DEPARTURE TIME CHOICE WITH TIME ALLOCATION MODEL: EMPIRICAL CASE ANALYSIS OF RAIL COMMUTERS IN CENTRAL TOKYO

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ABSTRACT

This paper aims to formulate a departure time choice model based on a time allocation model and analyze it with empirical data. Data on urban rail commuters are used for empirical analysis. Although our model follows the theoretical framework presented by Small (1982), our approach is not based on discrete-choice modeling, which is used in Small's paper. The model assumes continuous time choice in which an individual maximizes his/her utility under the constraints of time and monetary budgets. As our model explicitly incorporates the utilities stemming from sleeping hours and in-home or out-of-home leisure, the individual's preference of these activities can be analyzed directly. For example, the results of empirical analysis show that married individuals obtain higher marginal utility from sleeping time. Additionally, our survey included the SP survey about the dynamic fare system. The results of empirical analysis show that the fare level at the arrival time or at the time of starting work influence the individual's marginal utility with respect to the schedule delay of arrival, starting work, and sleeping.

Keywords: *Departure time choice, time allocation model, urban rail transit*

1. INTRODUCTION

Modeling the temporal response of travelers to transportation policy interventions has rapidly emerged as an important issue in many practical transportation-planning studies and is recognized to present particular challenges (Hess et al., 2007). Because of increasing variation in travel conditions at different times, as well as the interest in differential pricing, the topic is receiving greater attention. Even in the public transit system, the dynamic charging scheme is sometimes proposed, particularly by using the smart card system. Cities such as Washington D.C. have already introduced the semi-dynamic peak-load pricing scheme in their mass rapid transit. It is necessary to understand the departure time choice of travelers in order to analyze the impact of the dynamic charging scheme.

A number of different modeling approaches have been proposed to the treatment of time of day choice (see Bates, 1997). On the one hand, several authors, including Arnott et al. (1990) and de Palma et al. (1997), have presented frameworks in which the choice of departure time is modeled deterministically and as a continuous quantity based on the ideas originally proposed by Vickrey (1969). On the other hand, a number of researchers have analyzed the travelers' choice of when to travel with the discrete choice modeling framework. Studies on revealed-preference data include Abkowitz (1981), Small (1982), McCafferty and Hall (1982), Hendrickson and Plank (1984), Small (1987), Chin (1990), and Bhat (1998), while the studies with the stated-preference data include de Jong et al. (2003), Polak and Jones (1994), and Hess et al. (2007).

This paper proposes a departure time choice model based on the time allocation model with the revealed-preference data of rail transit users. Our model follows the theoretical framework presented by Small (1982). The model assumes a continuous time choice in which an individual maximizes his/her utility under the constraints of time and monetary budgets. We also introduce heterogeneity into the parameters of the utility function. Thus, our model is an econometric model in the continuous time choice framework. As for the utility function, Small (1982) assumed that the individual's utility function consists of a numeraire good and three types of time, leisure time, working time, and consumption time, where consumption time is assumed to be a function of a specific time of day. Rather than goods consumption, our model considers the variables pertaining to the time of day, including bedtime and the time of reaching the workplace. Bedtime is included because the model takes the utility from sleeping hours into consideration, while the time of reaching the workplace is included because the individual may choose the best time to reach there, considering the disutility of early/late arrival with the dynamic in-vehicle congestion of rail transit service. The model is estimated with the empirical stated-preference data of urban rail commuters in the Tokyo Metropolitan Area.

The paper is organized as follows. Section 2 formulates the econometric model, incorporating the choice of starting time of day and duration of activities. Section 3 describes the data used for the empirical analysis. Section 4 presents the estimation results and their implications. Finally, Section 5 summarizes the discussions and shows further research issues.

2. MODEL

2.1 Framework of the model

Suppose an individual who commutes from his/her home to the workplace by urban rail transit service. It is assumed that the individual maximizes his/her utility in a working day by allocating the time to activities and by determining the starting time of each activity. We formulate it as follows:

$$\max U\left(t_s, t_a, T_s, T_l^1, T_l^2, T_l^3\right)$$

subject to

$$T_s + T_w + T_l^1 + T_m^1 = T_1$$
$$T_l^2 + T_m^2 + T_l^3 = T_2$$
$$t_a = t_s + T_s + T_l^1 + T_m^1$$
$$t_s > 0, \quad t_a > 0, \quad T_s > 0, \quad T_l^1 > 0, \quad T_l^2 \geq 0, \quad T_l^3 > 0$$

where t_s refers to bedtime, t_a the time of reaching workplace, T_s the duration of sleep, T_l^1 the leisure time before departing for work, T_l^2 the out-of-home leisure time after work, T_l^3 the at-home leisure time in the evening, T_w the working hours, T_m^1 the travel time from home to workplace, T_m^2 the travel time from workplace to home, and T_1, T_2 the time constraints. T_m^1 and T_m^2 are assumed to be constant because the transit service expectedly gives stable service with a constant travel time during the day. It is also assumed that the working hours are fixed.

