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A Primary Model of Commuting Travel Mode Choice by Taking Account of Disutility of Commutation

by

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Abstract

To improve the services of mass transit systems so as to attract additional travelers switching from private cars, it is necessary to grasp the travel mode choice behaviors of the workers. This paper attempted to propose a travel mode choice model for the workers commuting by mass transit systems by taking account of disutility derived from both processes of going to work and returning home. First, commutation activity was defined as a complete process that starts on departure time from home in the morning and ends at home-returning time in the evening. Meanwhile, disutility involved in going to work process and returning home process were formulated based on the feature that commutation is conditional on temporal constraints of the appointed work start time and end time. Then, a travel mode choice model synthetically considering both processes of going to work and returning home was proposed and calibrated by applying Person Trip survey data in Fukuoka City. The result indicated that home-returning process actually affects the travel mode choices even if its influence is less than that of going to work process. The model has good fitness in representing travel mode choice behaviors of the workers using mass transit systems.

Keywords: Commutation activity, Disutility analysis, Commuting travel mode choice, Mass transit systems, Person Trip (PT) survey

1. Introduction

Promoting utilization of mass transits has equivalent importance as well as reducing car traffics in alleviating traffic congestion that became a severe problem concerning with sustainable urban development. To attract additional travelers switching from private cars, it is necessary to improve

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the services of mass transit systems by the effective policies of transportation demand management (TDM) that completely incorporate the travel mode choice behaviors of the workers.

There are many studies on model development of travel mode choices of the workers. In these studies, some exogenous factors that are relevant to transit systems or travel subjects who undertake travel behaviors were generally taken into account, such as: travel time, fare cost, services of transit systems, social and economic characteristics of individual worker, residential location, household structure and so on[1-3) et al.]. Some studies even remarked the worker's preference, perception and attitude to transit systems[4),5) et al.]. It is known that commutation is conditional on temporal constraints of the appointed work start time and end time, and the feature is thought to be one of the most significant factors in the study on commutation travel behaviors. Despite some models of departure time decision and route choice that were developed in terms of the context emphasized the influence of work start time on going to work process[6),7) et al.], the existed studies mostly did not pay enough attention on work end time or the home-returning process. Moreover, some literatures recently indicated that overtime work, business out of office or private activities after the regulated work hours affect home-returning time of a worker[8),9)], few studies clarified travel mode choice of the workers from a viewpoint considering the processes of going to work and returning home synthetically.

Based on the above-mentioned backgrounds and what we have addressed in our previous study that commutation comprises a series of activities undertaken in the period that starts on departure time from home in the morning and ends at home-returning time in the evening[10)], this paper attempted to propose a choice model of commuting travel mode with consideration of the disutility derived from entire commutation activity. Since there is a fundamental difference of commutation activity between the car-based workers and the workers using mass transits that the feature responding to road traffic congestion should be specifically introduced in describing commutation activity of the car-based workers[11)], this paper therefore put an emphasis on travel mode choice behaviors of the workers who commute by mass transits.

This paper was organized as follows: first, disutility of commutation activity derived from both processes of going to work and returning home were formulated except that related to the regulated work hours. Second, supposing a worker would select the one with minimal disutility among all available travel modes, a choice model with two alternatives of bus and rail was proposed based on a discrimination theory. Finally, the model was calibrated by applying data of Personal Trip (PT) survey in Fukuoka City.

2. Commutation Activity and Travel Mode Choice Model

2.1 Formulation of Commutation Activity

Considering commutation is conditional on the temporal constraints of work start time and end time, this paper thought commutation activity of three main processes in terms of the appointed work start time and end time, such as: going to work process, the regulated work hours and home-returning process. Travel time and fare cost, physical fatigue and work stress that are involved in all of these processes were further defined as disutility of commutation activity. Regardless of what associated with the regulated work hours, this paper put an emphasis on disutility derived from both processes of going to work and returning home. In addition, the disutility in temporal domain was taken into account excluding disutility of travel fee because the most enterprises usually pay the cost for their employers. The disutility related to the processes of going to work and returning home were respectively formulated as follows:

