A TIME-SERIES ANALYSIS ON CHARACTERISTICS OF RAILWAY ROUTE CHOICE BEHAVIOR BY AGE GROUP OF URBAN RAILWAY PASSENGERS

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ABSTRACT

The population in Japan has been declining since 2005. On the other hand, the aged population is growing at a faster pace. The decrease in population and the increase of aging citizens have significant impact on the urban travel demand such as commuting trips. It is therefore necessary to reconsider the railway service system taking into account these new trends. In this study characteristics of route choice of travellers by age groups are analyzed based on transportation census data, which has been collected every 5 year since 1960. The census includes the route from origin zone to destination zone, and also passengers' attributions, such as ages.

Keywords: Urban Railway Planning, Railway Route Choice Behavior, Time-series Analysis, Age Group

1. INTRODUCTION

There is high density of railway network in Tokyo metropolitan area. Many passengers have several alternative railway routes to their destination stations. They are able to choose the best route on the basis of the level of railway services such as time, fare, congestion in the train, the number of transfer at the station and so on.

Even though the Japanese population has been declining since 2005, the proportion of aged citizens has been increasing at a faster rate. The decrease in population and the increase of aged peoples have significant impact on the urban travel demand such as commuting trips. It is necessary to improve the railway in response to such trend of the social change.

Railway route choice behavior varies by the age of travelers. Even within the same age, the behavior may vary over time period. Therefore, analyzing the dynamics of the behavior is necessary to provide appropriate service for the aged society. For an effective urban railway planning in Tokyo metropolitan area, it is very important to make clear the difference of the behavior by age and the changes over time.

However, the main targets of urban railway development in the past were decrease of the congestion in the train and the impedance of transfer at the station. The main policy of railway for elderly people was limited on the introduction of transfer facilities such as elevators and escalators. The railway route choice model for demand forecast was not calibrated by each age group, although the variables about congestion and transfer were applied. There are only few studies that compares current model with past one in detail. The influence on the route choice behavior by period, age and cohort has not been clarified yet.

This study focuses on the variance of railway route choice behavior by age and period. Trip data of transportation census is used in order to model the behavior. The objectives of the study are to illustrate the characteristics of the behavior by the each age group based on the estimated results.

2. LITERATURE REVIEW AND SCOPE

Giuliano *et al*. (2003) and Hakamies-Blomqvist *et al*. (2004) provided an overview of the research areas on the transportation and the elderly. According to these papers, the research topics can be categorized into four main areas: i) mobility and the elderly, ii) travel patterns among the elderly, iii) senior drivers' characteristics, and iv) safety measures and safety improvements in transport infrastructure for the elderly.

The first area, mobility and the elderly, shows the significance of transportation or mobility for the elderly. As surmised in this paper, the significance of transportation and mobility for the elderly means keeping social relations, independence, avoiding social isolation, and maintaining critical elements in life satisfaction. In the same area, some literature investigated how mobility level changes the level of social participation. For example, Glasgow (2000) showed that non-metropolitan elderly with high mobility (car drivers) have higher levels of social participation and interaction than elderly with low mobility (non-drivers). Coughlin (2001) conducted a survey on how transportation is associated with the contentment of the elderly and found that mobility, indeed, is a critical factor of life satisfaction. Furthermore, Banister and Bowling (2004) investigated how mobility, accessibility and social networks determined quality of life (QOL) of the elderly using British statistics.

The second research area, travel patterns among the elderly, entails analysis of travel patterns of the elderly based on official statistics, e.g. National Household Travel Survey and General Social Survey, or secondary data from questionnaires or activity diary surveys. Many researchers from different countries have conducted research on this area. In North

America, Rosenbloom (2000) and Collia *et al*. (2003) analyzed travel patterns of the American elderly based on official statistics and Newbold *et al*. (2005) investigated driving behavior among older Canadians using cohort analysis. In Europe, Noble (2000) showed travel patterns of older British while Tacken (1998) showed travel patterns of the Dutch elderly. O'Fallon and Sullivan (2003) and Baxendine *et al*. (2005) analyzed travel patterns of the senior people in New Zealander. Rosenbloom (2001) and Alsnish and Henser (2003) conducted international comparative studies on the travel patterns of elderly based on data and findings of several studies. Most of the studies used country-level statistics and focused on car and the elderly. Very few studies used urban-level or metropolitan-level data for analyzing travel patterns of older people except for that of Scott *et al*. (2005). Moreover, there are limited studies that focused on transportation and the overall trip purposes of the elderly. An exception is Hibino (2005, 2006) who investigated transportation and tourism behavior of the elderly.

Hakamies-Blomqvist *et al*. (2004) comprehensively reviewed the third area, senior drivers' characteristics. Their report contains i) a comprehensive literature review of the research area, ii) an analysis of the characteristics and preferences of senior drivers, iii) situational profile on the increase in the elderly drivers, and iv) reasons for accidents involving older drivers.

Finally, the fourth area on safety driving and safety improvements in transport infrastructure for the elderly focused on policy measures to enhance safety for senior drivers and improvement of infrastructure through design modification. There are many studies on this topic in Japan, e.g., barrier-free facilities and universal design.

This study is categorized to the second area. However, three main points distinguish our research from existing literatures. The first point is that the study analyzed behavioral changes of older people by trip purpose, age, and sex in a very dense transportation network. The second point is that the study investigated travel pattern of the elderly in a unique setting - the shorter transition period from aging society to aged society compared to other industrialized countries. Existing studies do not need to consider this situation. Outcomes of the study may provide insights to East Asian countries in preparation to the expected rapid growth of aging population. The third definitive point is that the study simulated behavioral changes of the elderly in urban and metropolitan area using empirically rich computer simulation model that can depict consequences after baby boomers' retirement in Japan in a quantitative manner.

