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https://hdl.handle.net/2324/3317

出版情報：九州大学工学紀要. 64 (1), pp.17-33, 2004-03. 九州大学大学院工学研究院
バージョン：

Memoirs of the Faculty of Engineering, Kyushu University, Vol. 64, No. 1, March 2004

Structural Mechanism of Modal Choice Based on the Linked Structure of Trip Purpose and Transportation Choice

by

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(Received December 17, 2003)

Abstract

The behavior of modal choice with regards to taking a trip is greatly influenced by the transportation choices of preceding trips. Also, the sequential trips of an individual are related to one another, and are statistically represented by the connecting structure of the purpose of each trip. Therefore, the structural mechanism of traffic demand can be understood by considering the urban activities of individuals. This study aims to investigate a new approach of the modal choice model by analyzing the sequential mechanism of trip purpose and transportation choice.

The similarities and dissimilarities of travel activities with regards to personal attributes are analyzed. Next, the relationship of trip purpose and transportation choice between an intended trip and the preceding trip is investigated using a cross table. Modal choice models are constructed by considering the mode of the preceding trip and are applied based on the structural mechanism of the purpose of sequential trips with regards to personal attributes. The characteristics of the proposed modal choice model are also discussed.

Keywords: Disaggregate model, Sequential trip, User consciousness, Mode choice, Person trip survey

1. Introduction

The traditional disaggregate logit model is used to analyze and forecast the modal choice of trips in which the relationship between preceding and intended trips are not taken into consideration. However, the modal choice of a trip is (1) greatly influenced by the transportation measures of the preceding trip. Therefore, traditional models for modal choice can only be applied to the first generated trip of an individual. Modal choice models for second

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trips and over require careful consideration of the transportation choices of preceding trips to substantially deal with personal travel behavior. The traditional modal choice model analyzes each trip independently. (2) Trip chains throughout a single day of an individual are also represented by the connecting structure of each trip's purpose. The transportation mode used in sequential trips is related to the connecting structure of each trip's purpose. (3) Urban activities are undergoing major changes as a result of, for example, the increased aging and working female populations, and the structure of the modal choice model in urban areas is greatly influenced by these activities. The structural mechanisms of traffic demand should therefore be analyzed while considering these facts.

On the other hand, modal choice is influenced not only by physical factors but also by factors associated with an individual's consciousness. Even the evaluation of an individual's physical characteristics differs among various groups. In addition, it is difficult to evaluate the characteristics of each mode. The Analytic Hierarchy Process (AHP), which is useful for evaluating the consciousness of an individual, can be applied to include the model of modal choice as a dependent variable.

In this study, the structural mechanisms of modal choice based on the linked structure of trip purpose and transportation choice are investigated while considering user consciousness and personal attributes. Firstly, in each group of classified personal attributes, the relationships between the purpose of the intended (generated) trip and the preceding (attracted) trip are illustrated in a cross table. The sequential structure of trip purpose is then understood.

Modal choice models are constructed by considering AHP weights, which are investigated using AHP structure, and are analyzed through the application of Quantification theory 1 with personal attributes, transport service factors and so on. Therefore secondly, using these AHP weights as explanatory variables, a disaggregate logit model for modal choice is proposed. In other words, the consciousness of a traveler with regards to modal choice is introduced in the model. Using these results, the structural mechanisms of modal choice considering user consciousness are observed and evaluated.

Thirdly, the relationships in modes between preceding and intended trips are investigated in the cross table. Moreover, the independence, simultaneity or hierarchy of these relationships is investigated using correlation coefficients and so on, and the fundamental structural mechanism of the modal choice is revealed. Modal choice models are constructed by using the transportation choices of the preceding trips as the explanatory variables.

Finally, from these results, and based on the connecting structure of the trip purpose, the proposed modal choice models are applied and evaluated. In this study, trip purposes are classified into 15 types based on the data of the third person-trip survey (1993) obtained in Northern Kyushu, Japan. An urban area in Fukuoka, which is divided into 197 zones, was selected as shown in **Fig. 1**. This area is composed of eight cities, 13 towns and one village.

2. Classification of Personal Attributes Based on the Characteristics of Trips

To precisely understand the characteristics of a trip, it is important to classify individual personal attributes. That is, the similarities in distributions of trip productions and travel means as well as other travel characteristics, such as similarities in trip purposes, OD distribution, modal choices and the sequential linkage of trips.

To classify personal attributes, detailed divisions using a cross table of 5-year-interval age groups and 12 occupations can be considered as in **Tables 1** and **2**. Classification of each travel characteristic is analyzed by cluster analysis using the relationship between personal

