Analysis of Departure Time choice Behaviour of Urban Railway Users in Tokyo Metropolitan Area

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Peak shifting has long been recognised as one of the most effective policies to mitigate the congestion of urban railways, especially in congested mega-cities including Tokyo metropolitan area. To understand the behaviour of the peak shifting beneficiaries, modelling departure time choice is the essential way. Though most time-varying demand studies of urban railways assume a constant marginal utility of passengers' scheduling preference, a more general time-varying marginal utility of time would be more appropriate, but still lacks for empirical study. This paper analyses the features of departure time choice behaviour of Tokyo railway users through fundamental statistics of the latest Metropolitan Transportation Census of Tokyo in 2010. An empirical study for the theoretical model introduced by Vickrey (1973) is presented aiming at facilitating a basis of the peak shifting policy, which described scheduling preferences in detail by associating a time-varying utility rate with time spent at the origin and a similar time varying utility rate with time spent at the destination.

Key Words : *departure time choice model, time-varying marginal utility, peak shifting, urban railway,Tokyo metropolitan area*

1. Research background and motivation

Railway users, especially commuters, in Tokyo metropolitan area have been suffering from over-congested trains for more than half a century. Thanks to the large scale construction of new lines, the enlarged train capacity and the track sharing between different railway operators, the average congestion rate is continuously falling. However, about 15 sections' average congestion rates during the peak hour are still higher than 180 per cent, and the average congestion rate of 31 observed sections is 166 per cent during the morning peak, as shown in Fig.1. Moreover, about 30 per cent passengers of these lines concentrate with in one hour during the morning peak(quated from the Railway Congestion Rate of the Three Metropolitan Area). Though investment in the facilities is the ultimate solution of congestion, an achievable scale of capacity expansion often leads to the narrowing of the period of peaks, instead of reducing the maximum congestion level. An intuitive and cost-effective solution is to spread the peak demand over time dimension, which is similar to the situation in other kinds of transportation network or even any service with limited capacity.

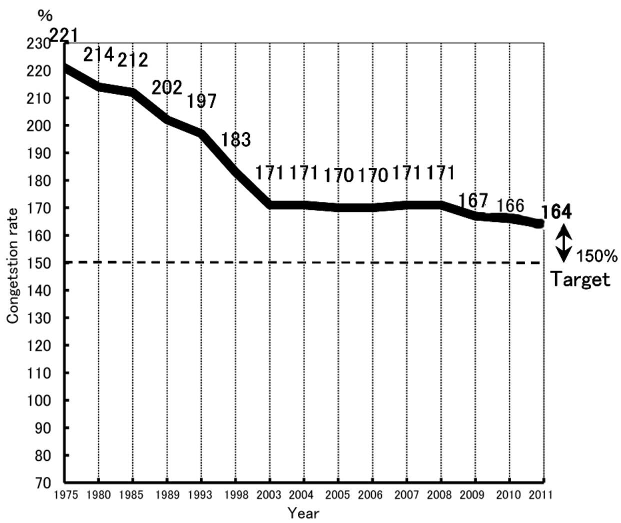

Fig. 1 Congestion rate changes over recent years (quoted from the Congestion Rate of Major Railway Sections 2011)

Given the scale of further capacity enlargements of railway facilities and trains is relatively limited due to the space constrain in Tokyo metropolitan area, to achieve the target of reducing the overall average peak congestion rate to 150 per cent by year 2015 is still a challenging task, even though we could expect a decline in working age population of Tokyo area. Under these circumstances, soft measures, including congestion pricing, train scheduling optimization, and multi-class train segmentation etc., might turn out to be the most possible way to alleviate the congestion. Even if there is no space limitation, railway operators and government still need to evaluate their strategy, policy and investment in order to understand how the users will interact with these changes. A travel demand model that precisely describes railway users' scheduling decision behaviour is thus crucial in transportation market.