3. ANALYZING METHOD

3.1 Outline of Analysis

The study is composed mainly of two analyses. First is to make the characteristics of route choice behavior clear by applying the Quantification Theory III analysis and by comparing selected route with alternative routes (Chapter 4). Second is to calibrate the route choice models by period and age based on the results of first analysis. Value of time that is calculated from the parameters is discussed (Chapter 5). Moreover, these two results lead to some effective urban railway policies for aged society.

3.2 Analyzing Data

The study uses the trip data of transportation census (1990, 1995, 2000 and 2005) of Tokyo metropolitan area. The census is implemented each 5 years since 1960 and obtains not only the route from origin zone to destination zone but also passenger's attribution such as age. Table 1 shows the number of commuting samples.

Table I – Number of Commuting Samples

Age \ Year	1990	1995	2000	2005
20s (20-29)	140,451 (40.2%)	106,004 (38.0%)	59,360 (26.5%)	13,070 (10.3%)
30s (30-39)	76,876 (22.0%)	58,092 (20.9%)	47,389 (21.2%)	29,660 (23.3%)
40s (40-49)	69,345 (19.9%)	53,776 (19.3%)	41,821 (18.7%)	31,659 (24.9%)
50s (50-59)	45,047 (12.9%)	43,429 (15.6%)	52,649 (23.5%)	37,149 (29.2%)
60s (60-69)	17,426 (5.0%)	17,300 (6.2%)	22,641 (10.1%)	15,660 (12.3%)
Total	349,145 (100.0%)	278,601 (100.0%)	223,860 (100.0%)	127,198 (100.0%)

4. TIME-SERIES ANALYSIS ON CHARACTERISTICS OF ROUTE CHOICE BEHAVIOR APPLYING QUANTIFICATION THEORY III ANALYSIS

4.1 Outline and Data Extraction

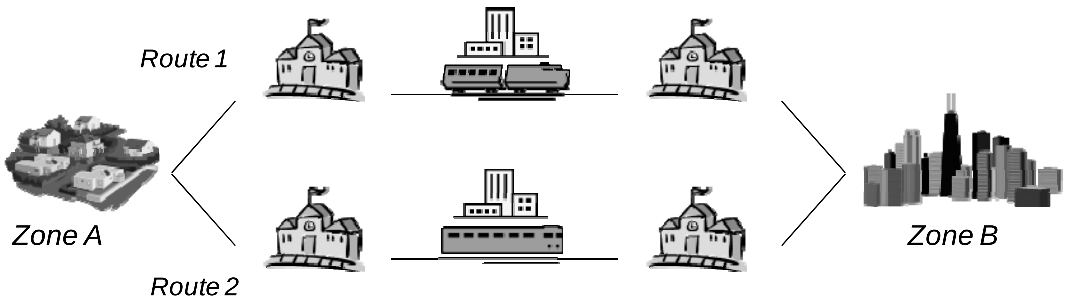
The level of services (fare, time, congestion etc.) of commuting routes and alternative routes are compared in order to make the characteristics of the route choice behavior clear. In the analysis, alternative routes are defined as the routes that are chosen by the other samples on the same OD. The samples are categorized to some types based on the characteristics. Moreover, the relation between age, period and category type is clarified.

The samples for Quantification Theory III analysis are extracted from all samples as shown in Table 1. The total number of OD pairs is 2,660,161 (1,631 zones x 1,631 zones). At first, the OD pairs with samples in all periods (1990, 1995, 2000 and 2005) are extracted. The number of these pairs is 22,422 (approximately 0.8 %). Next, the OD pairs with alternative routes are extracted from 22,422 OD pairs. Table 2 shows the number of extracted samples for

Quantification Theory III analysis. The share of every age and period is almost the same as shown in Table 1.

Table 2 – Number of Extracted Samples for Quantification Theory III Analysis

Year / Age	1990	1995	2000	2005
20s (20-29)	4,664 (43.2%)	3,493 (43.2%)	1,777 (28.7%)	413 (10.0%)
30s (30-39)	2,543 (23.5%)	1,692 (20.9%)	1,339 (21.6%)	1,033 (24.9%)
40s (40-49)	2,052 (19.0%)	1,357 (16.8%)	1,063 (17.2%)	1,123 (27.1%)
50s (50-59)	1,168 (10.8%)	1,134 (14.0%)	1,457 (23.5%)	1,102 (26.6%)
60s (60-69)	377 (3.5%)	417 (5.2%)	557 (9.0%)	471 (11.4%)
Total	10,804 (100.0%)	8,093 (100.0%)	6,193 (100.0%)	4,142 (100.0%)



	Fare	Riding Time	Transfer Time	Congestion in Train	Access and Egress Time
Route 1	500 yen	55 min	5 min	100	10 min
Route 2	600 yen	50 min	3 min	200	15 min

Sample X and *Z* choose the *Route 1*.
Sample Y chooses the *Route 2*.

Dataset for Quantification Theory III

	Fare	Riding Time	Transfer Time	Congestion in Train	Access and Egress Time
Sample X	1	0	0	1	1
Sample Y	0	1	1	0	0
Sample Z	1	0	0	1	1

Figure 1 – How to Make the Dataset for Quantification Theory III Analysis

Figure 1 shows how to make the dataset for Quantification Theory III analysis. This case means that there are two routes (*Route1* and *2*) from origin (*Zone A*) to destination (*Zone B*). The railway services are shown in the upper table in the figure. If there are three samples (*Sample X*, *Y* and *Z*) and *Sample X* and *Z* choose the *Route1* and *Sample Y* chooses *Route 2*, the dataset is made like the lower table in the figure. By comparing *Route1* with *Route2*, “1” is applied to better route and “0” is applied to another in each service. In the case of over 3 routes, “1” is applied to best one and “0” are the others.

