S_k^{W*}}{\sigma_N^W}\right] & (if\ N_k^{W*} > 0) \\ = \Phi\left[\dfrac{\ln(N_k^{W*} + 1) + \ln S_k^{W*}}{\sigma_N^W}\right] & (if\ N_k^{W*} = 0) \end{cases} \qquad (\forall k) \tag{20a}$$

$$L_{Nk}^{H} \begin{cases} = \dfrac{1}{\sigma_N^H \cdot \left(N_k^{H*} + 1\right)} \cdot \phi\left[\dfrac{\ln(N_k^{H*} + 1) + \ln S_k^{H*}}{\sigma_N^W}\right] & (if\ N_k^{W*} > 0) \\ = \Phi\left[\dfrac{\ln(N_k^{H*} + 1) + \ln S_k^{H*}}{\sigma_N^H}\right] & (if\ N_k^{W*} = 0) \end{cases} \qquad (\forall k) \tag{20b}$$

where

$$S_k^W = \frac{\left(\overline{L_k^{W*}} + t_k^W - t_R\right)}{L_{week}^*} \cdot \exp\left[GY_n - E^W Y_n - F^W X_k - \beta_t^W (t_k^W - t_R) - \beta_c^W (c_k^W - c_R)\right]$$
$$+ \frac{\left(\overline{Z_k^{W*}} + c_k^W - c_R\right)}{Z_{week}^*} \cdot \exp\left[HY_n - E^W Y_n - F^W X_k - \beta_t^W (t_k^W - t_R) - \beta_c^W (c_k^W - c_R)\right] \tag{21a}$$

$$S_k^H = \frac{\left(\overline{L_k^{H*}} + t_k^H\right)}{L_{week}^*} \cdot \exp\left[GY_n - E^H Y_n - F^H X_k - \beta_t^H \cdot t_k^H - \beta_c^H \cdot c_k^H\right]$$
$$+ \frac{\left(\overline{Z_k^{H*}} + c_k^H\right)}{Z_{week}^*} \exp\left[HY_n - E^H Y_n - F^H X_k - \beta_t^H \cdot t_k^H - \beta_c^H \cdot c_k^H\right] \tag{21b}$$

and $\phi(\cdot)$ is a probability density function of the normal distribution and $\Phi(\cdot)$ is a cumulative probability function corresponding to $\phi(\cdot)$. Finally, the unknown parameters are estimated by maximizing the following likelihood function:

$$LL_{week} = \sum_n \sum_k \ln L_{Nk}^W + \sum_n \sum_k \ln L_{Nk}^H\,. \tag{22}$$

3. Application

3.1 Data and model estimation

The data used in the empirical analysis comes from a time-use diary survey conducted in the Tokyo Metropolitan Area, Japan in 2001 (see EAST JAPAN

MARKETING & COMMUNICATIONS, INC., 2002). The survey collected a seven-day time-use diary data as well as socio-demographic characteristics and the purchase history from a sample of 2,900 respondents. The sample data used in this study contains only for the workers commuting to their offices by rail. The sample comprises 290 individuals who worked at least one day in a week and who engaged either the after-work-time leisure activity on the work day or the out-of-home leisure activity on the non-work day. Since the data of the unit cost in purchasing something in the leisure activities is not available in the surveyed data, it was collected by our original survey in 2002.

For the estimation of the one-day activity model, two models are specified separately because the behavior of people is expected to be different between work days and non-work days. The results of model estimation for the work day and for the non-work day are shown in Table 1 and 2 respectively. For the estimation of the weekly activity model, as discussed above, it is necessary to use the expected unit time and the expected unit cost. Although they can be obtained by the integrals shown in eq. (18a) and (18b), they cannot be led to the open form. Then, the expect unit time and expected unit cost are