The above model assumes that the individual's utility results from the choice of bedtime and arrival time at the workplace, in addition to the duration of activities. These timings are affected by the individual's ideal schedule and the exogenous schedule-dependent level of rail service, including the fare and in-vehicle congestion. It is assumed that out-of-home leisure time after work is greater than or equal to 0 while the durations of other activities are greater than 0. This is because individuals who go home directly do not engage in out-of-home leisure after work.

2.2 Specification of utility and sub-utility functions

It is assumed that the utility function is a linear function of sub-utility components. The sub-utility components include the sub-utilities pertaining to the choice of the time to sleep $u_{ts}(t_s)$; early arrival $u_{ta}(t_a)$, and late arrival $u_{tw}(t_a)$ at the workplace; choice of the arrival time at the station nearest to the workplace $u_C(t_a)$; the duration of sleep $u_{Ts}(T_s)$; leisure time before departing from home $u_{Tl1}(T_l^1)$; out-of-home leisure time after work $u_{Tl2}(T_l^2)$; and in-home leisure time after work $u_{Tl3}(T_l^3)$.
Now, the utility function is specified as

$$U(t_s, t_a, T_s, T_l^1, T_l^2, T_l^3) = u_{ts}(t_s) + u_{ta}(t_a) + u_{tw}(t_a) + u_C(t_a) + u_R(t_g) + u_{Ts}(T_s) + u_{Tl1}(T_l^1) + u_{Tl2}(T_l^2) + u_{Tl3}(T_l^3)$$

Next, the sub-utility functions are specified as follows:

First, it is assumed that the individual has a desirable time to sleep t_s^0. If the individual chooses a time after the desirable time to go to sleep, the sub-utility decreases in proportion to the schedule delay. If the individual chooses a time before the desirable time to sleep, the sub-utility is equal to 0. This is formulated as

$$u_{ts}(t_s) = \alpha_s (t_s - t_s^0) \cdot H(t_s - t_s^0) = \begin{cases} \alpha_s (t_s - t_s^0) & (t_s \geq t_s^0) \\ 0 & (t_s < t_s^0) \end{cases}$$

where $H(\cdot)$ implies the heavy-side function and α_s the unknown parameter.

Second, it is assumed that the individual has a desirable time to arrive at the workplace t_a^0. If the individual chooses a time earlier or later than the desirable time to arrive at workplace, the sub-utility decreases in proportion to the schedule delay. This can be formulated as

$$u_{ta}(t_a) = \begin{cases} \alpha_a (t_a - t_a^0) & (t_a \geq t_a^0) \\ -\alpha_a (t_a - t_a^0) & (t_a < t_a^0) \end{cases}$$

where α_a implies the unknown parameter.

Third, it is assumed that the individual loses utility when he/she arrives at the workplace later than the official starting time of work fixed by the workplace, t_w^0. The utility is lost in proportion to the schedule delay. If the individual arrives at the workplace earlier than the official starting time of work, no utility is lost. This can be formulated as

$$u_{tw}(t_a) = \alpha_w(t_a - t_w^0)\cdot H(t_a - t_w^0) = \begin{cases} \alpha_w(t_a - t_w^0) & (t_a \geq t_w^0) \\ 0 & (t_a < t_w^0) \end{cases}$$

where α_w implies an unknown parameter.

Fourth, it is assumed that the individual suffers disutility by traveling on the congested rail service. As the level of in-vehicle congestion changes dynamically, the sub-utility pertaining to in-vehicle congestion also depends on the time of travel. If the rail-use traveling time from an origin station to the destination station is constant throughout the day, the sub-utility from in-vehicle congestion depends on the time of arrival at the destination station. The sub-utility $u_C(t_a)$ is assumed to be in proportion to the product of travel time T_{train} and the congestion level $Cong(\cdot)$

$$u_C(t_a) = \alpha_C T_{train} Cong(t_a - T_{egress})$$

where α_c indicates an unknown parameter and T_{egress} is the travel time from the station nearest to the workplace. It is also assumed that T_{egress} is constant.