4.2 LOS Data

In the analysis, fare, riding time, transfer time congestion index in train, access time and egress time are used as the LOS (level of service) data. These are defined as follows;

1. Fare (yen/trip): This fare means the railway fare per one trip from origin station to destination station on the basis of the price of the commuter ticket. The price is calculated by dividing the price of 1 month commuter ticket by 40 trips (20 days). Table 3 shows the examples in change of commuter ticket price. The fare of some OD pairs was raised in several times.

Table 3 – Examples in Change of Commuter Ticket Price (US$ per Month)

		1990	1995	From 2000 onward
JR East	10 km	55	55	56
	15 km	69	69	70
	20 km	96	96	98
Tokyo Metro	10 km	64	82	83
	15 km	69	90	92
	20 km	72	93	95
Seibu Railway	10 km	58	75	84
	15 km	67	88	97
	20 km	74	98	109

2. Riding Time and Transfer Time (minutes): In train from origin station to destination station, Raiding Time is total time in train and Transfer Time is addition of waiting time to walking time at interchange station. Both in train time and waiting time are based on railway diagrams of peak commuting hour. The waiting time is assumed to be time of 1/2 at railway operation intervals.

3. Congestion in Train: This index is used as the unpleasantness to congestion in the train. The equation is shown as follows;

$$CI = \sum (Time_{i,j} \times Con_{i,j}^{2})$$

CI : *congestion index in train*
$Time_{i,j}$: *in train time from station i to station j*
$Con_{i,j}$: *congestion ratio in train from station i to station j*

4. Access and Egress Time (minutes): This time means both the time from the center point of the origin zone to the origin station and the time from the center point of the destination station to the destination zone.

4.3 Results

The result of Quantification Theory III analysis is shown in Table 4. Both eigenvalue and contribution are significant. Because of the accumulated contribution until second dimension is over 60%, the study uses the result of first and second dimension.

Table 4 – Result of Quantification Theory III Analysis

	Eigenvalue	Contribution	Accumulated Contribution
1	0.225	34.2 %	34.2 %
2	0.174	26.6 %	60.8 %
3	0.132	20.1 %	80.9 %
4	0.126	19.1 %	100.0 %

Figure 2 illustrates the category score. This graph shows the position of relation of the items on the route choice in the first dimension on the horizontal axis and the second dimension on the vertical axis. “Riding Time” is located in first quadrant, both “Fare” and “Access and Egress Time” are in second quadrant, “Transfer Time” is in third quadrant, and “Congestion in Train” is in fourth quadrant. All samples are classified into four types according to the image limit each sample is located in.

Figure 3 shows the sample score and the number of samples in each quadrant. Over 8,000 samples are located in the first quadrant. These samples mainly consider the riding time and most of samples fall under this category7,344 samples are in the third quadrant, 7,203 samples are in the second one, and 6,351 samples are in the fourth. There is in the order of (1) “Riding Time”, (2) “Transfer Time”, (3) “Fare” and “Access and Egress Time”, and (4) “Congestion in Train” a lot of numbers of samples.

The relation of the type, age and period is analyzed based on the order. The ratio of the types in each period is shown in Figure 4. These graphs have similar tendency in all periods and the share of "Riding Time" is the highest. The ratio of “Transfer Time” increases and the ratio of “Congestion in Train” decreases from 2000 to 2005. It is thought that the policy for