(1) Disutility Function of Going to Work Process

Suppose t_d, t_a and t_s are departure time from home, arrival time at workplace and the appointed work start time respectively. Given a certain t_d, arrival time in workplace t_a was determined as follows:

$$t_a = t_d + T_n \tag{1}$$

However, travel time T_n generally varies with operational feature of transit systems, arrival time t_a is thus indefinite and its probability density function (hereafter expressed as PDF) was given by:

$$\phi_{ta}(t \mid t_d) = \phi_{T_n}(t - t_d) \tag{2}$$

Because there is a possibility that arrival time t_a is later than the appointed work start time t_s, and there would be a material or mental penalty with being late, a worker has to take an evasion time T_{late} for not being late besides travel time T_n when he decides his departure time from home. That is to say, the actual departure time of the worker was determined by:

$$t_d = t_s - T_n - T_{late} \tag{3}$$

Since the virtue time cost for going to work is $t_s - t_d$ rather than $t_a - t_d$, and the earlier a worker departures from his home, the larger his disutility for work is, disutility for work D_W was therefore defined as a function of time duration $t_s - t_d$ as formula (4).

$$D_W(t_d) = \alpha_1(t_s - t_d) = \alpha_1(T_n + T_{late}) \tag{4}$$

Where: α_1 is a positive parameter.

(2) Disutility Function of Home-returning Process

Being similar with going to work process, t_e, t_l and t_r were respectively supposed as work end time, leave time from workplace and home-returning time. In terms of the appointed work end time, disutility of home-returning process D_R was assumed as a linear function increasing with t_r, because the later the worker returns home, the larger his disutility is.

$$D_R(t_r) = \alpha_2(t_r - t_e) \tag{5}$$

Where: α_2 is a positive parameter.

It is known, particularly in Japan, that the workers generally do not leave workplace just at the work end time. If we define the duration for overtime work or for workers' private things before leaving workplace as T_{over}, and the duration for other activities out of workplace including travel time for returning home as T_{out}, which were determined by formula (6) and formula (7) separately, the disutility of home-returning process expressed in formula (5) can be transformed into formula (8).

$$T_{over} = t_l - t_e \tag{6}$$

$$T_{out} = t_r - t_l \tag{7}$$

$$D_R(t_r) = \alpha_2(t_r - t_e) = \alpha_2(T_{over} + T_{out}) \tag{8}$$

(3) Conceptual Model of Commutation Activity

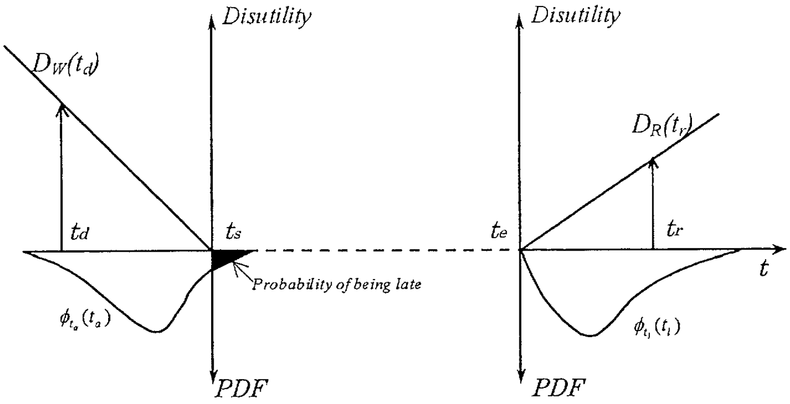

Fig. 1 The conceptual model of commutation activity

Taking X as a time axis representing a day cycle, whereas Y_1 and Y_2 as disutility axes that respectively intersect at work start time t_s and work end time t_e, **Fig. 1** described a conceptual model of commutation activity. The disutility consisting in both processes of going to work and returning home that were already defined as functions of departure time from home t_d and home-returning time t_r were shown as two solid lines in the left side and right side. Assuming disutility can be added, total disutility of commutation activity, $D_i\,(t_d\,,t_r)$, was therefore defined as the sum of D_W and D_R as follows:

$$D_i\,(t_d,t_r) = D_W\,(t_d) + D_R\,(t_r) = \alpha_1\,(t_s - t_d) + \alpha_2\,(t_r - t_e) + \beta_i \tag{9}$$

Where: i stands for a certain travel mode and β_i is a proper variable representing some specific attributes related to the *ith* travel mode.