This paper aims at providing an analysis of departure time choice behaviour of Tokyo railway users through fundamental statistics of the latest Metropolitan Transportation Census of Tokyo in 2010. Moreover, an empirical study for the theoretical model introduced by Vickrey (1973) is presented aiming at facilitating a basis of the peak shifting policy, which described scheduling preferences in detail by associating a time-varying utility rate with time spent at the origin and a similar time varying utility rate with time spent at the destination. The estimation result of both constant and time-varying marginal utility is compared.

2. Literature review and the departure time choice model

In the aforementioned situation of trip scheduling, we always want to arrive at our destination at a preferred arrival time that is neither too early nor too late, and we sometimes need to trade-off between our departure time and the travel time due to the congestion level of transportation services. So the problem we are facing is how each individual value their time and their scheduling.

Generally, the value of time is defined as the marginal utility or the utility rate generated by a series of activities, that is, the benefit each individual could obtain from spending one specific unit of time. This value is usually found to be higher during peak hours than off-peaks, and also changes owing to different activities performed at different times of day, which means the value of time is connecting with the scheduling.

(1) Constant marginal utility

Many researchers have devoted to describe the relationship between scheduling and value of time. If we consider the utility $u(t_D, a)$, generate by a scheduled trip, as a function of departure time t_D and arrival time a, which has the positive utility rate at t_D and negative utility rate at a. One of the special cases under this framework and maybe the most widely-used one is the "$\alpha - \beta - \gamma$" preference first depicted by Vickrey(1969), and further developed by several authors, including Arnott et al.(1993) and empirically studied by Small(1982), where a commuter prefers to arrive at a preferred arrival time a^*, suffering from scheduling cost at rate β per minute for early arrival, or γ per minute for late arrival, and travel time is valued as a rate of α. In this case, the travel cost (1) decomposes into three linear components, that is utilities of travel time, schedule delay early(SDE) and schedule delay late(SDL), with corresponding marginal utility of α, β and γ.

$$u(t_D, a) = \alpha(a - t_D) + \beta \min(0, a^* - a) + \gamma \max(0, a - a*) \quad (1)$$

(2) Time-varying marginal utility

A more general case under the same framework of scheduled trip utility proposed by Vickery(1973) is the time-varying preference. This insight was elaborated by Arnott et al.(1993), Tseng and Verhoef(2008), and Fosgerau and Engelson(2011). From the traveller's individual point of view, the scheduling preference can be described by a "time-varying rate of utility" spend at each location. Let two linear functions $H(t)$ and $W(t)$ represent the marginal utility of time spent at home and at work, respectively, associated with travelling at clock time t, which means the trip scheduling preference is connected with the activity before time t and after time a in a symmetric way, as shown in Fig.2

Suppose $H'(t)$ is decreasing with t and $W'(t)$ is increasing with time t, and the travel time is T, then the traveller would choose a optimal departure time $t*$, where $H(t^*) = W(t^* + T)$, since this optimal departure time balanced the marginal cost of time at home and at work. This specification also explains why value of time is observed to increase with trip length.

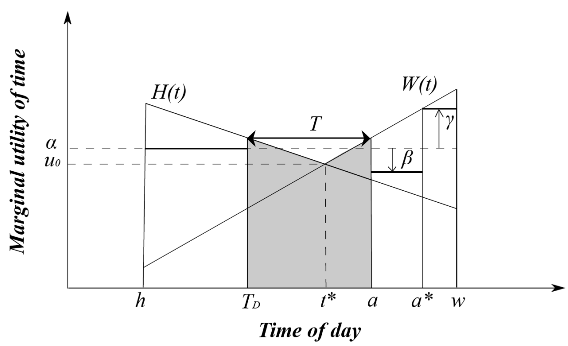

Fig. 2 Marginal utility of trip scheduling

As explained by Fosgerau and Small(2012) and Small(2012), the "alpha-beta-gamma" preference is a limiting case where $H(t)$ is a linear function with slope of α, and $W(t)$ is piecewise linear before and after the preferred arrival time, with slope of β and γ respectively. The intuition of this preference is that the individual prefers time at home to time traveling by amount α per unit time; the time spend at workplace prior to the preferred arrival time a^* is less valuable than the time at home by amount β, but after a^*, it is more valuable than home time by amount γ. This relationship can also be found in Fig.2.