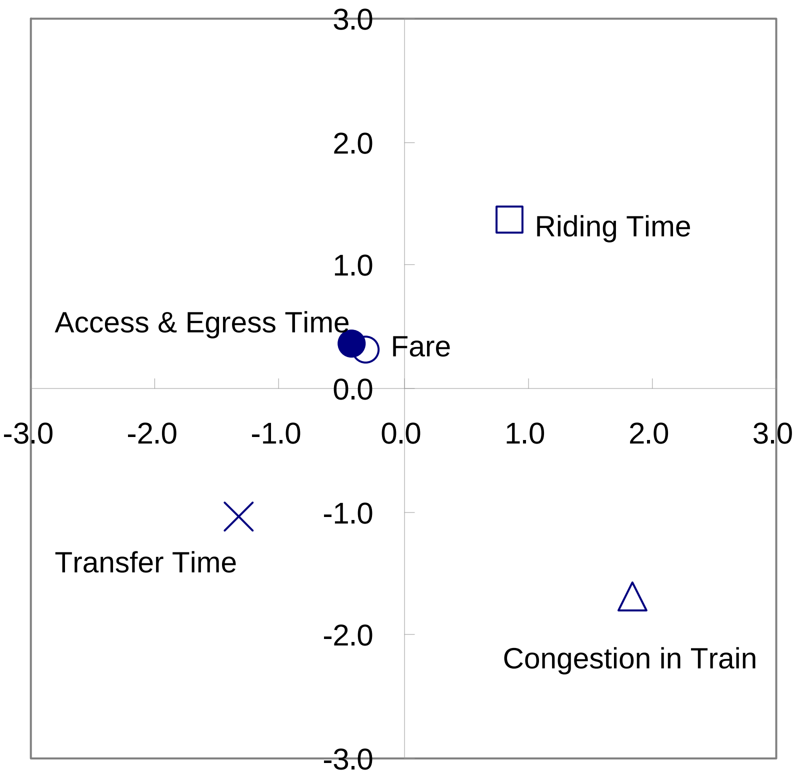


Figure 2 – Category Score

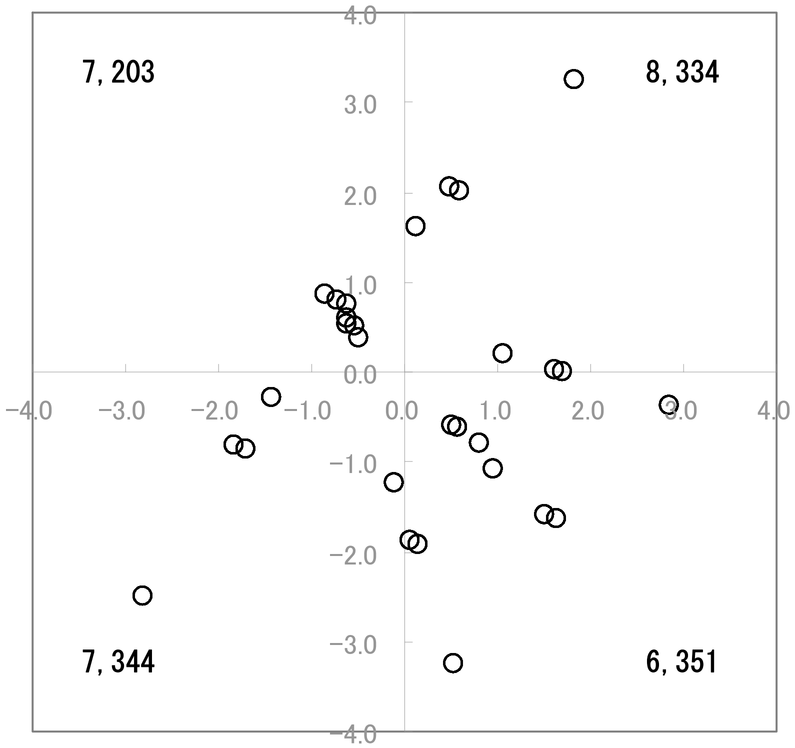


Figure 3 – Sample Score

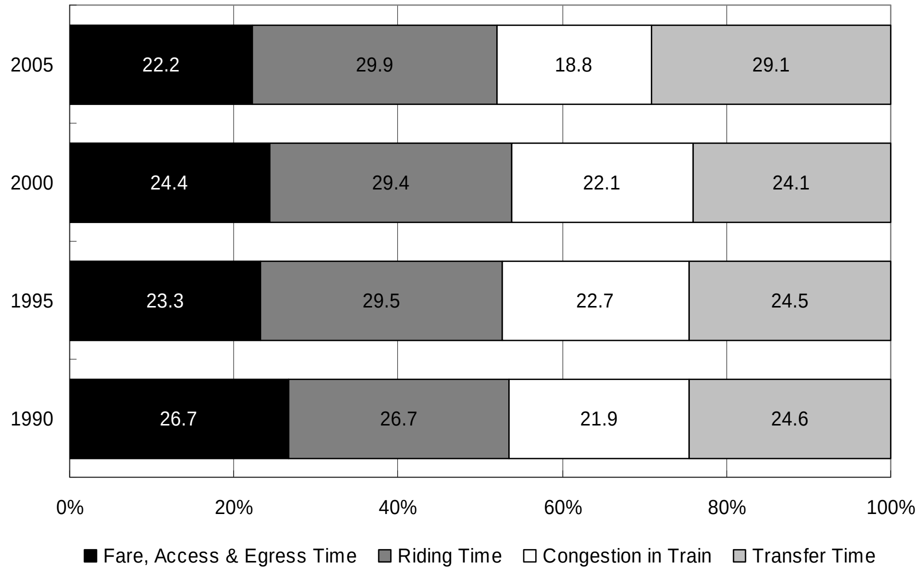


Figure 4 – Ratio of Types in Each Period

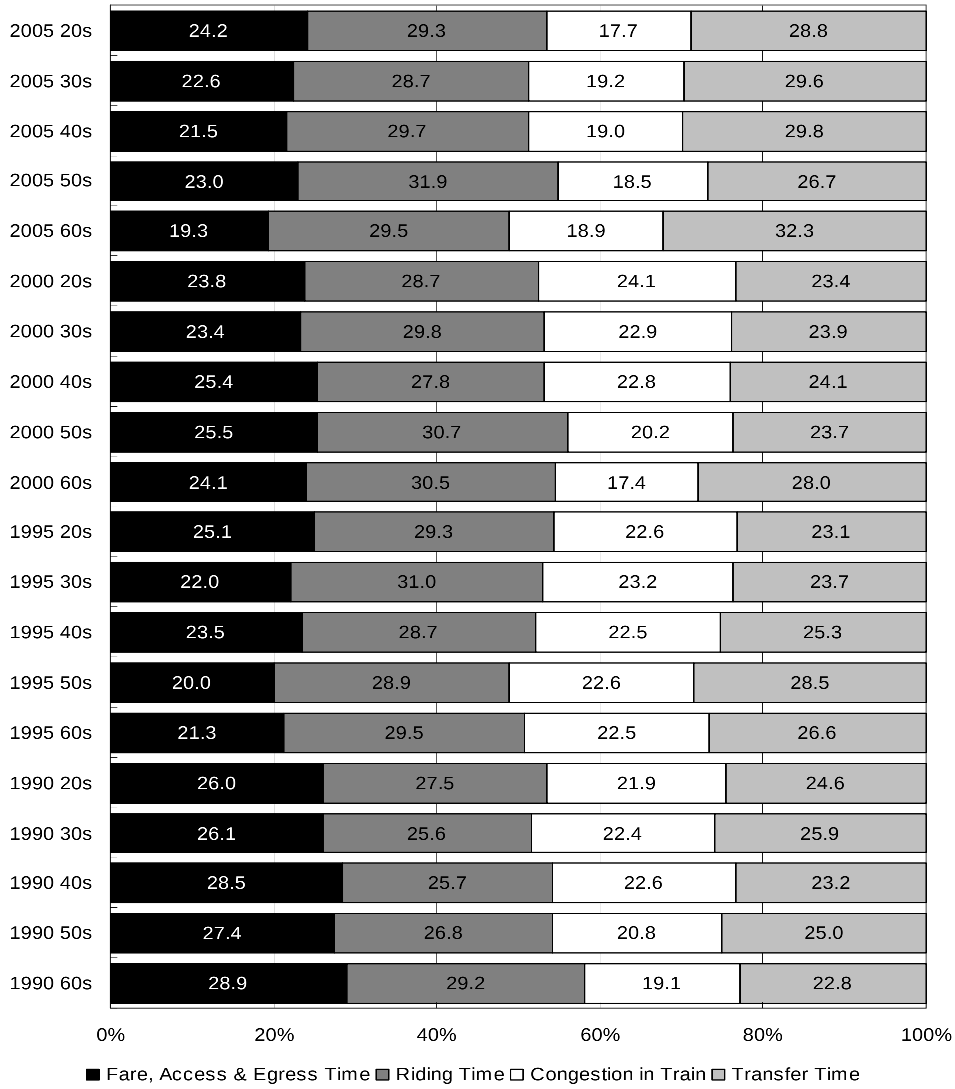


Figure 5 – Ratio of Types in Each Age Group and Period

transportation capacity reinforcement and the change of transfer environment are main reasons for this phenomenon. By the measures taken to improve transportation capacity such as construction of new lines, high frequency operation, many vehicles operation and so on, the congestion in train of whole railway network has decreased. By the development of big terminal, the transfer time became longer. On the other hand, direct operation service has reduced the necessity of making transfers. Therefore, the level of transfer service has been diversified.

The ratio of types in each age group and period is shown in Figure 5. Although the ratio of “Riding Time” is the highest in all periods in Figure 4, we can see there are graphs that the ratio of “Transfer Time” is higher than “Riding Time” by analyzing each age in detail. Therefore analysis of relationship between type, age and period is very important in order to calibrate the route choice model.

5. MODELING OF ROUTE CHOICE BEHAVIOR

5.1 Outline and Data Extraction

The study applies the route choice behavior model that is a disaggregate multinomial logit model. The equations are shown as follows;

$$P_i = \frac{\exp(V_i)}{\sum_j \exp(V_j)}$$

$$V_i = \alpha_1 X_1 + \alpha_2 X_2 + \cdots + \alpha_n X_n$$

P_i : *probability of choosing route* i
V_i : *utility of route* i
α_i : *parameters to be estimated*
X_n : *explanatory variables of the utility function*

As explanation variables, the analysis uses “Number of Transfer” in addition to “Fare”, “Riding Time”, “Transfer Time”, “Access and Egress Time”, “Congestion in Train” that were applied in Chapter 4. The number of choices from origin zone to destination zone is set three routes. 20 models (5 age gropes (20s, 30s, 40s, 50s and 60s) x 4 periods (1990, 1995, 2000 and 2005)) are calibrated.

Table 5 shows the number of samples for calibration of the models. In this analysis, the OD pairs with samples in all periods are used. The number of the OD pairs is 22,422 mentioned above.

Table 5 – Number of Samples for Calibration of Route Choice Model

Age \ Year	1990	1995	2000	2005
20s (20-29)	21,917 (44.7%)	17,193 (42.4%)	8,675 (29.9%)	2,398 (10.2%)
30s (30-39)	11,021 (22.5%)	8,570 (21.1%)	6,309 (21.8%)	5,822 (24.8%)
40s (40-49)	8,827 (18.0%)	7,196 (17.8%)	5,191 (17.9%)	6,242 (26.6%)