Considering the variation of travel time depending on operation features of mass transit systems, it can be thought that arrival time at workplace t_a in the process of going to work as well as leave time from workplace t_l in the process of returning home responding to a certain t_d or t_r was determined by $\phi_{ta}\,(t_a)$ or $\phi_{tl}\,(t_l)$. Therefore, the PDFs of t_a and t_l were also illustrated in **Fig. 1**.

2.2 Travel Mode Choice Model

Based on above-mentioned analysis of disutility of commutation activity, this paper applied discriminate distributions of disutility to deduce travel mode choice model. Given two kinds of travel modes as alternatives, we firstly denoted a worker's disutility using mode 1 and mode 2 as D_1 and D_2 respectively, in which disutility of both processes of going to work and returning home were included. According to an assumption that a worker would choose the one with minimum of disutility from both available travel modes, if $\Phi_{D1}\,(D_1)$ and $\Phi_{D2}\,(D_2)$ that are PDFs of different travel modes 1 and 2 were known, as shown in **Fig. 2**, the probability $\Delta_{q1}\,(D_1)$ that a worker judges $D_1 = D$ in a little ΔD section would be calculated by:

$$\Delta q_1\,(D_1) = \Phi_{D1}\,(D_1)\,\Delta D_1 \tag{10}$$

In the same condition, if the worker judges $D_2 > D$ and then decides to choose travel mode 1, his choosing probability was given as follows:

$$\Delta P_1\,(D_1) = \Phi_{D1}\,(D_1)\,\Delta D_1 \int_{D_1}^{\infty} \Phi_{D2}\,(D_2)\,dD_2 \tag{11}$$

Thus, the worker's choice probability of mode 1 in entire scope of D was determined by:

$$P_1(D_1)=\int_0^{\infty} \Delta P_1(D_1)\,dD_1=\int_0^{\infty} \Phi_{D1}(D_1)\int_{D_1}^{\infty} \Phi_{D2}(D_2)\,dD_2dD_1 \quad (12)$$

Although the model is generally applicable to individual choice behavior of travel mode, this study attempted to apply it to represent the travel mode choice behaviors of the workers who live in a specific zone, in which the conditions related to mass transit systems that are available to the workers to reach the same destination are almost identical. In such situation, if disutility distributions of all workers using mode 1 and mode 2 were known, which are primarily determined by different travel time of all workers, the theoretical choice probability of either travel mode in this zone would be obtained based on formula (12).

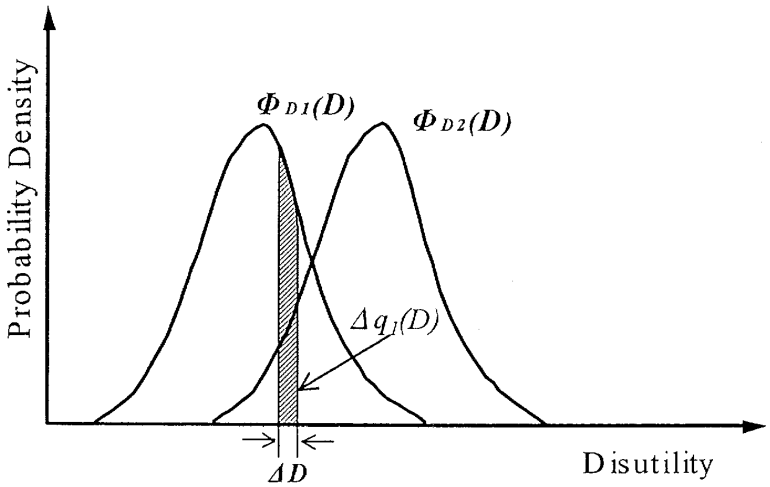

Fig. 2 Diagram of travel mode choice model

3. Parameter Estimating and Result Analysis

To calibrate the proposed travel mode choice model of the workers, this paper selected PT survey of all 111 c-zones in 7 administrative wards of Fukuoka City in 1993 as data source that well documents traveler activities in a day cycle.