Even though the Tokyo railway commuter's departure time choice has been studied by several researchers such as Iwakura and Harata (2005), Matsumura et al.(2011), and Takada et al.(2012), the marginal utility of travel time and schedule delay is assumed to be constant. Tseng and Verhoef (2008) introduced the time-varying utility and provided an estimation for commute trip through stated-preference data. However, estimations through revealed-preference is rare. This paper applies the time-varying marginal utility function developed by Vickrey (1973) and recently enhanced by Fosgerau and Engleson(2011), aiming at providing an empirical study to examine if the time-varying utility of time can more precisely capture the preference of departure time when estimated by a actual census data.

In the following sections, an detail explanation to the theoretical time-varying marginal utility model is conducted in section3. Section 4 provides an statistic result of basic departure time choice feature of Tokyo railway users through 2010 Metropolitan Transportation Census of Tokyo. The estimation method and result is explained in section 5.

(3) Formulation of departure time choice model

According to the result of 2010 Metropolitan Transportation Census of Tokyo, the average travel time is over 70 minutes, this relatively long period of travel time may lead to a large difference between the marginal utility before and after the trip. Thus the conventional $\alpha-\beta-\gamma$ approach may cause larger error when estimate the value of time. In this case, we would like to investigate the departure time choice preference under this specific practical situation by applying time-varying utility model.

Fosgerau and Engleson (2011) considered a traveller who departs from the orign at time d and arrive at the destination at time a within a time interval $[h, w]$, where T is travel time. Then the the total utility gained from this time interval can be represented as:

$$u(h, t_D, a, w) = \int_h^{t_D} (\beta_0 + \beta_1 s)ds + \int_a^{w} (\gamma_0 + \gamma_1 s)ds, \quad (2)$$

$\beta_1 < 0 < \gamma_1$.

If the travel time reduces to 0, the individual would departs and arrive at time t^*, to maximise the total utility within this time interval.

$$u(h, t_D, a, w)_{\max} = \int_h^{t^*} (\beta_0 + \beta_1 s)ds + \int_{t^*}^{w} (\gamma_0 + \gamma_1 s)ds \quad (3)$$

The travel cost can be therefore defined as the difference of u_{max} and u.

$$u(t_D, a) = \int_{t_D}^{t^*} (\beta_0 + \beta_1 s)ds + \int_{t^*}^{a} (\gamma_0 + \gamma_1 s)ds \quad (4)$$

As shown in Fig.2, we define u_0 as the utility level where

$$u_0 = H(t^*) = W(t^*) = \beta_0 + \beta_1 \frac{\gamma_0 - \beta_0}{\beta_1 - \gamma_1} \quad (5)$$

The the function of travel cost can be derived as

$$u(t_D, T) = \frac{u_0 + \beta_0}{2} T + \frac{\beta_1}{2} t_D T \quad (6)$$

If we assume H(t) is constantly equals to α, and W(t) equals to β and γ before and after determined preferred arrival time a^* respectively, then we could re-write the travel cost as

$$u(t_D, a) = \int_{t_D}^{a} \alpha dt + \begin{cases} \int_a^{a^*} \beta dt, & a < a^* \\ \int_{a^*}^{a} \gamma dt, & a \geq a^* \end{cases} \quad (7)$$

Thus, we could easily find out the travel cost is reduced into the form of equation (1)

3. Data descriptions and fundamental features

The data this paper analysed is the latest Metropolitan Transportation Census of Tokyo in 2010. Some aggregated census results provided by MLIT, as well as a line to line comparison of the scheduling behaviour in 22 major lines are presented in this section. All the results here is only the part of passengers who use commuter pass.