50s (50-59)	5,304 (10.8%)	5,442 (13.4%)	6,203 (21.4%)	6,285 (26.8%)
60s (60-69)	1,967 (4.0%)	2,127 (5.2%)	2,596 (9.0%)	2,691 (11.5%)
Total	49,036 (100.0%)	40,528 (100.0%)	28,974 (100.0%)	23,438 (100.0%)

5.2 Estimated Result of Route Choice Model

Parameters estimates of route choice model are shown in Table 6. Both sign and t value of the most variables are significant. Although a few models ("1990_all", "1995_60s" and "2000_60s") are not significant, 13 models are calibrated high accuracy. It is necessary to brash up these models by using detailed service level data. Some graphs are discussed by using the results of 1995 and 2005 because the same birth cohort can be compared.

5.3 Value of Time

Figure 6, 7 and 8 show the value of time on "Riding Time", "Transfer Time" and "Access and Egress Time". As a whole tendency, the value of time in 2005 is higher than 1995. The influence of the time saving becomes larger. Operation of new lines whose services are fast and high fare by development railway network is one of the reasons. Many passengers have used these new lines. In all age value of time on both "Transfer Time" and "Access and Egress Time" are higher than "Riding Time". Therefore improvement in and/or around stations has huge positive impact.

The difference of the time value on "Riding Time" and "Access and Egress Time" in 2005 except 60s by the age is few. On the other hand, the time value on "Transfer Time" is greatly different depending on the age. In Figure 6, the highest in 1995 is 40s and in 2005 is 50s. This means not only increasing the value of time in 50s but also influence of the cohort characteristics. In aged society, it is necessary to consider the time value by age. Especially consideration of the time value of over 60s who are increasing is important. Moreover, the focus point to the cohort is very important. Analyzing the past behavior is necessary for the railway planning as well as modelling using the latest data.

Table 6 – Parameters Estimates of Route Choice Model

Year	1995							
	20s		30s		40s		50s	
	parameters	t-values	Parameters	t-values	parameters	t-values	Parameters	t-values
Fare	-0.00520	-22.8	-0.00463	-14.9	-0.00493	-14.6	-0.00615	-14.9
Riding Time	-0.0509	-12.0	-0.0430	-7.00	-0.0388	-5.78	-0.0289	-3.74
Transfer Time	-0.125	-20.7	-0.120	-14.0	-0.146	-15.5	-0.130	-11.8
Number of Transfer	-0.904	-24.6	-0.901	-17.7	-0.799	-14.2	-0.963	-14.5
Congestion in Train	-0.00456	-6.87	-0.00611	-6.71	-0.00561	-5.45	-0.00399	-3.14
Access & Egress Time	-0.152	-36.6	-0.145	-24.4	-0.149	-23.2	-0.147	-19.8
Ratio of Likelihood	0.189		0.173		0.193		0.223	
Number of Samples	17,193		8,570		7,196		5,442	