Table 1 Results for the work day of the one-day activity model

	variables	parameter	t-statistics
A	number of retailers in 1km2	0.000663	2.11
B	dummy of car-ownership	1.07	1.13
C	constant	0.885	4.74
	dummy of marriage for woman	1.68	4.42
	dummy of 30's-year-old	-0.477	-1.94
D	constant	-2.56	-10.1
σ	vaiance of time	1.81	24.9
	variance of cost	4.3	24.8
	log-likelihood ratio		0.404
	mumber of observation		290

Table 2 Results for the non-work day of the one-day activity model

	variables	parameter	t-statistics
A	dummy of car-ownership	-0.226	-1.67
B	dummy of car-ownership	1.21	2.22
C	constant	1.20	4.74
	dummy of 40's-year-old	0.404	2.43
D	constant	-1.44	-2.92
	dummy of woman	-3.07	-4.93
	dummy of marriage	-1.37	-2.18
	dummy of 40's and 50's-year-old	1.59	2.55
σ	vaiance of time	1.18	25.5
	variance of cost	4.47	25.5
	log-likelihood ratio		0.436
	mumber of observation		287

Table 3 Results for the weekly activity model

	variables	parameter	t-statistics
E(work day)	dummy of 30's and 40's-year-old	-0.39	-3.17
F(work day)	number of retailers in 1km^2	0.00158	7.93
β_t(work day)	travel time by rail	-0.0129	-2.46
E(non-work day)	dummy of 40's and 50's-year-old	-0.398	-3.49
F(non-work day)	number of retailers in 1km^2	0.00156	6.74
	dummy of car-ownership	2.5	10.5
β_t(non-work day)	travel time by rail	-0.00024	-0.14
	travel time by auto	0.00536	3.39
G	constant	3.94	20.6
H	constant	0.762	2.41
	dummy of woman	-1.15	-2.79
	dummy of marriage	0.309	1.21
σ	vaiance of time	1.2	17.9
	variance of cost	1.02	17.5
	log-likelihood ratio		0.446
	mumber of observation		389

simulated for all sample individuals by applying the Simpson method to the integral in eq. (18a) and (18b). The Table 3 shows the result of the parameter estimation of the weekly activity model.

From the results of parameter estimation, the following properties of time allocation behavior are found:

- The time engaging the after-work-time leisure activity by married females are less than that by other types of consumers including non-married females and males
- The cost consumed on non-work days by females are more than that consumed by males
- The frequency of the after-work-time leisure activities tends to be higher at the area where there are more retailers.

3.2 Valuation of VTTS

For the valuation of the VTTS, the definition proposed by DeSerpa (1971) is applied to the utility function of the weekly activity model. As shown earlier, DeSerpa defines the VTTS as a sum of the value of time as a resource and that as a commodity, which are derived from the first-order conditions corresponding to the utility maximization problem. In this paper, the VTTS can be derived from the weekly activity model shown in eq. (11) as

$$VTTS_k = \frac{\mu_2^*}{\lambda_2^*} - \left.\frac{\partial U_{week}/\partial t_k}{\lambda_2}\right|_{U_{week}^*} \qquad (23)$$

where λ_2 is the Lagrange multiplier for the budget constraint of the weekly activity model, μ_2 is the Lagrange multiplier for the time constraint of the weekly activity model, U_{week} is the utility function of the week and t_k is the travel time corresponding to the activity engaged at the place k.

As the optimum Lagrange multipliers are derived from the specified utility function, the value of time as a resource can be shown as

$$\frac{\mu_2^*}{\lambda_2^*} = \frac{\partial U_{week} / \partial L_{week}}{\partial U_{week} / \partial Z_{week}}\bigg|_{U_{week}^*} = \frac{\exp(GY_n)/L_{week}}{\exp(HY_n)/Z_{week}}\bigg|_{U_{week}^*} = \exp(GY_n - HY_n)\frac{Z_{week}^*}{L_{week}^*}. \qquad (24)$$

On the other hand, the value of time as a commodity is also derived from the utility function as

$$\frac{\partial U_{week} / \partial t_k}{\lambda_2}\bigg|_{U_{week}^*} = \frac{\partial[\alpha_k \ln(N_k + 1)] / \partial t_k}{\partial U_{week} / \partial Z_{week}}\bigg|_{U_{week}^*} = \beta_t \cdot Z_{week}^* \cdot e^{EY_n + FX_k + \beta_t t_k^* + \varepsilon_{Nk} - HY_n} \cdot \ln(N_k^* + 1) \qquad (25)$$

Since the value of time as a commodity includes the error term, the expected value will be used for the individual expected value of time.