3.1 Data Processing

In every c-zone, all commutation trips toward CBD were firstly extracted in terms of travel purpose and destination. From **Fig. 3**, it was known that the durations of 8:00-9:00 and 17:00-19:00 are respectively the peaks of arrival time at workplaces and leave time from workplaces. Thus, the workers who arrive in CBD during 8:00-9:00 and leave workplaces after 17:00 were selected in every c-zone. Moreover, since how the other private or business activities on the stops of way to and from work influence choice behavior of travel mode was not revealed clearly, this paper took into account the workers who have two trips only for work and home rather than those who have multi-trips.

The commuting travel modes of the workers included in PT survey were mainly categorized into 4 types: by car, bus, rail system and others (e.g. motorcycle, bicycle and walking). The obvious differences were found in the shares of travel modes in all c-zones where have different traffic conditions and distances from CBD. For examples: the most workers who live far from CBD and along rail lines would like to choose rail system because it can provide great convenience as well as punctuality. Meanwhile, the workers living near CBD prefer to bus or other travel modes such as: bicycle, motorcycle or walking.

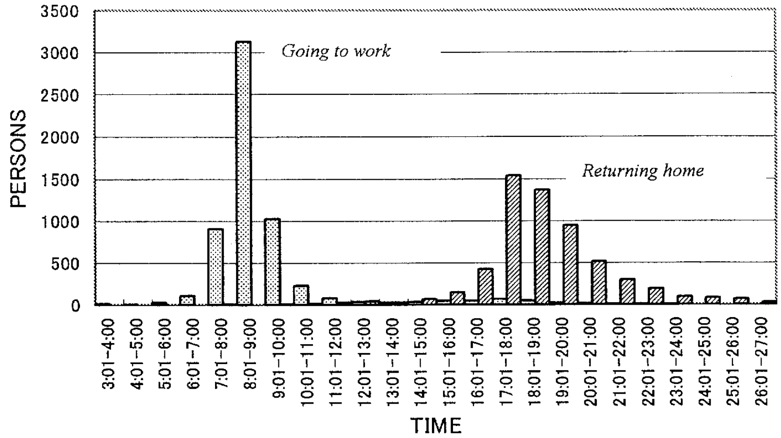

Fig. 3 Distributions of arrival time in CBD and leave time from CBD in a day cycle

Table 1 A simple description of the selected zones

Unit:minutes

No.	Numbers of c-zone	samples	travel time by bus		travel time by rail		actual choice rate of rail
			Ave	Std	Ave	Std	
1	2 (107,110)	81	46.2	8.26	35.1	7.61	0.90
2	2 (108,109)	42	49.7	9.23	38.3	12.07	0.48
3	4 (81,82,83,84)	36	45.1	10.95	46.8	18.22	0.42
4	2 (36,37)	72	30.2	8.65	25.3	7.9	0.56
5	2 (59,60)	55	45.1	8.28	38.1	9.15	0.98
6	2 (63,72)	64	34.2	6.34	33.9	8.67	0.89
7	3 (65,66,69)	59	51.3	11.97	47.5	9.52	0.24
8	2 (70,71)	44	36.7	8.54	27.6	5.42	0.59
9	3 (75,76,58)	81	43.3	5.77	31	6.06	0.81
10	2 (90,91)	53	44.1	7.62	42.3	8.22	0.79
11	2 (92,93)	50	54.2	6.84	40.3	7.63	0.92
12	2 (77,80)	44	31.1	8.55	25.7	7.21	0.64
13	4 (111,112,113,115)	67	55.1	12.12	50.9	10.15	0.30
total	32	748					

*: ( ) what is included are codes of c-zones

As mentioned above, this paper emphasized on modeling travel mode choice behaviors of the workers commuting by mass transit systems. The workers who have possibilities using cars for commutation should be excluded from those who commute by bus or by rail system. For this purpose, the actual situation of permission to commute by cars was surveyed by a telephone interview among the principal industrials in CBD including construction, finance, wholesale and service. It was known from the surveyed result that about 29% of all workplaces don't restrain the car-based commutation. Using this rate, the actual numbers of the workers commuting by bus or rail system were adjusted and estimated. Furthermore, the following c-zones were taken out of consideration, including: 1) the ones with insufficient samples, 2) the ones in which either rail or bus is not available to be used and 3) the ones in which the category of other modes occupies a high share. As the result, 32 c-zones were determined and further merged into 13 zones in terms of similar traffic conditions of mass transit systems including travel time, bus stops or railway stations being available to be used and so on.