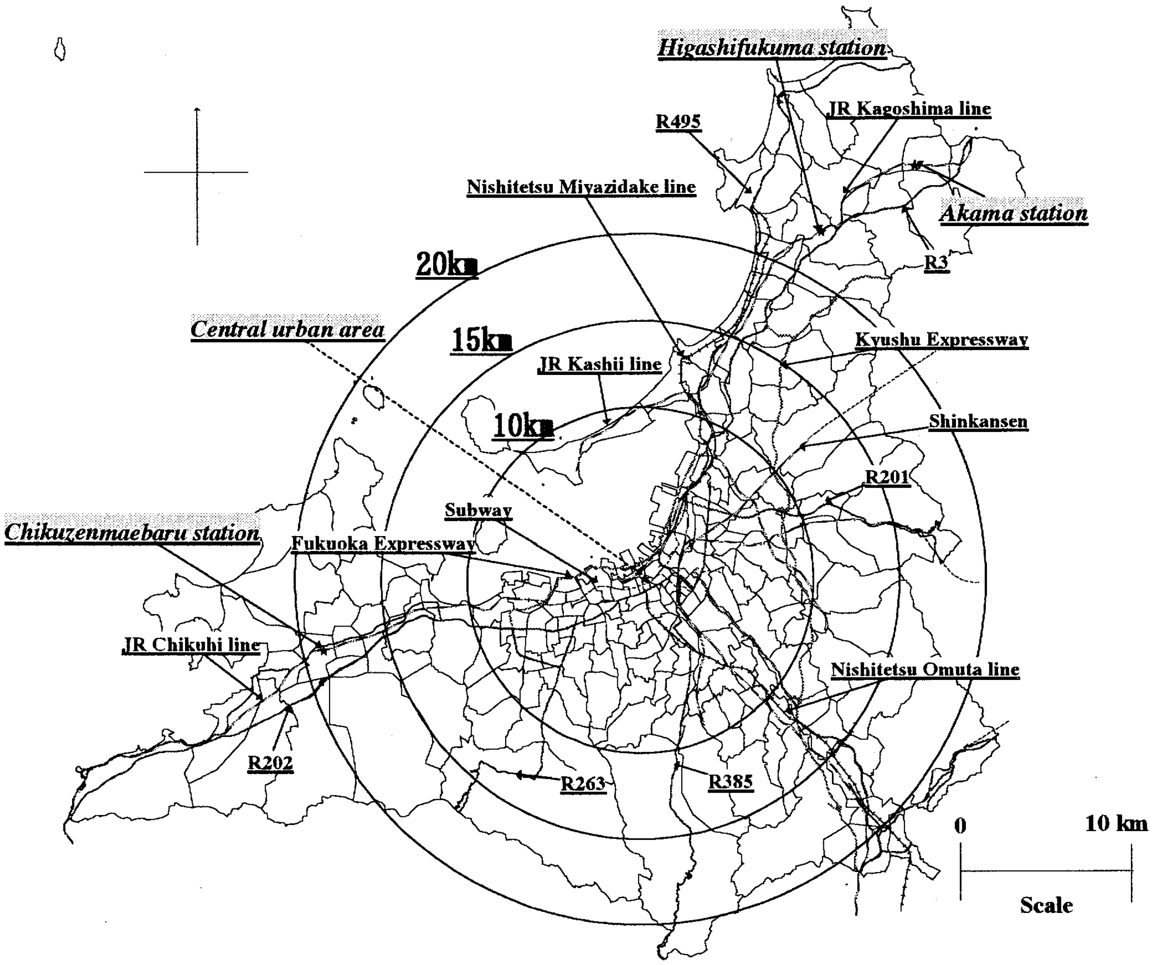

Fig. 1 Fukuoka urban area, Northern Kyushu.

Table 1 Male Age Groupings in Twelve Occupations.

Occupation \ age	0～4	5～9	10～14	15～19	20～24	25～29	30～34	35～39	40～44	45～49	50～54	55～59	60～64	65～69	70～74	75～79	80～84	85～89	90～94	95～99
Clerical and related workers				1									2							
Managers and officials					3		4							5						
Sales workers				6		7			8					9						
Agricultural workers				10			11							12						
Workers in transportation				13							14									
Production process workers				15									16		17					
Miners					18						19									
Service workers				20		21									22					
Students				23	24		25													
Children		26	27	28																
Housekeepers																				
Unemployed				29			30			31				32						

Note: Blanks represent no trip or a small number of samples.
Numbers represent the Group No. for each category of males.

Table 2 Female Age Groupings in Twelve Occupations.

<table>
<tr><th>Occupation \ age</th><th>0～4</th><th>5～9</th><th>10～14</th><th>15～19</th><th>20～24</th><th>25～29</th><th>30～34</th><th>35～39</th><th>40～44</th><th>45～49</th><th>50～54</th><th>55～59</th><th>60～64</th><th>65～69</th><th>70～74</th><th>75～79</th><th>80～84</th><th>85～89</th><th>90～94</th><th>95～99</th></tr>
<tr><td>Clerical and related workers</td><td colspan="3"></td><td colspan="2">1</td><td colspan="5">2</td><td colspan="2">3</td><td colspan="4">4</td><td colspan="4"></td></tr>
<tr><td>Managers and officials</td><td colspan="3"></td><td colspan="3">5</td><td colspan="2">6</td><td colspan="4">7</td><td colspan="4">8</td><td colspan="4"></td></tr>
<tr><td>Sales workers</td><td colspan="3"></td><td colspan="2">9</td><td colspan="9">10</td><td colspan="2">11</td><td colspan="4"></td></tr>
<tr><td>Agricultural workers</td><td colspan="4"></td><td colspan="3">12</td><td colspan="11">13</td><td colspan="2"></td></tr>
<tr><td>Workers in transportation</td><td colspan="4"></td><td colspan="4">14</td><td colspan="4">15</td><td colspan="8"></td></tr>
<tr><td>Production process workers</td><td colspan="3"></td><td colspan="3">16</td><td colspan="3">17</td><td colspan="2">18</td><td colspan="5">19</td><td colspan="4"></td></tr>
<tr><td>Miners</td><td colspan="20"></td></tr>
<tr><td>Service workers</td><td colspan="3"></td><td colspan="3">20</td><td colspan="2">21</td><td colspan="5">22</td><td colspan="3">23</td><td colspan="4"></td></tr>
<tr><td>Students</td><td colspan="3"></td><td>24</td><td>25</td><td colspan="7">26</td><td colspan="8"></td></tr>
<tr><td>Children</td><td></td><td>27</td><td>28</td><td>29</td><td colspan="16"></td></tr>
<tr><td>Housekeepers</td><td colspan="3"></td><td colspan="3">30</td><td colspan="2">31</td><td colspan="5">32</td><td colspan="5">33</td><td colspan="2"></td></tr>
<tr><td>Unemployed</td><td colspan="3"></td><td colspan="6">34</td><td colspan="5">35</td><td colspan="6">36</td></tr>
</table>

Note: Blanks represent no trip or a small number of samples.
Numbers represent the Group No. for every category of females.

attributes. This resulted in 32 categories for males and 36 categories for females.

From the viewpoint of travel demand, differences in the occupations of males and females were observed. For example, no male housekeepers and no female miners were observed. Divisions of clerical and related workers also differed: 2 male divisions and 4 female divisions were observed. The remaining occupation groups revealed few differences between males and females with regards to age group subdivisions.

As mentioned above, a classification of personal attributes under various trip characteristics was revealed. As a result, sequential linkage structural models of trip production, generation and attraction can be constructed.

3. Linked Structure of Trip Purposes in Each Group

Various trip purposes were identified such as commuting, attending school and business, private purposes and so on as shown in **Table 3**, which were also obtained by analyzing similarities in trip characteristics. Most persons start their trips at home and finish away from home. Therefore, most people undergo two or more linked trips in one day. In this case, these individual chains are classified by similarities in trip characteristics within each group of personal attributes as mentioned in Section 2.

The fact that the travel purposes of preceding and following trips are related is obvious. But, these relationships greatly differ depending on personal attributes as well as transportation facilities, traffic conditions, and so on. However, it is assumed that the relationships among trip production, generation and attraction can be standardized in each group with similar travel characteristics.

Our aim is not to show the individual cycles of a trip chain. Rather, the aim of this study is to relate the connecting structure of trip purposes among attracted preceding trips and generated following trips (**Fig. 2**). The linked structure of trip purposes throughout a single day in an individual group can be calculated by considering the sequential linkages of preceding and following travels. A linkage model is represented in **Table 4**. Each row in the

Table 3 Classification of Trip Purposes and Relative Percentages.