The estimated parameters shown in Table 1, 2 and 3 are applied to simulate the

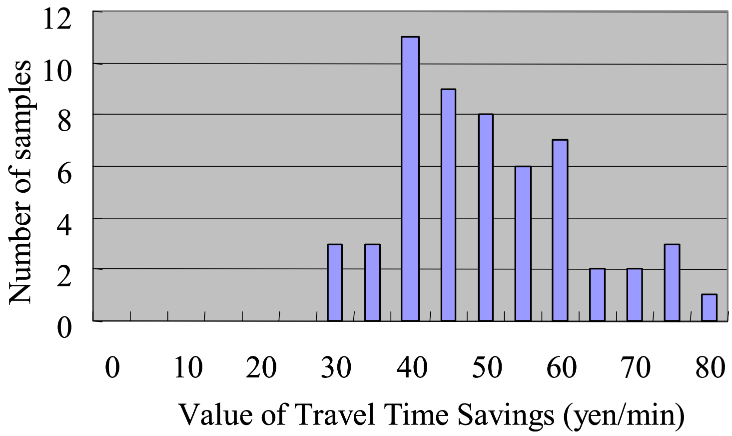

Figure 1 Distribution of value of travel time savings in the sample individuals (travel for the after-work-time leisure activities)

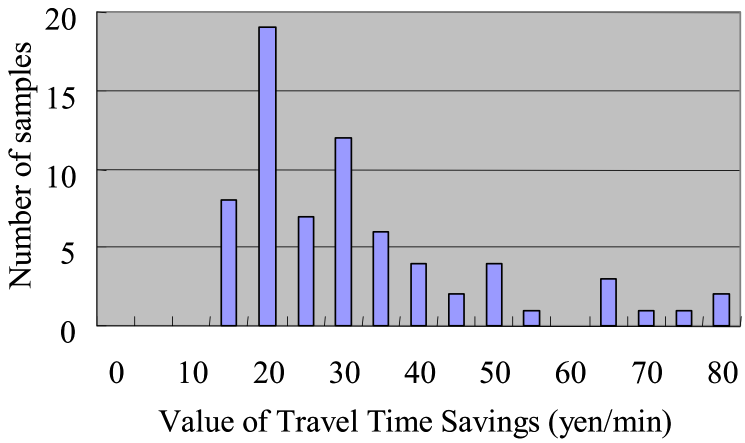

Figure 2 Distribution of value of travel time savings for the sample individuals (travel by rail for the out-of-home leisure activities)

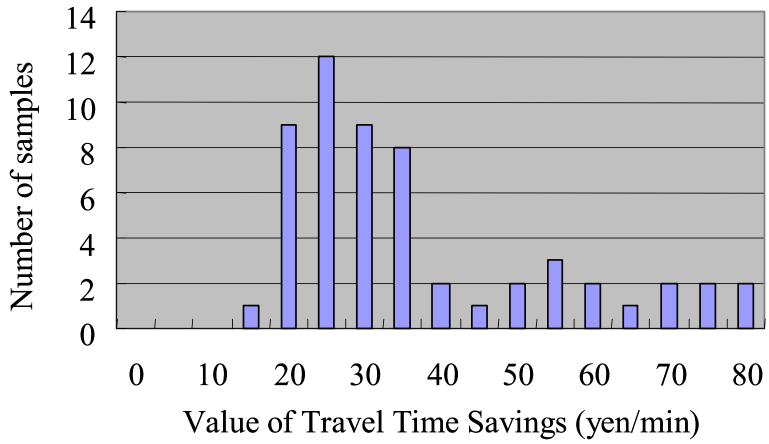

Figure 3 Distribution of value of travel time savings for the sample individuals
(travel by auto for the out-of-home leisure activities)