Year	2000							
	20s		30s		40s		50s	
	parameters	t-values	Parameters	t-values	parameters	t-values	Parameters	t-values
Fare	-0.0053	-16.4	-0.00468	-13.5	-0.00365	-10.1	-0.00524	-15.2
Riding Time	-0.0427	-7.39	-0.0389	-5.83	-0.0400	-5.53	-0.0369	-5.56
Transfer Time	-0.0586	-11.4	-0.0658	-10.6	-0.0712	-9.79	-0.0708	-10.2
Number of Transfer	-1.21	-26.3	-1.09	-21.8	-1.15	-20.1	-1.15	-21.8
Congestion in Train	-0.0107	-8.76	-0.0101	-7.95	-0.00700	-5.04	-0.00455	-3.81
Access & Egress Time	-0.145	-26.3	-0.127	-19.2	-0.130	-18.4	-0.129	-19.4
Ratio of Likelihood	0.193		0.170		0.170		0.192	
Number of Samples	8,675		6,309		5,191		6,203	

Year	2005							
	20s		30s		40s		50s	
	Parameters	t-values	Parameters	t-values	parameters	t-values	Parameters	t-values
Fare	-0.00515	-8.96	-0.00459	-12.6	-0.00439	-13.3	-0.00394	-12.2
Riding Time	-0.0792	-6.57	-0.0711	-8.91	-0.0698	-9.52	-0.0558	-7.78
Transfer Time	-0.133	-8.63	-0.146	-14.5	-0.153	-16.1	-0.146	-15.7
Number of Transfer	-0.849	-9.29	-0.792	-13.8	-0.659	-12.5	-0.846	-15.7
Congestion in Train	-0.00501	-2.26	-0.00764	-5.34	-0.00861	-6.34	-0.00667	-5.04
Access & Egress Time	-0.152	-13.1	-0.153	-19.8	-0.140	-19.4	-0.125	-17.5
Ratio of Likelihood	0.179		0.174		0.167		0.186	
Number of Samples	2,398		5,822		6,242		6,285	

Year	2005	
	60s	
	Parameters	t-values
Fare	-0.00556	-11.4
Riding Time	-0.0201	-1.95
Transfer Time	-0.126	-9.50
Number of Transfer	-0.615	-7.64
Congestion in Train	-0.00426	-2.06
Access & Egress Time	-0.114	-11.1
Ratio of Likelihood	0.178	
Number of Samples	2,691	