Fifth, it is assumed that the sub-utilities from the in-home leisure time in the morning, the out-of-home leisure time after work, and the in-home leisure time in the evening are functions of the corresponding leisure time. The sub-utility increases while the marginal utility decreases as leisure time increases. The following logarithmic function is used for each sub-utility:

$$u_{Tl1}(T_l^1) = \beta_{Tl1} \ln(T_l^1 + 1)$$
$$u_{Tl2}(T_l^2) = \beta_{Tl2} \ln(T_l^2 + 1)$$
$$u_{Tl3}(T_l^3) = \beta_{Tl3} \ln(T_l^3 + 1)$$

where $\beta_{Tl1}, \beta_{Tl2}, \beta_{Tl3}$ denote the unknown parameters. We add 1 to the time of the sub-utility functions. There are two reasons for this. First, we add a positive constant value to the utility element function because it approaches $-\infty$ as the time approaches zero without the addition of some positive constant. Second, we use 1 as the constant positive value because we assume that no utility stems from nil activity time.

Sixth, it is assumed that the sub-utility pertaining to sleeping hours increases monotonically while the marginal utility decreases as sleeping hours become longer. The following logarithmic function is used again:

$$u_{Ts}(T_s) = \beta_{Ts} \ln(T_s + 1)$$

where β_{Ts} denotes an unknown parameter.

Seventh, it is assumed that the sub-utility pertaining to the rail fare depends on the ratio of the dynamic fare to the minimum constant fare. We also assume the dynamic charging system in which the rail fare is charged when the rail-use traveler arrives at the destination station. The sub-utility is assumed to be in proportion to the dynamic fare:

$$u_R(t_a) = \alpha_R \cdot R(t_a - T_{egress})$$

where α_R denotes an unknown parameter.

Finally, the parameters introduced into the sub-utility functions shown earlier are assumed to have the following structure, considering heterogeneity:

$$\alpha_s = -\exp(A_s X_n),\ \ \alpha_a = -\{\exp(A_a X_n) + \varepsilon_a\}$$
$$\alpha_w = -\exp(A_w X_n),\ \ \alpha_C = -\exp(A_C X_n)$$
$$\alpha_R = -\exp(A_R X_n),\ \ \beta_{Ts} = \exp(B_s X_n)$$
$$\beta_{Tl1} = \exp(B_{l1} X_n + \varepsilon_{l1}),\ \ \beta_{Tl2} = \exp(B_{l2} X_n + \varepsilon_{l2}),\ \ \beta_{Tl3} = \exp(B_{l3} X_n)$$

where A_s, A_a, A_c, A_w, A_R, B_s, B_{l1}, B_{l2}, and B_{l3} denote the vectors of parameters, X_n indicates the personal attributes of the individual n, and $\varepsilon_a, \varepsilon_{l1}, \varepsilon_{l2}$ represent the error components.

Finally, the utility function is summarized as follows:

$$U(t_s, t_a, T_s, T_l^1, T_l^2, T_l^3) = u_s(t_s) + u_{ta}(t_a) + u_{tw}(t_a) + u_c(t_a) + u_R(t_a) + u_{Ts}(T_s) + u_{Tl1}(T_l^1) + u_{Tl2}(T_l^2) + u_{Tl3}(T_l^3)$$

if $t_a \ge t_a^0$, *then*

$$= -e^{A_s X_n}(t_s - t_s^0) \cdot H(t_s - t_s^0) - (e^{A_a X_n} + \varepsilon_a) \cdot (t_a - t_a^0) - e^{A_w X_n}(t_a - t_w^0) \cdot H(t_a - t_w^0)$$

$$-e^{A_C X_n} T_{train} Cong\left(t_a - T_{egress}\right) - e^{A_R X_n} R\left(t_a - T_{egress}\right) + e^{B_s X_n} \ln\left(T_s + 1\right) + e^{B_{l1} X_n + \varepsilon_{l1}} \ln\left(T_l^1 + 1\right)$$

$$+ e^{B_{l2} X_n + \varepsilon_{l2}} \ln\left(T_l^2 + 1\right) + e^{B_{l3} X_n} \ln\left(T_l^3 + 1\right)$$

$if\ \ t_a < t_a^0, then$

$$= -e^{A_s X_n}\left(t_s - t_s^0\right) \cdot H\left(t_s - t_s^0\right) + \left(e^{A_a X_n} + \varepsilon_a\right) \cdot \left(t_a - t_a^0\right) - e^{A_w X_n}\left(t_a - t_w^0\right) \cdot H\left(t_a - t_w^0\right)$$

$$-e^{A_C X_n} T_{train} Cong\left(t_a - T_{egress}\right) - e^{A_R X_n} R\left(t_a - T_{egress}\right) + e^{B_s X_n} \ln\left(T_s + 1\right) + e^{B_{l1} X_n + \varepsilon_{l1}} \ln\left(T_l^1 + 1\right)$$

$$+ e^{B_{l2} X_n + \varepsilon_{l2}} \ln\left(T_l^2 + 1\right) + e^{B_{l3} X_n} \ln\left(T_l^3 + 1\right)$$