Table 1 is a simple description of the selected 13 zones. Here, the mean and the standard deviation of travel time by using bus or rail system in every zone were also listed in **Table 1**.

3.2 Calculation of Disutility

In principle, if t_s-t_d and t_r-t_e of the workers in each zone were known when they use travel mode 1 or mode 2, the commutation disutility related to different travel modes D_1 and D_2 would be determined based on previous formula (9), given arbitrary values to the parameters of α_1, α_2 and β. Furthermore, the theoretical choice probabilities of both travel modes in all zones can be calculated by applying formula (12). Through adjusting the given values of α_1, α_2 and β repeatedly, and comparing the square difference between the actual and the theoretical choice probabilities of bus and rail in all zones, the most appropriate α_1, α_2 and β_i would be consequently estimated when the value of square difference between the actual and the theoretical choice probabilities of bus and rail becomes the least.

However, we can't calculate the disutility of going to work or returning home directly by t_s-t_d or t_r-t_e because the work start time t_s and the work end time t_e are not recorded in PT survey. For this reason, we adopted the following methods to calculate the disutility of both processes of going to work and returning home separately.

(1) Disutility Calculation of Going to Work Process

According to formula (4), we applied $T_n + T_{late}$ instead of t_s-t_d to calculate the disutility of going to work. Here, travel time $T_{n(i)}$ of the workers who actually use travel mode i were obtained directly by calculating the difference between departure time from home and arrival time at workplace that are recorded in PT data. While, travel time $T_{n(j)}$ of the alternative travel mode j of these workers were appropriately appended by referencing the running schedules of transit systems.

About the evasion time for being late T_{late}, we assumed that it equals to the difference between T_{max} and t_0 as shown in **Fig. 4** and it is a fixed value in a certain zone. In our previous study, the PDF of being late probability $(T_n \geq T_{max})$ was proved to be well approximated by the following function: [12)]

$$f_\lambda(\lambda) = Af_1(\lambda) + Bf_2(\lambda)$$

$$f_i(\lambda) = \frac{1}{\sqrt{2\pi}\sigma_i \lambda} e^{-(\ln \lambda - \mu_i)^2/2\sigma_i^2} \qquad i = 1, 2 \tag{13}$$

Where: $A = B = 0.5$, $\mu_1 = -4.0174$, $\sigma_1 = 1.0108$, $\mu_2 = -8.0652$, $\sigma_2 = 1.9680$. The mean and the standard deviation of probability of being late λ were 0.016 and 0.032 respectively.

Supposing T_n attributes to normal distribution $N(t_0, \sigma_t^2)$, formula (14) was obtained by taking 0.016 as the probability of being late.

$$P(z > T_{\max}) = 0.016 \tag{14}$$

By a transformation of $z = (T_{\max} - t_0)/\sigma_t$, the evasion time for being late T_{late} was thus determined as follows:

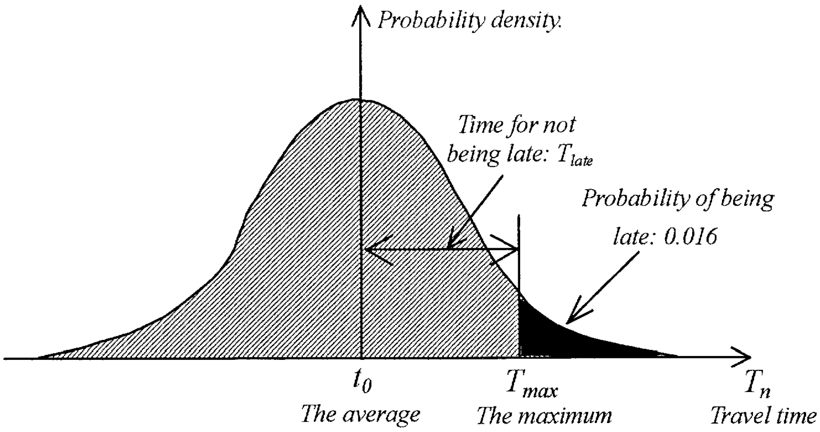

Fig. 4 Distribution of travel time and the evasion time for being late

$$T_{late} = 2.144\ \sigma_t \tag{15}$$

Where: σ_t represents the standard deviation of travel time T_n of a certain mode in a zone.