Code	Trip purpose	Definition	%
Purpose 1	Commuting	Going to work	14.6
Purpose 2	Attending school	Going to school	10.0
Purpose 3	Business 1	Goods delivery	3.7
Purpose 4	Business 2	Going to meeting/business related trip	3.6
Purpose 5	Business 3	Travel for appliance service of repair	1.6
Purpose 6	Business 4	Returning to office	5.4
Purpose 7	Business 5	Going to farm, fishery and forest	0.4
Purpose 8	Private 1	Shopping/Recreation	12.5
Purpose 9	Private 2	Returning from school/private trip	8.8
Purpose 10	Return from commute	Returning from work	12.9
Purpose 11	Return from attending	Returning from school	9.6
Purpose 12	Other private trip	Returning from private trip	0.5
Purpose 13	Business 5 (return)	Returning from farm, fishery and forest	0.3
Purpose 14	Private 1 (return)	Returning from private trips 1	9.8
Purpose 15	Private 2 (return)	Returning from private trips 2	6.3
Total			100.0

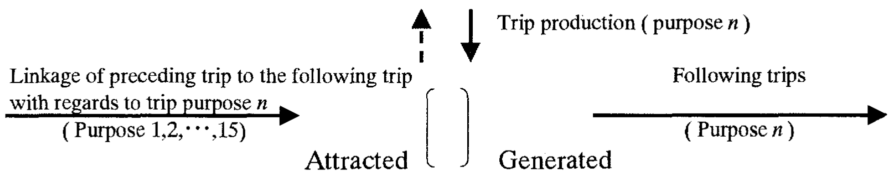

Fig. 2 Basic Concept of the Linkage of Trip Purposes.

Table 4 Linkage of Trip Purposes based on the Relationship between Attracted Preceding Trips and Generated Following Trips.

Purpose of following trip / Purpose of preceding trip	Purpose 1	···	n	···	Purpose 15	
Trip production a	···		t_{an}		···	
Purpose 1						
·			·			
·			·			
·			·			
m	···		t_{mn}		···	
·			·			
·			·			
·			·			
Purpose 15	···		t_{15n}		···	
Total	G_1	···	G_n	···	G_{15}	

n : Number of purpose in following trip
m : Number of purpose in preceding trip
t_{an} : Amount of productions in purpose n
t_{mn} : Amount of preceding attracted trips with purpose m and following generated trips with purpose n of following generated trip
G_n : Total trip generations for purpose n in following trips

Table 5 Connecting Structure in Purposes between Sequential Preceding Attracted Trips and Following Generated Trips (All Male and Female Groups).

(×1000trip)

Following trip / Preceding trip	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total
Trip production	1389.6	1019.7	83.6	71.1	65.8	0.9	68.3	563.6	460.7	10.9	0.0	13.8	0.0	0.0	0.0	3748.2
1	0.0	0.0	126.6	94.9	50.7	0.2	0.5	121.1	45.9	1020.0	0.0	0.0	0.0	0.0	0.0	1459.8
2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.3	30.9	0.0	967.2	0.0	0.0	0.0	0.0	1030.3
3	9.1	0.0	211.2	23.7	6.4	245.1	0.9	15.2	9.1	0.0	0.0	39.0	0.0	0.0	0.0	559.7
4	6.6	0.0	19.3	79.0	8.3	142.6	0.3	18.5	10.8	0.0	0.0	56.5	0.0	0.0	0.0	341.8
5	1.7	0.0	5.9	10.3	28.1	99.1	0.2	4.6	3.0	0.0	0.0	29.9	0.0	0.0	0.0	182.9
6	0.0	0.0	86.7	39.9	18.0	0.1	3.1	35.4	18.8	210.3	0.0	0.0	0.0	0.0	0.0	412.3
7	0.1	0.0	0.9	0.6	0.1	2.2	4.0	2.3	1.5	0.0	0.0	6.7	99.6	0.0	0.0	118.2
8	10.1	1.7	8.5	8.9	2.5	38.2	1.5	115.5	74.3	0.0	0.0	0.0	0.0	1052.8	0.0	1314.0
9	14.8	4.5	6.2	6.4	1.3	16.0	0.7	133.4	122.9	0.0	11.7	0.0	0.0	0.0	692.2	1010.0
10	6.8	0.0	2.5	4.7	0.3	19.0	1.0	39.4	23.5	0.0	0.0	0.0	0.0	0.0	0.0	97.2
11	0.0	2.0	0.0	0.0	0.0	0.0	0.0	77.6	96.7	0.0	0.0	0.0	0.0	0.0	0.0	176.4
12	5.0	0.3	2.7	2.5	0.8	2.5	1.7	6.6	5.3	0.0	0.0	0.0	0.0	0.0	0.0	27.4
13	0.0	0.0	1.6	1.3	0.3	0.0	31.2	4.5	3.1	0.1	0.0	0.0	0.0	0.0	0.0	42.0
14	8.5	1.1	3.2	2.5	0.7	1.4	2.6	85.8	61.9	0.0	0.0	0.0	0.0	0.0	0.0	167.7
15	6.0	2.4	3.8	2.5	0.8	1.3	2.8	69.3	74.7	0.0	0.0	0.0	0.0	0.0	0.0	163.6
Total	1458.2	1031.7	562.8	348.1	184.3	568.5	118.8	1325.1	1043.2	1241.3	978.8	146.1	99.6	1052.8	692.2	10851.5

Notes : Purpose number is shown in Table 2   (shaded): over 30000 trip

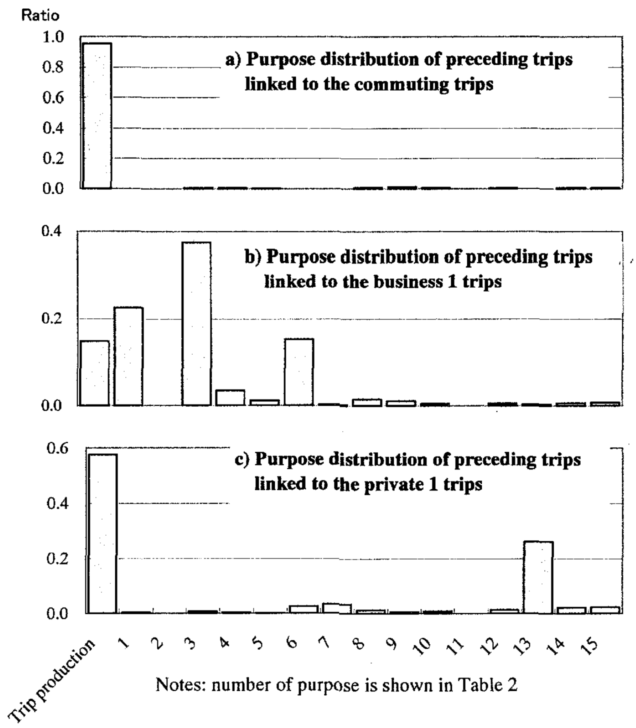

Fig. 3 Purpose Distribution of Preceding Trips Linked to the Following Trip (All Male and Female Groups).

table shows the attracted preceding trips with purpose "m" and each column shows the generated following trips with purpose "n". The purpose "n" of the following trips are given by additional producing trips with the same purpose and the preceding trips. When a following trip is the first generated trip in a single day, it does not have a preceding trip. Therefore, the preceding trips are defined as trip productions.