2.3 Optimality conditions

The first optimality conditions of the utility maximization under the constraints are shown as follows:

$$\left.\frac{\partial U}{\partial t_s}\right|_{t_s = t_s^*} + \left.\frac{\partial U}{\partial t_a}\right|_{t_a = t_a^*} \begin{cases} = 0 & \left(t_a^* \neq t_a^0\right) \\ < 0 & \left(t_a^* = t_a^0\right) \end{cases}$$

$$\left.\frac{\partial U}{\partial T_s}\right|_{T_s = T_s^*} = \left.\frac{\partial U}{\partial T_l^1}\right|_{T_l^1 = T_l^{1^*}}$$

$$\left.\frac{\partial U}{\partial T_l^2}\right|_{T_l^2 = T_l^{2^*}} \begin{cases} = \left.\dfrac{\partial U}{\partial T_l^3}\right|_{T_l^3 = T_l^{3^*}} & \left(T_l^{2^*} > 0\right) \\ < \left.\dfrac{\partial U}{\partial T_l^3}\right|_{T_l^3 = T_l^{3^*}} & \left(T_l^{2^*} = 0\right) \end{cases}$$

Then, the following equations can be derived with respect to the error components:

$$\varepsilon_{Tl1} = \ln\left(T_l^{1^*} + 1\right) - \ln\left(T_s^* + 1\right) + B_s X_n - B_{l1} X_n$$

$$\varepsilon_{Tl2} \begin{cases} = \ln\left(T_l^{2^*} + 1\right) - \ln\left(T_l^{3^*} + 1\right) + B_{l3} X_n - B_{l2} X_n & \left(if\ \ T_l^{2^*} > 0\right) \\ < \ln\left(T_l^{2^*} + 1\right) - \ln\left(T_l^{3^*} + 1\right) + B_{l3} X_n - B_{l2} X_n & \left(if\ \ T_l^{2^*} = 0\right) \end{cases}$$

$$\varepsilon_a = -e^{A_s X_n} H\left(t_s^* - t_s^0\right) - e^{A_a X_n} - e^{A_w X_n} H\left(t_a^* - t_w^0\right) - e^{A_C X_n} T_{train} Cong'\left(t_a^* - T_{egress}\right)$$

$$-e^{A_R X_n} R'\left(t_a^* - T_{egress}\right) \quad \left(t_a^* > t_a^0\right)$$

$$\varepsilon_a > -e^{A_s X_n} H\left(t_s^* - t_s^0\right) - e^{A_a X_n} - e^{A_w X_n} H\left(t_a^* - t_w^0\right) - e^{A_C X_n} T_{train} Cong'\left(t_a^* - T_{egress}\right)$$

$$-e^{A_R X_n} R'\left(t_a{}^* - T_{egress}\right) \quad \left(t_a{}^* = t_a^0\right)$$

$$\varepsilon_a = e^{A_s X_n} H\left(t_s{}^* - t_s^0\right) - e^{A_a X_n} + e^{A_w X_n} H\left(t_a{}^* - t_w^0\right) + e^{A_C X_n} T_{train} Cong'\left(t_a{}^* - T_{egress}\right)$$

$$+ e^{A_R X_n} R'\left(t_a{}^* - T_{egress}\right) \quad \left(t_a{}^* < t_a^0\right)$$

We add the assumptions that the error components $\varepsilon_a, \varepsilon_{Tl1}, \varepsilon_{Tl2}$ follow an independent normal distribution with zero mean and variances of $\sigma_a^2, \sigma_{Tl1}^2, \sigma_{Tl2}^2$, respectively. Then, the following likelihood functions can be derived:

$$p_{Tl1} = \frac{1}{\sigma_{Tl1} \cdot \left(T_l^{1^*} + 1\right)} \cdot \phi\left[\frac{\ln\left(T_l^{1^*} + 1\right) - \ln\left(T_s^* + 1\right) + B_s X_n - B_{l1} X_n}{\sigma_{Tl1}}\right]$$

$$p_{Tl2} = \begin{cases} \dfrac{1}{\sigma_{Tl2} \cdot \left(T_l^{2^*} + 1\right)} \cdot \phi\left[\dfrac{\ln\left(T_l^{2^*} + 1\right) - \ln\left(T_l^{3^*} + 1\right) + B_{l3} X_n - B_{l2} X_n}{\sigma_{Tl2}}\right] & \left(T_l^{2^*} > 0\right) \\ \Phi\left[\dfrac{\ln\left(T_l^{2^*} + 1\right) - \ln\left(T_l^{3^*} + 1\right) + B_{l3} X_n - B_{l2} X_n}{\sigma_{Tl2}}\right] & \left(T_l^{2^*} = 0\right) \end{cases}$$