(1) Fundamental scheduling features of Tokyo railway users

Fig.3 is the first on-boarding time in a day aggregated from three censuses conducted in year 2000, 2005 and 2010 respectively. We could observe a trend that more people in 2010 census chose to depart before 8:00 than the one of 2000 and 2005, particularly

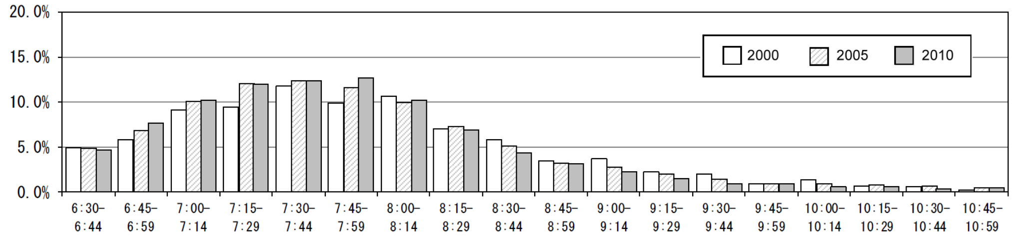

Fig. 3 On-barding time of day (quoted from the 2010 Metropolitan Transportation Census)

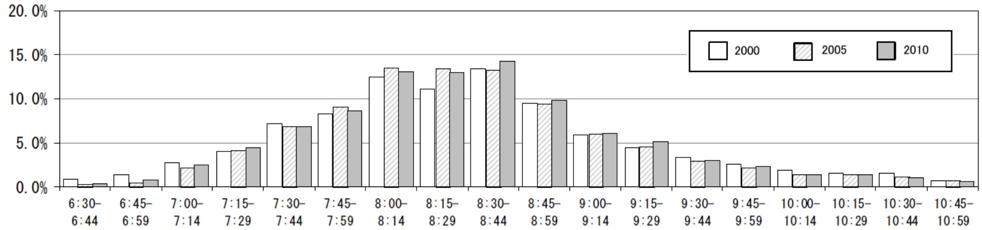

Fig. 4 Off-boarding time of day (quoted from the 2010 Metropolitan Transportation Census)

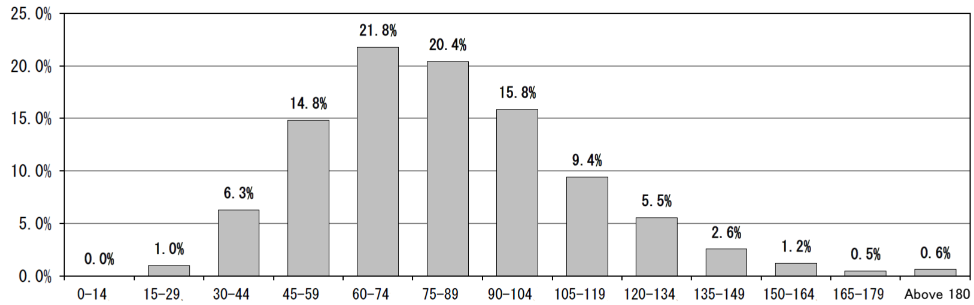

Fig. 5 Total travel time distribution (quoted from the 2010 Metropolitan Transportation Census)

between 7:15 and 8:00. However, there is no obvious moving trend in off-boarding time distribution as Fig.4. As a result, the average total travel time, including access and egress time, increased from 68.2 minutes in 2000 to 70.4 minutes in 2010. The distribution of the total travel time can be viewed in Fig.5.

For passengers commute to the workplace, as shown in Fig.6, over 1/3 or people's official start working time is 9:00, and another 22.7 per cent starts at 8:30. Fig.7 shows the average schedule delay in different work start time groups. Since those who works under flexible time system were directed to report the start time of core working hours, we could infer that most individuals start work after 9:30 are working under flexible time system. Notably, about 30 per cent of this group chose to arrive 90 minutes or more earlier than their start time of core working hours, while the average schedule delay of all workers in this census is 25.4 minutes.