Because of the lack of space, it is not possible to show all of the tables of linkage structure in every male and female group. Therefore, to understand the trends in trip purposes linkage, graphs showing the relationships between the attracted preceding trips and the generated following trips are shown for all groups of male and female.

Typical linkages of purpose distributions of trips preceding the commuting, business 1 and private 1 trips for all male and female groups are shown in **Fig. 3**. The y-axis represents the ratio of purposes of preceding trips, in terms of the following generated trip. It seems that the purposes of trips preceding commuting almost occupy the trip productions, as in the case of males. Therefore, commuting can be assumed to be the first trip in a day and are given only by preceding trip productions; others are negligible. In preceding trips, business 1 trips have various purposes as shown in **Fig. 3(b)**. The purposes of trips preceding business 1 are business 1, commuting and production. Some business 1 trips are repeated, and succeeding business 1 trips are somewhat affected by preceding business 4 trips. With private 1 trips, approximately half of the preceding trips are the starting trips of the day (trip productions) (**Fig. 3 (c)**). This therefore includes a large number of trips that are taken by housewives. In addition, there is a slight trip generation of private 1 trips that are succeeded by commuting and private 2 trips.

4. Modal Choice Model Considering Traveler Consciousness

4.1 Summary of Questionnaire Survey and its Analysis using the Analytic Hierarchy Process

For the questionnaire, three station areas (Akama, Maebaru and Higashifukuma) on the JR Kyushu line were selected. These areas were all located in residential areas near Fukuoka City (**Fig. 1**). The questionnaire survey data was analyzed to evaluate the modal choice of commuting passengers and students attending school. The factors for modal choice were identified by a preliminary questionnaire, and summarized in a flow chart arranged into five grades (**Fig. 4**). The investigation was carried out from October 21st to 23rd, 1999. A summary of this questionnaire survey is shown in **Table 6**.

Modal choice is influenced not only by physical factors but also by consciousness. An Analytic Hierarchy Process (AHP), which is useful for evaluating consciousness with regards to modal choice, can be applied to build a model of modal choice. But, the AHP model is not as precise as the disaggregate logit model. Therefore, using AHP weights as

Table 6 Summary of Questionnaire Survey.

Method of survey	Leave-and -mail survey		
Distribution date	21-23 October 1999		
Collection date	21-31 October 1999		
District	Munakata	Chikushi	Maebaru
Number distributed	140	140	140
Number collected	47	44	45
Percentage of questionnaire collected	33.6%	31.4%	32.1%

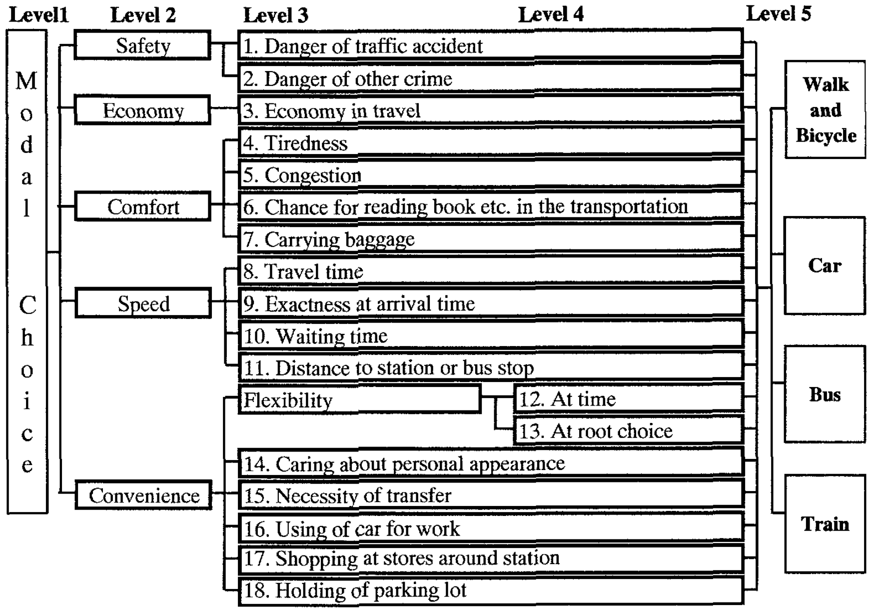

Fig. 4 Consciousness of Modal Choice.

alternatives of explanatory variables, a disaggregate logit model for modal choice was proposed and applied in this study. To apply this model using not only questionnaire survey data but also data concerning an individual's trip, these AHP weights were represented by various factors in the application of the Quantification theory 1. The modal choice hierarchy of the AHP method is shown in **Fig.** 4. There are four selected modes of transport (by foot or bicycle, car, bus and train).

4.2 Estimation of AHP Weights for Alternative Mode

Eighteen factors of AHP weights for alternative modes at level 5 were analyzed using Quantification Theory 1. The AHP weights used as dependent variables were assumed using the following logistic curve equation:

$$Y_i=1/[1+\exp\{-\textstyle\sum_{j=1}^{R}\sum_{k=1}^{C_j}a_{jk}\delta_i(jk)\}] \qquad (i=1,2,\cdots,18) \tag{1}$$

where $\delta_i(jk)=$ (1 : if i individual selects k category of j item, 0 : otherwise)

a_{jk} : category score
R : number of item
C_j : number of category in j item

By converting equation (1),

$$-\ln(1/Y_i)=\textstyle\sum_{j=1}^{R}\sum_{k=1}^{C_j}a_{jk}\delta(jk) \tag{2}$$

The results of the model for the car and train modes in factor 1 are shown in **Table 7.** The multiple correlation coefficient is 0.565 and the partial correlation coefficient was highest at 0.427 with regards to age. Also, the coefficients of personal attributes such as occupation were high. The range, and partial and multiple correlation coefficients for each factor are indicated in **Table** 8. The highest multiple correlation coefficient was observed for factor 8, "travel time", as 0.729. Those of the other models were low at 0.547–0.719. Modal choice models for all trips were constructed with AHP weights as explanatory variables, which were

Table 7 Results of Quantification Theory 1 for Factor 1.