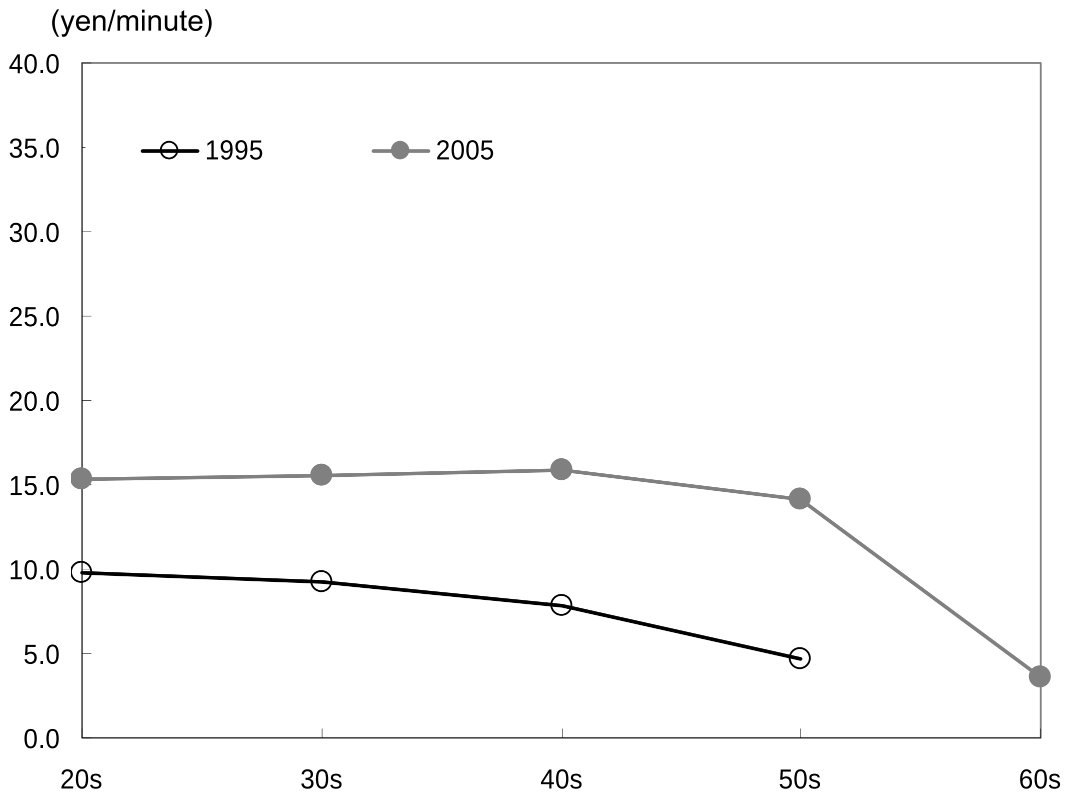


Figure 6 – Value of Time on Riding Time

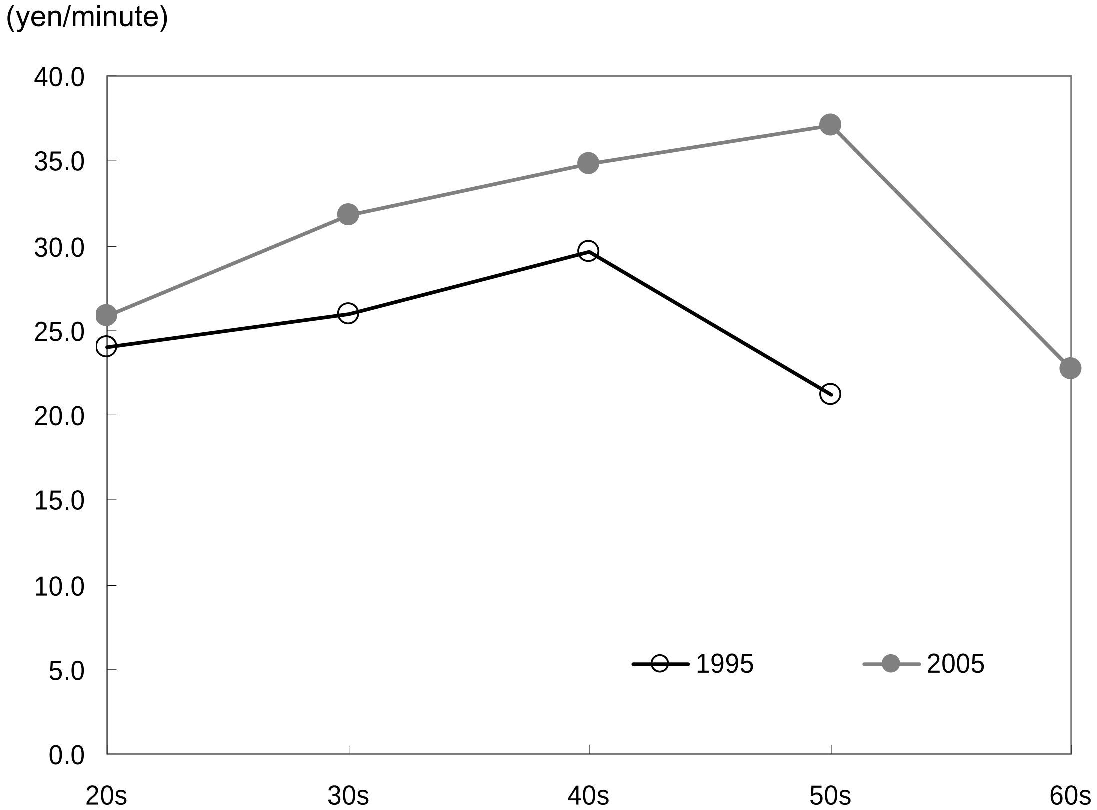


Figure 7 – Value of Time on Transfer Time

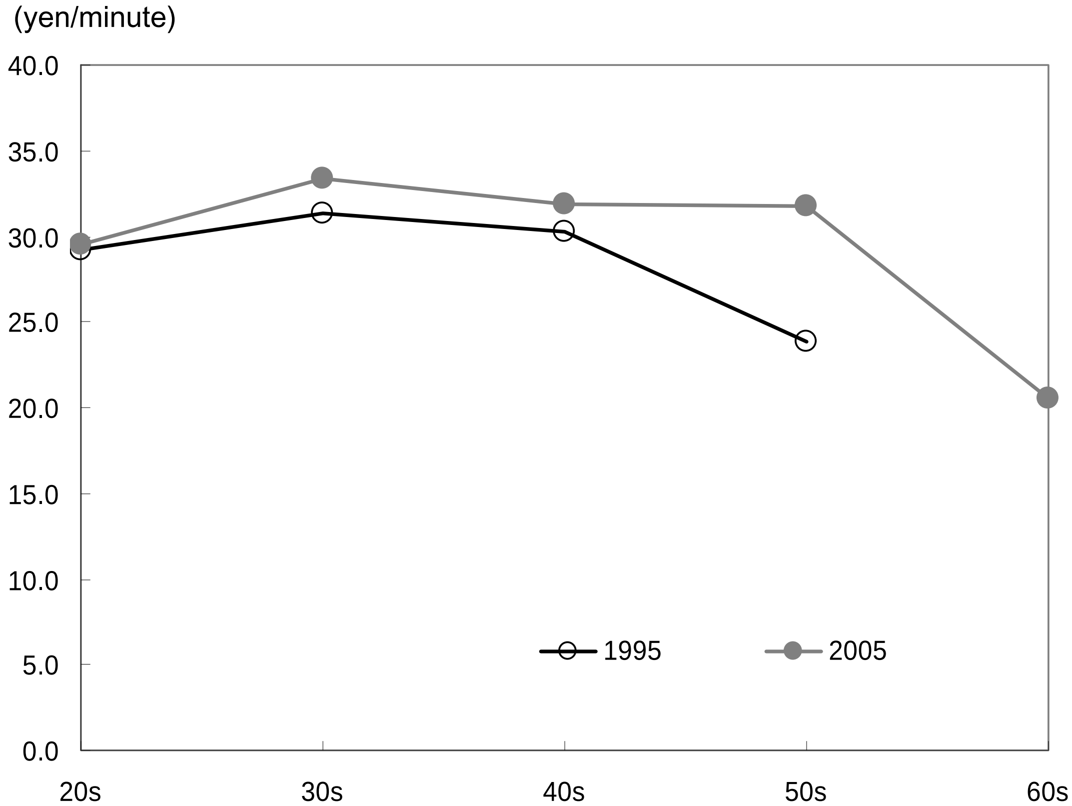


Figure 8 – Value of Time on Access & Egress Time

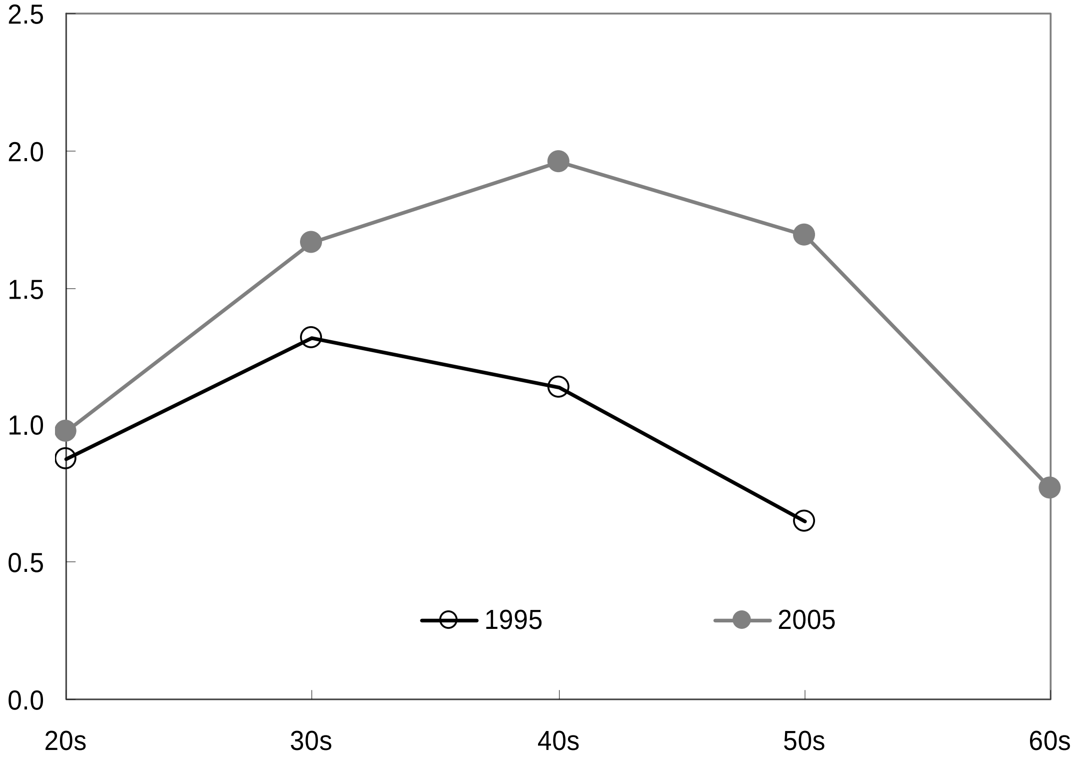


Figure 9 – Money Conversion Value of Congestion in Train

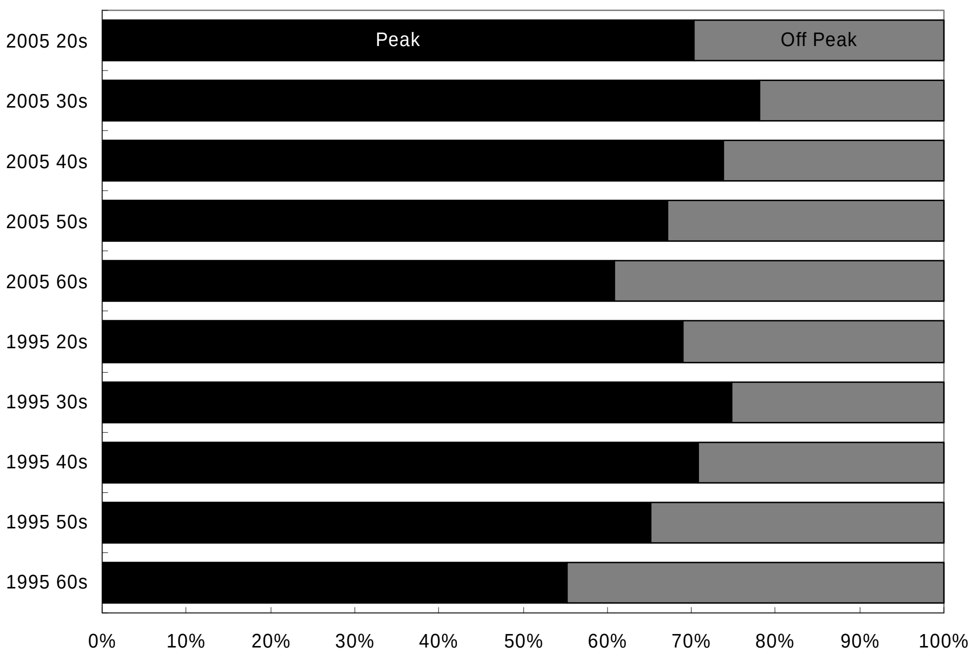


Figure 10 – Ratio of Home Departure Time of Commuters

Money conversion value of “Congestion in Train” is shown in Figure 9. These are calculated by dividing the parameter of “Congestion in Train” by the parameter of “Fare”. The highest in 1995 is 30s and in 2005 is 40s. The tendency of this generation to choose the route in consideration of congestion is strong. On the other hand, the lowest in 1995 is 50s and in 2005 is 60s. This is because the senior avoids the congested time zone. Ratio of home departure time of commuters is shown in Figure 10. Peak time is from 7:00 to 9:00. This graph shows that the ratio in which off-peak commutes is high with aging. It is necessary to consider time and the space to analyze the choice behavior according to the age group.

6. CONCLUSION

In this study, route choice characteristics by age group are analyzed based on the census data from 1990 to 2005. The study classifies samples into four types based on route choice behavior and makes the relationship between the type, age and period clear by applying Quantification Theory III analysis. Furthermore, the route choice models by age and period are calibrated by applying disaggregate analysis. The study discusses the change of the value of time.

The conclusions of the study are as follows. (1) The value of time for 30 - 59 years old is higher than for the elderly. (2) Recently, this tendency is becoming clearer. (3) The effect of the railway time saving has become smaller and smaller because of the increase of the elderly passengers. (4) Measures of transfer time saving are effective. (5) Consideration of not only age and period but also cohort is necessary for effective railway policy in aged society. In future railway planning consideration of time (age, period, cohort, schedule etc.) and space (network) would be very important.

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