$$p_a = \begin{cases} \dfrac{1}{\sigma_a}\phi\left(\dfrac{-e^{A_s X_n} H\left(t_s{}^* - t_s^0\right) - e^{A_a X_n} - e^{A_w X_n} H\left(t_a{}^* - t_w^0\right) - e^{A_C X_n} T_{train} Cong'\left(t_a{}^* - T_{egress}\right) - e^{A_R X_n} R'\left(t_a{}^* - T_{egress}\right)}{\sigma_a}\right) & \left(t_a{}^* > t_a^0\right) \\ \Phi\left(\dfrac{e^{A_s X_n} H\left(t_s{}^* - t_s^0\right) + e^{A_a X_n} + e^{A_w X_n} H\left(t_a{}^* - t_w^0\right) + e^{A_C X_n} T_{train} Cong'\left(t_a{}^* - T_{egress}\right) + e^{A_R X_n} R'\left(t_a{}^* - T_{egress}\right)}{\sigma_a}\right) & \left(t_a{}^* = t_a^0\right) \\ \dfrac{1}{\sigma_a}\phi\left(\dfrac{e^{A_s X_n} H\left(t_s{}^* - t_s^0\right) - e^{A_a X_n} + e^{A_w X_n} H\left(t_a{}^* - t_w^0\right) + e^{A_C X_n} T_{train} Cong'\left(t_a{}^* - T_{egress}\right) + e^{A_R X_n} R'\left(t_a{}^* - T_{egress}\right)}{\sigma_a}\right) & \left(t_a{}^* < t_a^0\right) \end{cases}$$

where $\phi(\cdot)$ denotes the probability density function of the standard normal distribution and $\Phi(\cdot)$ the cumulative probability function of the standard normal distribution. The total likelihood function is derived from the product of the above likelihood functions for all individuals. Then, the unknown parameters will be estimated by maximizing the total likelihood functions.

3. DATA

3.1 Data collection

The study team, including ourselves, conducted a paper-based questionnaire survey in central Tokyo. The data include rail commuter's daily activities on weekdays and their rail route choices. The survey also requests respondents to provide stated preferences on the price variation of rail service. The survey sheet shows two different types of dynamic pricing systems in which the rail fare varies according to the arrival time during morning peak hours. Two dynamic pricing systems are illustrated in Figure 1. These systems provide for additional prices to rail users when they arrive at the destination station between 8:00 a.m. and 9:00 a.m. The fare levels are defined by a ratio to the original fare, applicable to other arrival times. This means that the additional payment during peak