Item	Category	Number	Cat. Sco.	Range / Par. corr.
Sex	Male	96	0.017	0.042
	Female	63	-0.025	0.054
Age	Under 30	23	-0.168	0.66
	30-39	13	0.483	0.427
	40-49	35	0.145	
	50-54	23	-0.069	
	55-59	23	-0.073	
	60-64	24	-0.044	
	60 and over	18	-0.177	
Occupation	Sales and service workers etc.	21	-0.187	0.409
	Clerical and related workers	30	0.222	0.34
	Technical workers	35	-0.126	
	Managers	20	0.093	
	Students	7	-0.025	
	Housekeepers	18	0.078	
	Others	28	-0.050	
Distance by road	0-17.5km	85	0.082	0.176
	17.5km-	74	-0.094	0.238
Traffic congestion	0-1.1	74	0.015	0.028
	1.1-	85	-0.013	0.038
Constant				-1.609
Multiple correlation coefficient				0.565

Table 8 Results of Quantification Theory 1 for all Factors except Factor 1.

Factor		a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	R
1	Range	0.042	0.660	0.409	0.176			0.028									0.565
	Partial corr.	0.054	0.427	0.340	0.238			0.038									
2	Range	0.548	1.333	0.532		0.330	0.175										0.570
	Partial corr.	0.289	0.459	0.184		0.128	0.085										
3	Range	0.552	1.600	0.787	0.352							0.170				0.169	0.621
	Partial corr.	0.296	0.464	0.180	0.191							0.065				0.061	
4	Range	0.811	1.833	1.161	0.484		0.042								0.092		0.639
	Partial corr.	0.353	0.498	0.347	0.223		0.018								0.033		
5	Range	0.038	0.677	0.918		0.204		0.398				0.222	1.286				0.647
	Partial corr.	0.024	0.279	0.321		0.132		0.252				0.110	0.471				
6	Range	0.771	1.369	1.068		1.462	0.094	0.459									0.719
	Partial corr.	0.390	0.395	0.376		0.506	0.044	0.189									
7	Range	0.026	0.721	0.839			0.106					0.094					0.615
	Partial corr.	0.027	0.472	0.423			0.061					0.068					
8	Range	0.065	0.953	1.938	1.288			0.285	0.438			0.059			0.191		0.729
	Partial corr.	0.043	0.345	0.589	0.468			0.129	0.172			0.023			0.061		
9	Range	0.329	0.684	1.244		0.444	0.177	0.188	0.112								0.675
	Partial corr.	0.304	0.395	0.557		0.359	0.107	0.146	0.104								
10	Range	0.238	0.806	0.541		1.715						0.602	0.499		0.604		0.616
	Partial corr.	0.162	0.354	0.224		0.520						0.278	0.222		0.257		
11	Range	0.326	1.547	1.790	0.460		0.083										0.582
	Partial corr.	0.193	0.465	0.455	0.239		0.050										
12	Range	0.206	0.901	0.809	0.264								0.227				0.560
	Partial corr.	0.155	0.364	0.387	0.198								0.151				
13	Range	0.009	1.112	1.237	0.149									0.205			0.657
	Partial corr.	0.007	0.506	0.520	0.082									0.158			
14	Range	0.174	0.501	1.386	0.079												0.656
	Partial corr.	0.175	0.360	0.551	0.081												
15	Range	0.080	0.452	1.467								0.689		0.514			0.547
	Partial corr.	0.069	0.243	0.332								0.463		0.316			
16	Range	0.715	0.466	1.403	1.016												0.605
	Partial corr.	0.354	0.182	0.268	0.480												
17	Range	0.804	1.452	1.731			0.468			0.350	0.482						0.646
	Partial corr.	0.384	0.434	0.467			0.234			0.157	0.233						
18	Range	1.044	1.019	0.946	0.731						0.188						0.615
	Partial corr.	0.463	0.372	0.280	0.329						0.093						

Note : R = multiple correlation coefficient. Factor number is shown in Figure 4.

a: sex
b: age
c: occupation
d: distance to office by road
e: distance to office by train
f: access distance to staion
g: traffic congestion degree
h: number of road line
I: 3rd industries employee in generating zone
j: 3rd industries employee in generating zone
k: number of transfer times by train
l: number of train
m: converted difference of distance
n: converted difference of time
o: converted difference of expense

Table 9 AHP-type Disaggregate Logit Model for Train and Car modes.

Explanatory variable	Commuting		Attending school		Private 1		Private 2	
	Parameter	T-value	Parameter	T-value	Parameter	T-value	Parameter	T-value
Dummy (car)			-27.046	-3.664 *	1.450	4.359 *	1.294	2.605 *
AHP1								
AHP2	3.796	3.240 *	16.214	6.844 *				
AHP3								
AHP4								
AHP5								
AHP6			5.437	6.394 *				
AHP7			60.271	5.969 *				
AHP8	3.967	6.490 *	4.985	6.832 *				
AHP9								
AHP10	1.622	3.700 *						
AHP11	1.660	3.028 *						
AHP12								
AHP13			37.533	8.601 *			2.317	3.900 *
AHP14	8.127	6.055 *						
AHP15	2.187	2.251 *						
AHP16					1.501	3.735 *	2.323	4.786 *
AHP17	1.204	3.797 *			0.693	2.833 *	1.156	3.535 *
AHP18								
Holding of license	-0.673	-5.742 *	-0.384	-3.596 *	-0.441	-6.177 *	-0.305	-3.761 *
Holding of car	-1.953	-5.492 *	-1.814	-3.236 *	-1.035	-4.2442 *	-1.967	-6.4806 *
Number of data	592		541		679		563	
Number of mode	2		2		2		2	
Likelihood ratio	0.336		0.453		0.129		0.241	
Hit ratio Total	79.7%	592	82.1%	541	68.9%	679	75.1%	563
Hit ratio Car	90.5%	390	77.5%	249	77.4%	319	83.8%	339
Hit ratio Train	58.9%	202	86.8%	292	61.4%	360	62.1%	224

Notice : * is significant level at 5%. Factor number is shown in Figure 4.

calculated using Quantification theory 1. For example, the results of the model for the car and train modes are shown in **Table 9**. The likelihood ratios ranged from 0.129 to 0.453. The hit total ratios ranged from 68.9% to 82.1%. As the t-values of variables such as having a license and car were high in all models, these variables were considered to have an impact on modal choice in many purposes.