(2) Disutility Calculation of Home-returning Process

Similarly, since disutility of home-returning process was also thought of a function of T_{over} and T_{out} as expressed in formula (8), we applied an integrated distribution of T_{over} and T_{out} to represent the distribution of disutility for home. For the workers with only two trips for work and home who were selected in this paper, their T_{out} are actually equivalent to travel time for returning home T_n'. Therefore, applying the same method used in going to work process, travel time $T_{n(i)}'$ of the workers who use travel mode i were obtained directly by calculating the difference between home-returning time and leave time from workplace that are recorded in PT data, while travel time $T_{n(j)}'$ of the alternative travel mode j of these workers were appropriately appended by referencing the running schedules of transit systems.

We have mentioned above that the workers generally do not leave their workplace just at the work end time. Supposing there is no occasional difference among the workplace-leaving behaviors of all workers, which means that the workers decide their leave time from workplace based on the same mental state, we obtained the distribution of T_{over} by investigating leave time from workplace of the staffs those who work in the Government of Fukuoka Prefecture. The result was shown in **Fig. 5**. When distributions of T_n' and T_{over} were known, the distribution of disutility of home-

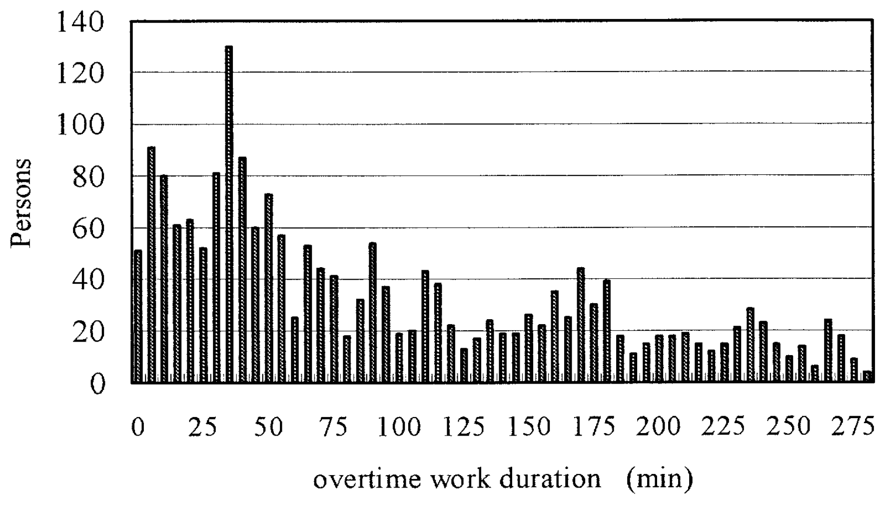

Fig. 5 Distribution of leave time from workplace

returning process or $\phi(t_r - t_e)$ was calculated by the following formula.

$$\phi(t_r - t_e) = \iint \phi_{T_{over}}(T_{over}) \phi_{T_n'}(T_n') dT_{over} dT_n' \tag{16}$$

3.3 Result Analysis

Applying the above-mentioned method and data of the selected 13 zones, the proposed model was calibrated. There were four parameters of α_1, α_2, β_i and β_j that should be estimated. However, since this paper just took into account both travel modes of bus and rail, we assumed the proper variable of rail β_{rail} to be 0 so that an relative value of β_{bus} can be calculated simply. Meanwhile, to contrast the weight of disutility of going to work process with that of returning home process, we gave 1 to parameter α_1 and calculated the parameter α_2 relatively. Consequently, $\alpha_2 = 0.126$ and $\beta_{bus} = 0.1$ were estimated.