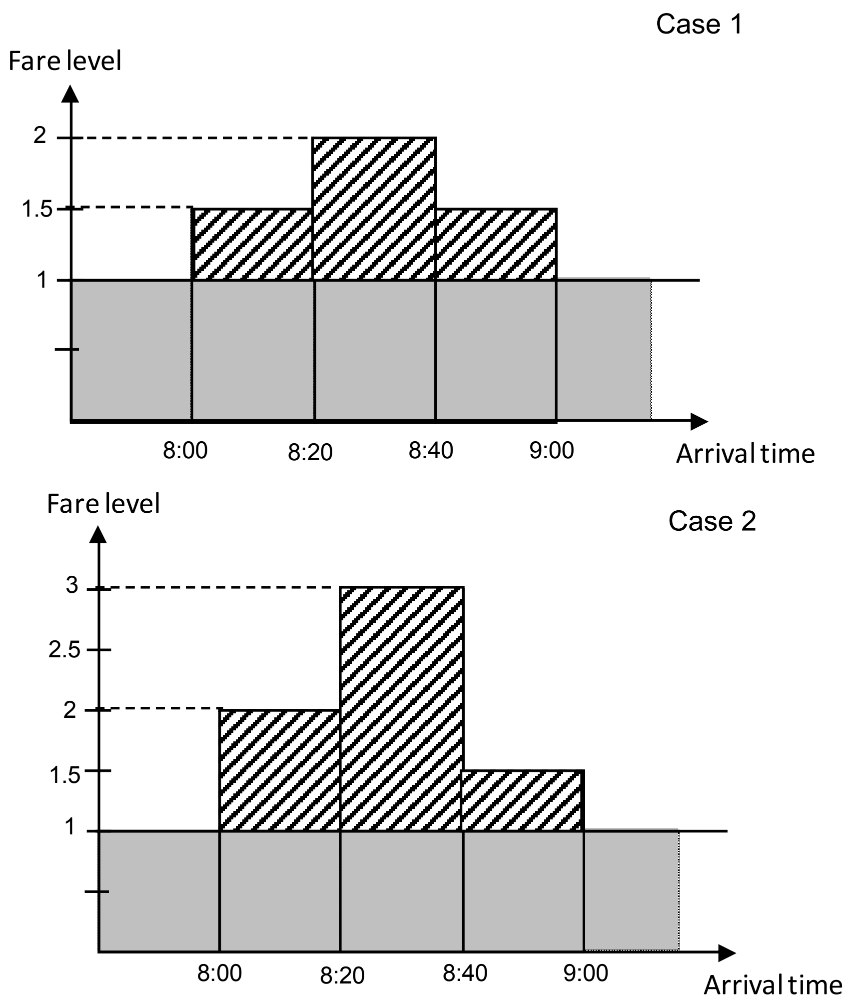

Figure 1 — Two cases of dynamic pricing systems used in SP survey

hours may vary among individuals. The survey assumes that only the additional prices are paid by the commuters, because, according to Japanese custom, commuters usually receive a fixed commuting cost from their employers. The respondents will describe their schedule plan of activities during a day, including their bedtime, departure time, and arrival time. The survey also asked them to describe their individual attributes, including the type of job, title, annual income, working system, working experience, gender, age, marital status, number of household members, and the number of children. Additionally, the respondents are requested to answer their preference on the introduction of peak-load pricing system, in-home leisure, and out-of-home leisure. The survey was conducted in October and November 2004. Thirty-nine companies and workplaces located at the ward area in Tokyo participated in the survey. Note that the ward area includes the central business district of Tokyo. Data on 221 respondents were collected.

3.2 Socio-demographics and results of RP and SP surveys

Table 1 shows the socio-demographic data of survey respondents. First, males outnumber females. This reflects the distributions of employees with respect to gender in Japan. Second, most respondents are in their thirties, followed by those in their fifties and forties. This may reflect the participants' concerns about our survey. Third, about 65% of the respondents are married while 35% are unmarried. Fourth, respondents with annual income of less than 600 million yen are the dominant group.

Table 1 – Socio-demographic data on survey respondents

Variables						
Gender	Male	Female				
	76.6 %	23.4 %				
Age	20–29	30–39	40–49	50–59	60–69	
	20.2 %	30.7 %	21.1 %	25.7 %	2.3 %	
Marriage status	Not married	Married				
	35.3 %	64.7 %				
Annual income	–400	400–600	600–800	800–1,000	1,000–1,200	1,200–
(Million Yen)	23.3 %	30.1 %	19.4 %	13.6 %	8.3 %	5.4 %
Working system	Fixed	Flexible	Free	Others		
	66.5 %	25.3 %	6.8 %	1.4 %		

Note that the average annual income in Tokyo is 6.01 million yen per household as of 2007. Finally, working systems are categorized into fixed, flexible, and free working time systems. The fixed working time system implies that employees must work from a fixed starting time to a fixed ending time. Under the flexible system, the employees can choose the time to start work under the constraints of given core hours. The employees are required to work during the core hours, for example, from 10:00 a.m. to 3:00 p.m. The free working time system allows employees to choose a working schedule they prefer. From the viewpoint of departure or arrival time choice, the flexible working time system may be regarded as having the same impact as does the free working time system on the individual's decision making. As Table 1 shows, the fixed working time system is more popular than the other systems. Figure 2 shows the arrival time distribution of respondents. This shows that the peak arrival time is from 8:30 a.m. to 9:30 p.m. There are two peaks because the arrival time distribution of respondents under the flexible working system has two peaks as shown later. Most respondents arrive at their workplace between 7:00 a.m. and 10:00 a.m. Figure 3 shows distributions of observed arrival time of respondents by working system. The peak arrival time of respondents under the fixed working system is between 8:50 a.m. and 9:10 a.m. This is because many companies start at 9:00 a.m. in Tokyo. Under the flexible working time system, respondents have two peak arrival times: 8:30 a.m. to 8:50 a.m. and 9:10 a.m. to 9:30 a.m. This is probably because they avoid the greatest congestion between 8:50 a.m. and 9:10 a.m.

Next, Figures 4 and 5 show the results of the stated-preference survey on arrival time under dynamic pricing systems, in cases 1 and 2, respectively. These show that commuters under the fixed working time system schedule their arrival to an earlier time.

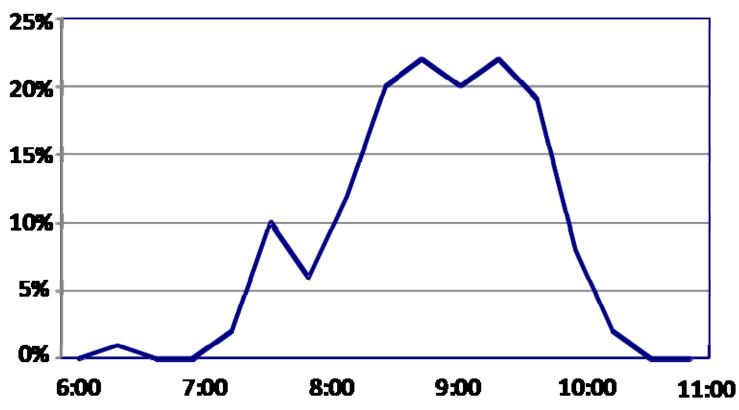

Figure 2 – Distribution of observed arrival time (revealed preference)

This is because commuters under the fixed working time system avoid paying the additional price but cannot postpone their arrival time to a later time. Commuters under the flexible working time system shift their arrival to a later time in order to, first, avoid the payment of additional price, and second, keep away from the traffic congestion caused earlier by a large number of commuters under the fixed working time system.