5. Modal Choice Model Considering the Relationship of Transportation Choice of the Preceding and the Following Trips

The disaggregate logit model is usually applied to analyze the modal choice of trips in which the relationship between preceding and following trips are not taken into consideration. However, the modal choice of a trip is strongly influenced by the transportation choice of the preceding trip. Therefore, the traditional model for modal choice can only be applied to the first generated trips of an individual. However, with modal choice models for second trips and over, careful consideration of the transportation choice of preceding trips is required to substantially deal with personal travel behavior. The relationships between transportation choices of preceding and following trips are shown in **Table 10**. Ninety-five % of persons who use a car for preceding trips, also used a car in the following trip. Also, 89.6% of the preceding trips made by bicycle are made by bicycle in the following trip. Therefore, most of the transportation modes used in a subject trip are the same as those used in the preceding trip and that transportation choice in a subject trip is strongly influenced by the transportation choice of the preceding trip.

The number of trips in a day in order of generation is shown in **Table 11**. The ratio of

Table 10 Relationships between Transportation Choice of Preceding and Following Trips.

The following trip / The preceding trip	Walk	Bicycle	Bike	Taxi	Car	Bus	Train	Other	Sum
First generated trip	26.8%	10.4%	3.5%	0.8%	39.9%	7.3%	11.0%	0.3%	100.0%
Walk	81.6%	3.8%	0.4%	0.9%	8.3%	2.7%	2.4%	0.1%	100.0%
Bicycle	3.5%	89.6%	0.3%	0.2%	5.0%	0.6%	0.8%	0.0%	100.0%
Bike	2.7%	0.6%	86.5%	0.2%	9.4%	0.2%	0.4%	0.1%	100.0%
Taxi	12.6%	1.1%	0.3%	61.3%	9.8%	7.6%	6.8%	0.5%	100.0%
Car	2.5%	0.6%	0.3%	0.3%	95.0%	0.5%	0.7%	0.1%	100.0%
Bus	14.6%	1.3%	0.3%	3.0%	7.8%	68.8%	4.2%	0.1%	100.0%
Train	9.1%	1.8%	0.5%	1.6%	9.5%	3.6%	73.6%	0.2%	100.0%
Other	5.5%	1.3%	0.7%	1.8%	18.3%	3.0%	3.9%	65.5%	100.0%

Table 11 Number of Trips in a Day in order of Generation.

Order of generation	Number of trips (×10000 trip)	ratio
First generated trip	428	53.2%
Second generated trip	155	19.3%
Third generated trip	111	13.8%
Fourth generated trip	46	5.7%
Fifth generated trip	30	3.7%
Sixth generated trip	17	2.1%
Seventh generated trip	9	1.1%

Table 12 Correlation Coefficients of Modal Choice among Generated Trip Numbers

Correction	1	2	3	4	5	6	7
1.First generated trip	1.000	0.879	0.917	0.772	0.788	0.710	0.732
2.Second generated trip	**	1.000	0.980	0.964	0.964	0.937	0.933
3.Third generated trip	**	**	1.000	0.948	0.955	0.912	0.921
4.Fourth generated trip	**	**	**	1.000	0.999	0.994	0.992
5.Fifth generated trip	**	**	**	**	1.000	0.992	0.994
6.Sixth generated trip	**	**	**	**	**	1.000	0.995
7.Seventh generated trip	**	**	**	**	**	**	1.000

Result of Test of correlation : * is significant at :5% ** is significant at 1%

first generated trips was highest at 53.2%. The numbers of second and third generated trips taken in a day were 19.3% and 13.8%. The sum of the ratio of these three generated trips is 86.3%. Differences in the relationships of modal choice between preceding and following trips and generated trip numbers were investigated. The results of the correlation coefficients among the modal choice of generated trip numbers are shown in **Table 12**. Most correlation coefficients were over 0.800.

The relationships of the correlation coefficients in modal choice among generated trip number were analyzed by analyzing the correlations. The null hypothesis is "the correlation coefficient in modal choice between a pair of generated trip numbers is zero". The results of correlation analysis are shown in **Table 12**, and marked with * and **. All pairs of generated trip numbers were significant at 1%. As a result, the relationships of transportation measures between preceding and following trips did not differ among orders of a generated trip. Therefore, modal choice models for two types of trips, first generated trips and other generated trips, were constructed for each trip purpose.

The numbers of first and other orders of generated trips under each trip purpose category are shown in **Table 13**. With commuting and attending trips, the ratios of first generated trips were 96.9% and 99.5%, respectively. Most of the trips categorized under these purposes were first generated trips. On the other hand, the ratios of other orders of generated trips in business 1, 2 and 3 were high at 97.7%, 97.9% and 95.0%, respectively. Also, other orders of generated trips in business 4, return commute, return from attending, business 5 (return), other private trip (return), private 1 (return) and private 2 (return) occurred almost 100% and completely followed other generated trips. These trips are the return trips

Table 13 Number of First and Other Orders of Generated Trips in Each Trip Purpose Category.

		Number(×1000 trip)		Ratio	
		First trip	Others	First trip	Others
1	Commuting	492.6	15.8	96.9%	3.1%
2	Attending school	348.4	1.8	99.5%	0.5%
3	Business 1	3.0	125.6	2.3%	97.7%
4	Business 2	2.7	124.3	2.1%	97.9%
5	Business 3	2.8	54.2	5.0%	95.0%
6	Business 5	7.1	5.9	54.7%	45.3%
7	Private 1	158.8	278.0	36.4%	63.6%
8	Private 2	126.6	179.5	41.4%	58.6%
9	Business 4	0.0	189.0	0.0%	100.0%
10	Commuting (return)	0.1	450.1	0.0%	100.0%
11	Attending school (return)	0.0	333.8	0.0%	100.0%
12	Other private trip (return)	0.0	9.0	0.0%	100.0%
13	Business 5 (return)	0.0	17.5	0.0%	100.0%
14	Private 1 (return)	0.0	342.3	0.0%	100.0%
15	Private 2 (return)	0.0	220.2	0.0%	100.0%

: Constructed model

Table 14 AHP-type Disaggregate Logit Model for First Generated Trip for Train and Car Modes.