In order to investigate if the scheduling preferences differ among different lines, we chose 22 major lines, connecting suburb and the city centre of Tokyo. The average schedule delay early is 24.3 minute.The average line-haul time ranges from 34.9 to 54.9 minutes, however, we are not able to find obvious difference of schedule delay among lines, where we assume the official work start time as the preferred arrival time.The schedule delay The average and standard deviation of line-haul time, schedule delay early and total travel time is presented in Fig.8, and the matching of line codes and their names are listed in Table 1.

(2) Departure time choice features of Tokyu Denentoshi line

The estimation, presented in the following section, is based on the data of Tokyu Denentoshi line. We chose 626 samples of which origin and destination are in Denentoshi line and the relevant information is completely reported. The entire morning peak from 6:00 to 10:00 was divided into 16 time intervals with 15 minutes each. The compositions of each station's departure times are shown in Fig.9, while Fig.10 is

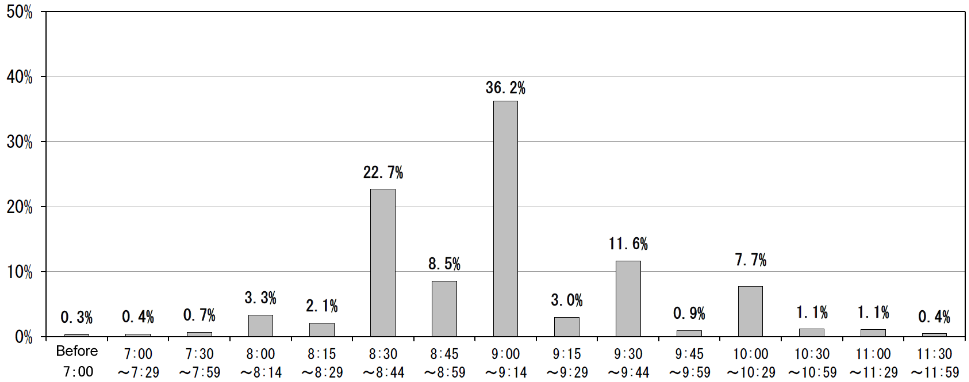

Fig. 6 Official work start time (quoted from the 2010 Metropolitan Transportation Census)

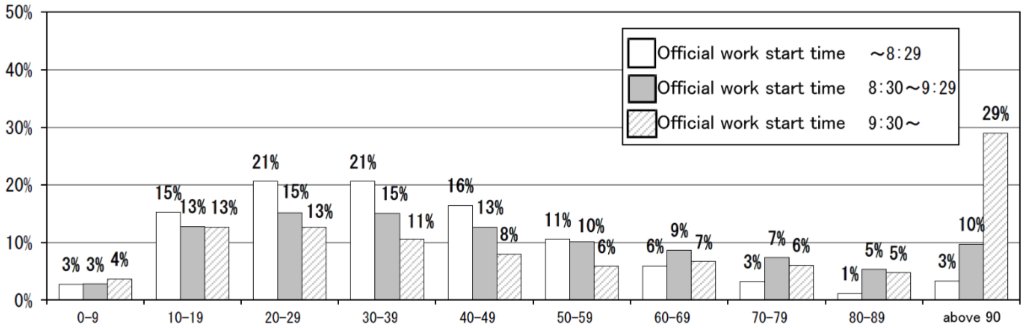

Fig. 7 Average schedule delay(quoted from the 2010 Metropolitan Transportation Census)