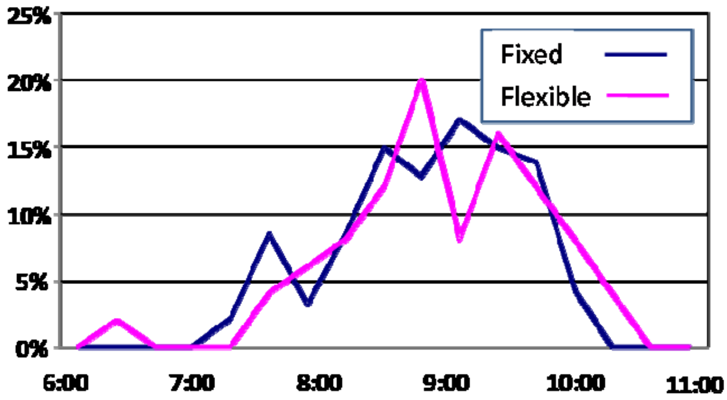

Figure 3 – Distribution of observed arrival time by working system (revealed preference)

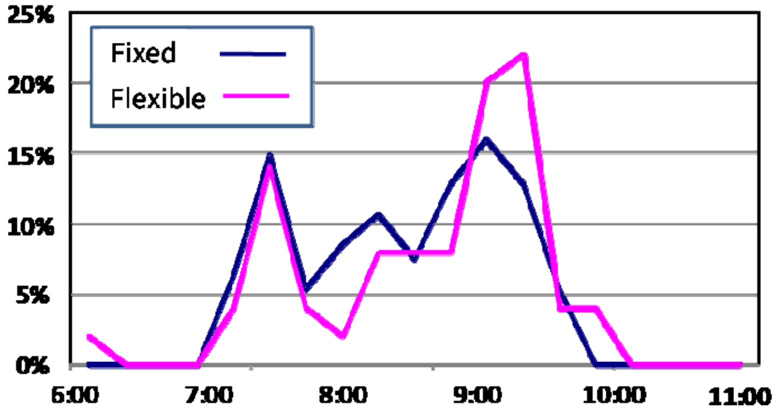

Figure 4 – Distribution of arrival time (stated preference: case 1)

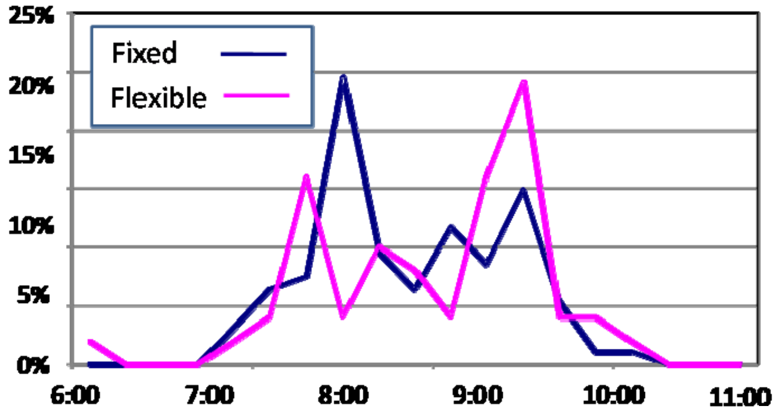

Figure 5 – Distribution of arrival time (stated preference: case 2)

4. EMPIRICAL ANALYSIS

The estimation result is shown in Table 2. The fare level is defined as the ratio of fare to the original fare. The dummies are defined as follows:

- The dummy of age for an individual in his/her forties or fifties is equal to 1, and 0 otherwise.
- The dummy for the fixed working time system is equal to 1, and 0 otherwise.
- The relevant dummy is equal to 1 if the individual is female, and 0 if otherwise.
- The dummy for leisure is equal to as 1 if the individual prefers the in-home leisure to out-of-home leisure, and 0 otherwise.
- The dummy for marital status is equal to 1 if the individual is married, and 0 if not.

The variance w.r.t. sub-utility for arrival time means the variance of the error component ε_a in the parameter of the sub-utility function for arrival time. The variance w.r.t. sub-utility for in-home morning leisure indicates the variance of the error component ε_{l1} in the parameter of the sub-utility function for in-home leisure time before departing from home. The variance w.r.t. sub-utility for after-work-time leisure means the variance of the error component ε_{l2} in the parameter of sub-utility function for the after-work leisure time.