Explanatory variable		Commuting			Attending school			Private 1			Private 2		
		Parameter	T-value		Parameter	T-value		Parameter	T-value		Parameter	T-value	
Dummy (car)					-27.046	-3.664	*	2.690	2.012	*	3.840	7.572	*
AHP1													
AHP2		3.701	3.122	*	16.214	6.844	*	4.117	3.025	*			
AHP3													
AHP4													
AHP5													
AHP6					5.437	6.394	*						
AHP7					60.271	5.969	*						
AHP8		3.983	6.407	*	4.985	6.832	*						
AHP9													
AHP10		1.729	3.860	*									
AHP11		1.730	3.091	*									
AHP12													
AHP13					37.533	8.601	*						
AHP14		8.097	5.957	*				5.606	2.544	*			
AHP15		2.185	2.223	*									
AHP16													
AHP17		1.290	3.990	*									
AHP18													
Holding of license		-0.700	-5.817	*	-0.384	-3.596	*	-0.707	-5.551	*	-0.389	-3.532	*
Holding of car		-1.952	-5.427	*	-1.814	-3.236	*	-1.891	-3.351	*	-1.947	-4.666	*
Number of data		581			541			234			246		
Number of mode		2			2			2			2		
Likelihood ratio		0.343			0.453			0.248			0.234		
Hit ratio	Total	80.2%	581		82.1%	541		77.8%	234		76.0%	246	
	Car	90.9%	428		77.5%	249		81.1%	106		93.6%	156	
	Train	59.6%	153		86.8%	292		75.0%	128		45.6%	90	

Notice : * is significant level at 5%. Factor number is shown in Figure 4.

of each trip purpose category. In private 1 and 2 trips, the other generated trips were higher than the first generated trip in terms of ratio. In business 5, the ratio of the first generated trip was high at 54.7%. Both ratios of the first generated trips and other generated trips exceeded 30% in business 5, private 1 and private 2. Modal choice models for each purpose category with many trips should be constructed. Consequently, for first generated trips, construction of modal choice models for commuting, attending, business 1, 2, 3, 5 and private 1, 2 is required. Also, for other generated trips, modal choice models for all purpose categories except those for attending trips were constructed.

Models for first generated trips were constructed as shown in **Table 14**. Due to the limitations of space, models for some trip purposes in the car and train modes were focused on using random sampling data of approximately 500 trip surveys. The explanatory variables used were car dummy as car specific variables, AHP weights at Level 5 for modes in 18 factors as the common variables, and holding of a license and car as car specific variables. The hit ratios were 76.0-82.1% and the likelihood ratios were 0.234-0.453. As the t-values of variables such as holding of a license and car were high in all models, these variables were considered to have impacts on modal choice in many purpose categories. With commuting trips, the t-value of travel time was high. From the results, travel time was also observed as being very important for commuting trip modal choice. Also, the t-values of the danger of other crimes were high in commuting, attending and private 1 trips. Consciousness of the danger of other crimes seems to influence modal choice behavior.

Models for the other orders of generated trips were constructed as shown in **Tables 15**

Table 15 AHP-type Disaggregate Logit Model for Other Generated Trips for Train and Car Modes (1).

Explanatory variable		Business 1		Business 2		Private 1		Private 2	
		Parameter	T-value	Parameter	T-value	Parameter	T-value	Parameter	T-value
Dummy (car)									
AHP1						2.246	2.268 *		
AHP2									
AHP3						1.929	3.122 *		
AHP4									
AHP5									
AHP6		2.966	2.665 *						
AHP7									
AHP8						1.014	2.038 *		
AHP9						1.689	2.304 *		
AHP10				0.503	1.300				
AHP11		3.983	2.651 *						
AHP12									
AHP13									
AHP14									
AHP15									
AHP16				0.849	1.427	3.166	3.686 *	2.443	3.477 *
AHP17								2.533	3.882 *
AHP18									
Holding of license		-1.917	-3.083 *			-0.217	-2.052 *	-0.328	-2.239 *
Holding of car				-0.886	-2.832 *			-1.200	-3.041 *
Mode of preceding trip	Walk			0.908	2.409 *	1.425	4.525 *	1.592	3.911 *
	Car	4.212	4.970 *	2.671	8.506 *	3.570	10.790 *	4.066	8.037 *
	Bus							1.417	2.125 *
Number of data		100		365		445		317	
Number of mode		2		2		2		2	
Likelihood ratio		0.536		0.252		0.353		0.434	
Hit ratio	Total	88.0%	100	75.3%	365	81.1%	445	82.6%	317
	Car	88.7%	62	72.0%	225	75.6%	213	82.0%	183
	Train	86.8%	38	80.7%	140	86.2%	232	83.6%	134

Notice : * is significant level at 5%. Factor number is shown in Figure 4.

Table 16 AHP-type Disaggregate Logit Model for Other Generated Trips for Train and Car Modes (2).

Explanatory variable		Return commute		Return from attending		Private 1 (back)		Private 2 (back)	
		Parameter	T-value	Parameter	T-value	Parameter	T-value	Parameter	T-value
Dummy (car)				-4.900	-7.403 *				
AHP1		4.307	2.785 *						
AHP2		3.166	1.985 *						
AHP3									
AHP4									
AHP5									
AHP6									
AHP7									
AHP8		4.404	4.379 *						
AHP9						3.239	5.362 *		
AHP10		1.784	2.881 *	3.408	2.632 *				
AHP11						1.521	2.503 *		
AHP12									
AHP13									
AHP14		7.745	3.376 *						
AHP15									
AHP16									
AHP17		1.322	2.348 *						
AHP18									
Holding of license						-0.519	-4.441 *		
Holding of car		-1.355	-2.326 *					-2.118	-6.784 *
Mode of preceding trip	Walk	2.073	3.668 *	5.960	5.714 *	1.136	3.220 *	2.696	3.828 *
	Car	5.710	12.122 *	10.035	8.126 *	6.459	9.503 *	6.078	9.799 *
	Bus	5.446	4.225 *			1.822	3.364 *	1.936	2.588 *
Number of data		589		533		448		312	
Number of mode		2		2		2		2	
Likelihood ratio		0.738		0.929		0.587		0.707	
Hit ratio	Total	93.9%	589	98.9%	533	88.2%	448	92.9%	312
	Car	96.0%	408	98.5%	261	81.0%	216	93.4%	198
	Train	89.2%	181	99.3%	272	94.8%	232	92.1%	114

Notice : * is significant level at 5%. Factor number is shown in Figure 4.

and **16**. They were constructed in the same way as the models for first generated trips using random sampling data of trip surveys. Because of the limitations of space, only models of the car and train modes are shown. Car dummy was used as the car specific variables, AHP weights at Level 5 for modes in 18 factors as the common variables, and holding of a license and car as car specific variables. Moreover, the modes of the preceding trips were used as dummy variables. The hit ratios were 75.3–98.9% and the likelihood ratios were 0.252–0.929. High precision was obtained in many models, especially for return trip models. Their hit ratios were over 90% and their likelihood ratios were over 0.550. As the t-values of the variables for modes of preceding trips were high in all models, it can be suggested that these variables have a strong impact on modal choice for all generated trips except the first one. With private 1 trips, the t-values of using a car for work and economy in AHP weights were high. Therefore, private 1 trips of other generated trips, transportation expense and using of car for work had an impact on modal choice. With return commutes, the t-value of travel time in AHP weights was high as with the first generated trip. With return from private 1 trip, the exactness of arrival time and the distance to the station or bus stop were important factors. Comparisons between the traditional model, which is a disaggregate logit model for all trips in each trip purpose category (**Table** 8), and our proposed model is shown in **Table 17** for private 1 and 2 trips. In our opinion, the proposed model has many advantages over the traditional model. As a result, it was revealed that the transportation choice of the preceding trips has a strong influence on the modal choice of subject trips. Also, the

Table 17 Comparisons of the Traditional and Proposed Models.