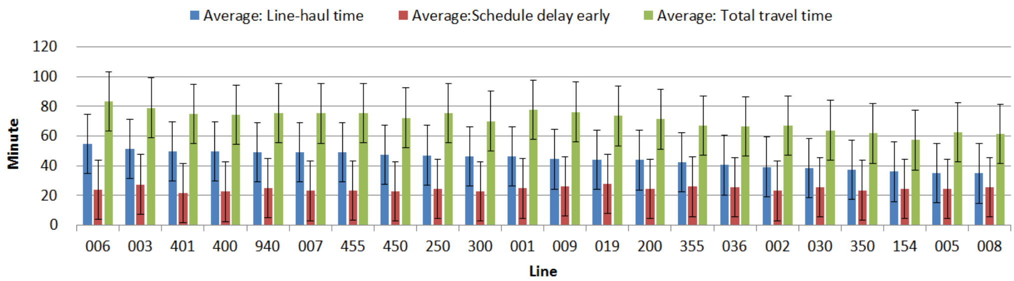

Fig. 8 Scheduling features of morning commute in 22 major lines

the projection of Fig.9, through which we could easily observe that the on-boarding peak moving along with time and stations in the direction towards city centre. Table 1 maps the station codes to their names.

4. Estimation Results

We are going to apply some discrete choice models to estimate parameters in the underlying scheduling model. The estimation results will be reported and distributed during the conference.

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Table 1 Mapping rule of line codes and names

Line code	Line name
001	JR Tokaido Main Line
002	JR Chouo Main Line
003	JR Tohoku Main Line
005	JR Keihintohoku Line
006	JR Joban Line Rapid Service
007	JR Joban Line Local Service
008	JR Sobu Line Local Service
009	JR Sobu Main Line
019	JR Yokosuka Line
030	JR Saikyo Line
036	JR Keiyo Line
154	Tokyo Metro Tozai Line
200	Keikyu Main Line
250	Odakyu Odahara Line
300	Keio Line
350	Tokyu Toyoko Line
355	Tokyu Denentoshi Line
400	Seibu Shinjuku Line
401	Seibu Ikebukuro Line
450	Tobu Izesaki Line
455	Tobu Tojo Line
940	Tsukuba Express Line

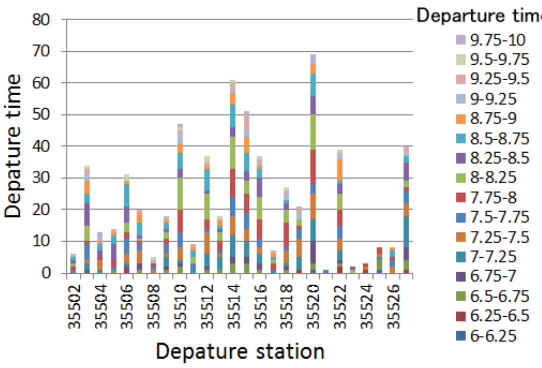

Fig. 9 Onboarding time of Tokyu Denentoshi line

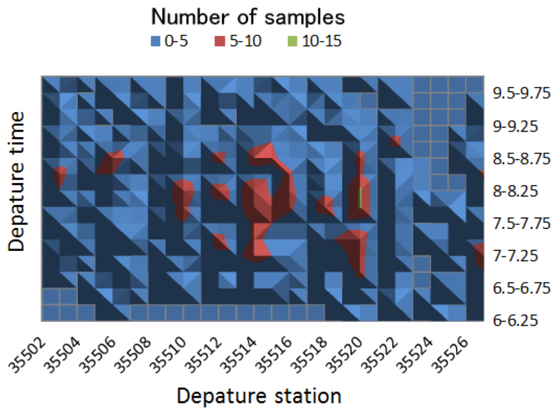

Fig. 10 Onboarding time of Tokyu Denentoshi line (projected)

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Table 2 Mapping rule of station codes and names

Station code	Station name
35501	Shibuya
35502	Ikejiri-ohashi
35503	Sangen-jaya
35504	Komazawa-daigaku
35505	Sakura-shinmachi
35506	Yoga
35507	Futako-tamagawa
35508	Futako-shinchi
35509	Takatsu
35510	Mizonokuchi
35511	Kajigaya
35512	Miyazakidai
35513	Miyamaedaira
35514	Saginuma
35515	Tama-plaza
35516	Azamino
35517	Eda
35518	Ichigao
35519	Fujigaoka
35520	Aobada
35521	Tana
35522	Nagatsuta
35523	Tsukushino
35524	Suzukakedai
35525	Minami-machida
35526	Tsukimino
35527	Chuo-rinkan

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