First, the fare level at the observed arrival time is statistically significant. Its negative sign means that the marginal disutility with respect to a schedule delay of going to sleep decreases as the fare level at arrival time increases. This implies that the increase in the fare level affects the disutility caused by the schedule delay of going to sleep less seriously.

Second, the fare level at the observed arrival time is also statistically significant. Its negative sign means that the marginal disutility with respect to a schedule delay in arrival at the workplace decrease as the fare level at the arrival time increases. This implies that the increase in fare level affects the disutility caused by the schedule delay of arrival less seriously.

Third, the fare level at the time of starting work is statistically significant. Its negative sign means that the marginal disutility with respect to a schedule delay in starting work decreases as the fare level at the arrival time increases. This implies that the increase in fare level affects the disutility caused by schedule delay of starting work less seriously.

Fourth, the dummy of age for individuals in their forties and fifties is statistically significant. Its negative sign means that the marginal disutility with respect to in-train congestion would be lower if the individual is in his/her forties or fifties. This probably implies that commuters in their forties and fifties are less concerned about in-vehicle congestion as compared to younger or older commuters.

Fifth, the dummy for preference of in-home leisure is statistically significant. Its negative sign means that the marginal disutility with respect to out-of-home leisure time after work is lower if the individual prefers in-home leisure. This seems very reasonable.
Sixth, the dummy for female commuters is statistically significant. Its positive sign means that the marginal disutility with respect to in-home leisure time in the evening is lower for females. This may show that females prefer out-of-home leisure after work time.
Seventh, the dummy of marital status is statistically significant. Its positive sign means that the marginal disutility with respect to sleeping hours is higher if the individual is

Table 2 – Estimation results

Parameters	Variables	Coefficients	t-statistics
α_s	Age dummy for individuals in his/her forties and fifties	–0.66	–0.7
	Fare level at the observed arrival time	–2.59	–8.4
α_a	Dummy of fixed working time system	0.04	0.1
	Fare level at the observed arrival time	–2.70	–6.6
α_w	Fare level at the time of starting work	–2.43	–3.5
	Dummy of fixed working time system	–2.78	–0.4
α_c	Dummy of age in his/her forties and fifties	–2.93	–4.4
	Dummy of female	–3.36	–1.7
β_{Tl1}	Dummy of female	–0.10	–1.2
β_{Tl2}	Dummy of preference of in-home leisure	–8.80	–8.3
	Fare level at the time of starting work	0.19	0.3
β_{Tl3}	Dummy of female	–2.85	–3.2
	Dummy of fixed working time system	0.51	0.7
β_{Ts}	Dummy of marriage status	1.06	13.9
	Fare level at the time of starting work	0.65	11.3
ε_a	Variance w.r.t. sub-utility for arrival time	0.21	24.0
ε_{l1}	Variance w.r.t. sub-utility for in-home morning leisure	0.70	27.7
ε_{l2}	Variance w.r.t. sub-utility for after-work-time leisure	6.30	12.9

married. This is probably because married individuals face tougher time-use conditions than unmarried individuals, living as they do jointly with family members.

Eighth, the fare level at the time of starting work is statistically significant. Its positive sign means the marginal disutility with respect to sleeping hours is higher as the fare level becomes higher. This is probably because the higher fare forces the individuals to change their time of starting work and it reduces their sleeping hours, then this causes an increase in marginal utility with respect to sleeping hours.

5. CONCLUSIONS

This paper aims to formulate a departure time choice model based on the time allocation model and analyze it with empirical data. Data on urban rail commuters are used for the empirical analysis. Although our model basically follows the theoretical framework presented by Small (1984), our approach is not based on the discrete-choice modeling used in Small's paper. The model assumes continuous time choice in which an individual maximizes his/her utility under the constraints of time and monetary budgets. As our model explicitly incorporates utilities stemming from sleeping hours and in-home or out-of-home leisure, the individual's preference for these activities can be analyzed directly. For example, the results of empirical analysis show that the married individual has higher marginal utility with respect to sleeping hours. Additionally, our survey included the SP survey on the dynamic fare system. The results of empirical analysis show that the fare level at the arrival time or at the time of starting work influences the individual's marginal utility with respect to the schedule delay of arrival, starting work, and going to sleep.

Although our study shows some interesting results regarding the simultaneous choice of duration and schedule, there are clearly limitations to our approach, particularly in our survey. The SP survey used in our study requested the respondents to provide not only their choice of arrival time but also their schedule plan of activities during the day, including bedtime, departure time, and arrival time. As the daily schedule should be very complicated, the burden on respondents is rather heavy with a paper-based questionnaire survey. Data collection could be improved by using more sophisticated SP survey methods such as Doherty and Miller (2000).

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