expected VTTS for all sample individuals whose data was used for model estimation. The distribution of simulated individual VTTS are shown in Figure 1 for the travel to the after-work-time leisure activities, in Figure 2 for the travel by rail to the out-of-home leisure activities and in Figure 3 for the travel by auto to the out-of-home leisure activities respectively. From these results, it is found that the VTTS for the after-work-time leisure activity ranges from 2,000 to 4,000 yen per hour whereas that for the out-of-home leisure activity ranges from 1,500 to 2,500 yen per hour. Since the average wage rate of the Tokyo Metropolitan Area is about 3,000 yen per hour in 2002, it can be concluded that the VTTS for the after-work-time leisure is almost equivalent to the wage rate, but that for the out-of-home leisure may be less than the wage rate.

Finally, the characteristics of the simulated VTTSs are examined through the case analyses. The following two results are obtained from the analyses. First, the more the given time available is, the less the VTTS is. This means that the constrained consumers tend to have higher VTTS even in the non-work time activity. Second, the longer the travel time to the place where the after-work-time leisure activity is engaged is, the less the VTTS is. When examining the VTTS more in details, the value of time as a resource increases but that as a commodity decreases when the travel time increases.

4. Conclusions

A discrete-continuous time allocation model to the discretionary leisure activities has been formulated as an econometric model that is corresponding to the non-linear Tobit model in this study. The empirical analysis has used the weekly time-use diary data from the 2001 Tokyo Metropolitan Area of Japan. Then, the VTTSs for three types of travels: the travel to the after-work-time leisure activities on the work day, the travel by rail to the out-of-home leisure activities on the non-work day and the travel by auto to the out-of-home leisure activities on the non-work day have been valuated based on the

DeSerpa's definition of VTTS. The VTTS for the after-work-time leisure activity ranges from 2,000 to 4,000 yen per hour whereas that for the out-of-home leisure activity ranges from 1,500 to 2,500 yen per hour. It could be concluded by the empirical analysis that the VTTS for the after-work-time leisure is almost equivalent to the wage rate, but that for the out-of-home leisure is less than the wage rate.

For the future research, there are several points which should be discussed further more. First, the utility function used in this paper is based on the sum of logarithm function. When the utility function is based on the logarithm function, the ratio between the marginal utility of time and the marginal utility of cost is equal simply to the ratio of cost and time. However, when applying the other type of function to the utility function, the econometric results of model estimation may be different from the result of this paper and this may lead to another result of VTTS. The verification of the results should be tested by using other types of model. Second, in this research the consumer's behavior of time allocation is modeled as the nested structure. The unknown parameters in the model are estimated sequentially. This assumption should be verified by more general model scheme. Third, the size of data used for the estimation should be checked statistically. It may be too small to say the estimated results are reliable enough. However this means greater survey is required. Finally, the VTTSs of the other types of travels than private travel, including the travel to workplace and school, should be analyzed for the discussion of public investment policy.

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References

Axhausen, K. W., and Garling, T, 1992. Activity-based approaches to travel analysis: conceptual frameworks, models, and research problems, Transport Reviews, 12(4), 323-341.

Bates, J. J., 1987. Measuring travel time values with a discrete choice model: a note, The Economic Journal, 97, 493-498.

Becker, G., 1965. A Theory of the allocation of time, The Economic Journal, 75, 493-517.

Bhat, C. R., 1998. A model of post home-arrival participation behavior, Transportation Research Part B, 32(6), 387-400.

Blayac, T. and Causse, A., 2001. Value of travel time: a theoretical legitimization of some nonlinear representative utility in discrete choice models, Transportation Research Part B, 35, 391-400.

DeSerpa, A.C., 1971. A Theory of The Economics of Time, The Economic Journal, 81(324), 828-846.