As other study indicated, the workers are greatly free to decide his activities in the period after the work end time t_e with a comparison of the time period before the appointed work start time t_s[13]. It well explained why disutility of home-returning process is less than that of going to work process. However, it is not able to ignore that the home-returning process indeed affects the choice behavior of travel modes even if the value of α_2 is not so great.

Figure 6 compared the estimated and the measured rail choice probabilities in all selected zones to examine the fitness of the presented model. The size of a circle represented the sample numbers in every zone. From the result that the correlation coefficient with weighted adjustment is 0.866, the model was proved to represent the travel mode choice behaviors of the workers with good fitness.

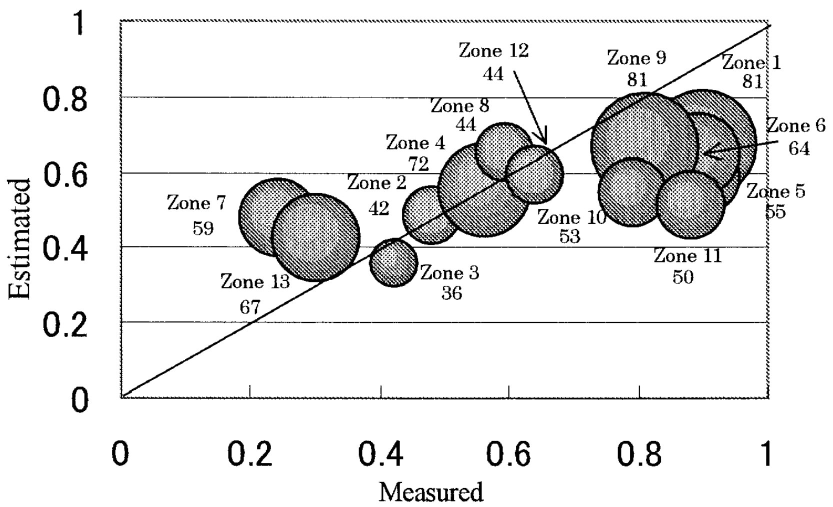

Fig. 6 Comparison between the estimated and the actual values of choice probability of rail system

4. Discussions and Conclusions

In this paper, commutation was defined as a series of activities undertaken by the workers in a day cycle that include going to work process in the morning and home returning process in the evening. Based on the characteristics of commutation that the work start time and end time are appointed and there is a material or mental penalty with late arrival or early leave, disutility derived from both processes of going to work and returning home were formulated with respect to the influences of being late and overtime work. In terms of the principle of minimum disutility, a travel mode choice model for the workers using mass transit systems was proposed and further calibrated by applying PT survey data in Fukuoka City. By comparing the theoretically estimated values with the actual values of travel mode choice probabilities in all selected zones, it was indicated that the proposed model with consideration of home-returning process has good fitness in representing travel mode choices of the workers using mass transit systems.

However, it was noticed that there are some problems not being resolved very well in this primary study, which considered the processes of going to work and returning home synthetically in a travel mode choice model. Firstly, the proposed model with linear structure of disutility for going to work and returning home seems to be too simple to contain all influencing factors of travel mode choice behaviors, even the influence of home-retuning process was indicated.

In addition, limited by the difficulties in elaborately collecting the individual information about the commutation activity and commuting travel mode choices of all workers who have different and various origin-destination pairs, this paper attempted to apply the existing data of PT survey to deal with travel mode choice behaviors of a group of workers in a specific zone. However, this paper did not take into account the individual difference among all workers that responds to social and economical characteristics of the workers individually and affects the distribution of disutility.

Except these problems, we should take account of the following aspects in further study to complement the proposed model. 1) Commutation activity of the car-based workers should be formulated with consideration of disutility related to driving safety and stress resulted in traffic congestion so that a complete mode choice model with three alternatives of bus, rail and car would be calibrated. 2) Not only the workers with 2 trips for work and home and their commutation activities, but also the diversified and complicated commutation behaviors of the workers with multi-trips should be well grasped. An applicable and complete travel mode choice model incorporating home-returning process is expected to play an important role in evaluating effects of TDM measures by predicting workers' transferring possibilities among various travel modes.

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