East Japan Marketing & Communications, Inc., 2002. 2001 Tokyo Metropolitan Area activity-travel survey data.

Evans. A., 1972. On the theory of the valuation and allocation of time, Scottish Journal of Political Economy, 19, 1-17.

Gunn, H. F., 2000. An introduction to the valuation of travel-time savings and losses, Handbook of Transport Modelling, Hensher, D. A. and Button, K. J. eds., Elsevier Science Ltd, 433-448.

Hamed, M. M. and Mannering, F. L., 1993. Modeling Traveler's Postwork Activity Involvement: Toward A New Methodology, Transportation Science, 27(4), 381-394.

Hensher, D. A., 1997. Behavioral Value of Travel Time Savings in Personal and Commercial Automobile Travel, The Full Costs and Benefits of Transportation, Greene, D. L., Jones, D. W. and Delucchi, M. A.eds., Springer.

Jara-Diaz, S. R., 1990. Consumer's surplus and the value of travel time savings, Transportation Research Part B, 24, 73-77.

Jara-Diaz, S. R., 2000. Allocation and Valuation of Travel-time Savings, Handbook of Transport Modelling, Hensher, D. A. and Button, K. J. eds., Elsevier Science Ltd, 303-318.

Jara-Diaz, S. R., 2003. On the Goods-Activities Technical Relations in the Time Allocation Theory, Transportation, 30, 245-260.

Kitamura, R., 1984. A model of daily time allocation to discretionary out-of-home activities and trips, Transportation Research Part B, 18, 255-266.

Kitamura, R., 1988. An evaluation of activity-based travel analysis, Transportation, 15, 9-34.

Kitamura, R., Fuji, S. and Pas, E. I., 1997. Time-use data, analysis and modeling: toward the next generation of transportation planning methodologies, Transport Policy, 4(4), 225-235.

Mackie, P. J., Jara-Diaz, S. D. and Fowkes, A. S., 2001. The value of travel time savings in evaluation, Transportation Research Part E , 37(2-3).

Pas, E. I., 1988. Weekly travel-activity behavior, Transportation, 15, .89-109.

Prasetyo, I., Tamura, S. and Yai, T., 2002. Travel Time Saving Benefit Based on Commuter's Perception (Jakarta, Indonesia Case Study), Proceedings of World Conference for Transport Research, Paper Number 7606.

Prasetyo, I., Yoshino, H., Fukuda, D. and Yai, T., 2001. Time Allocation Modeling for Weekend Travel in Tokyo, Using Combined Utility Maximization and Activity Choice Approaches, Proceedings of the International Meeting of the Psychometric Society, 561-568.

Prasetyo, I., Yoshino, H., Fukuda, D. and Yai, T., 2003. Analysis of Travel Time Saving Benefit by Understanding Individual Needs and Vale of Activity Time (Case Study: Tokyo and Jakarta), a paper presented at the 82nd Annual Meeting of Transportation Research Board.

Small, K. A., 1982. Scheduling of consumer activities: Work trips, American Economic Review,.72,467-479.

Small, K. A., 1992 Urban Transportation Economics, Harwood Academic Publishers GmbH.

The MVA Consultancy, Institute of Transport Studies at Leeds University, Transport Studies Unit at Oxford University, 1994. Cost - Benefit Analysis, Layard, R. and Glaister, S. eds, 235-271.

Train, K. and McFadden, D., 1978. The goods/leisure tradeoff and disaggregate work trip mode choice models, Transportation Research, 12, 349-353.

Truong, T. P. and Hensher, D. A., 1985. Measurement of travel time values and opportunity cost from a discrete-choice model, The Economic Journal, 95, 438-451.

Truong, T. P. and Hensher, D. A., 1987. Measuring travel time values with a discrete choice model: a reply, The Economic Journal, 97, 499-501.

Yamamoto, T. and Kitamura, R., 1999. An analysis of time allocation and out-of-home discretionary activities across working days and non-working days, Transportation, 26, 211-230.