Traditional model	Likelihood ratio	Hit ratio	
Private 1 trip	0.129		68.9%
Private 2 trip	0.241		75.1%

Proposed model	Likelihood ratio		Hit ratio		
	First trip	Others	First trip	Others	Total
Private 1 trip	0.353	0.248	81.1%	77.8%	80.0%
Private 2 trip	0.434	0.234	82.6%	76.0%	79.8%

construction of modal choice models for the first and other order generated trips provided an understanding of modal choice behavior and a higher precision.

6. Modal Choice Model Based on the Linked Structure of Trip Purpose and Transportation Choice

In the previous section, modal choice models for intended trips considering the transportation choice of the preceding trip were constructed. More precise models can also be constructed. The structure of the transportation choices of sequential trips is also related to the connecting structure of trip purposes. Trip chains in a single day for each person group were represented by the connecting structure of trip purposes. In Section 2, the structure mechanism of trip purposes was analyzed. The proposed model of modal choice based on the linked structure of trip purposes in each group of personal attributes was proposed as a more accurate method for providing an understanding of travel behaviors.

In detail, the connecting structure between sequential trips differs among the different groups of personal attributes. That is, traffic activities differ among personal attribute groups (sex, age, occupation). In each group in Section 3, the characteristics of trip chains were studied using cross tables of the connecting structure of the purposes of sequential trips. As an example, the structure of the trips taken by a male manager is shown in **Fig. 5**. Commuting is the start of the connecting flow and in order is generally followed by trip attraction for commuting trip, trip generation for business trip, trip attraction for a further business trip, trip generation for a private trip, trip attraction for a private trip, and trip generation for a return private trip.

The modal choice models, which were constructed in the previous section, are applied based on this connecting structure of trips. It is assumed that the OD distribution of each trip is already known. With the commuting trip as the starting trip, the models for both the first trip and other generated trips were used. For trip purposes, which are indicated by a black arrow in **Fig. 5**, the modal choice models for other orders of generated trips were used.

7. Conclusion

In this study, the travel characteristics were examined using the trip connecting structure in each group of personal attributes while considering the paradigm shift of society. Also, the characteristics of travel behavior of modal choice based on the sequential structure of the trip purpose and transportation choice was understood. Modal choice models considering a traveler's consciousness were constructed and applied based on the structural mechanisms of travel. The following is a summary of the results:

(1) The occupation and age of the surveyed male and females were categorized into 36 and 32 groups, respectively, while considering similar travel characteristics such as the linked

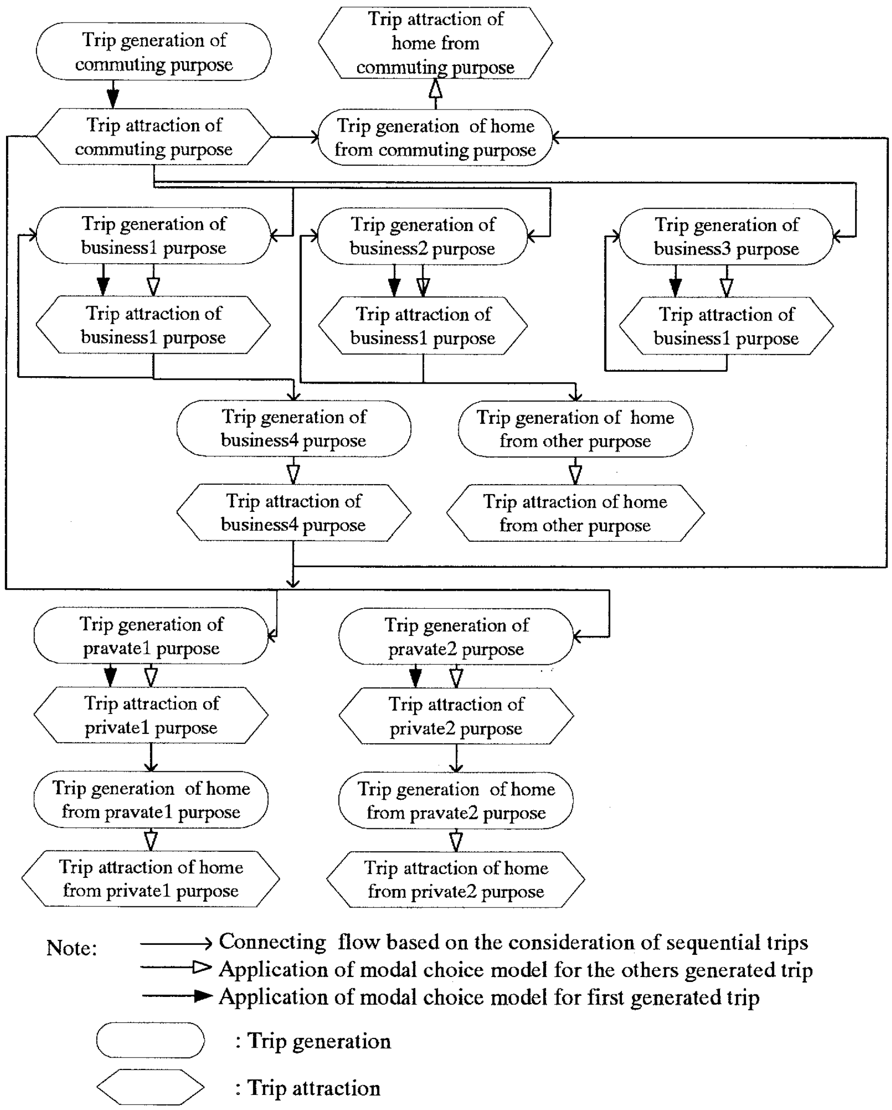

Fig. 5 Sequential Structure of the Trips Taken by a Male Manager.

structure of trip purposes. Details concerning the travel behaviors of each group of personal attributes under the paradigm shift of society, which is affected by various factors, can therefore be understood.

(2) AHP weights for alternatives, which are useful for evaluating an individual's consciousness for modal choice, were analyzed using Quantification theory 1. Disaggregate logit models for modal choice using AHP weights for alternatives as the explanatory variables, were constructed. These models were highly precise. Therefore, a traveler's consciousness for modal choice was included in a logit model.

(3) To understand the effects of mode choice in subject trips by viewing the preceding trip, the relationship of transportation choice between preceding and following trips was studied. As a result, it was revealed that the transportation choice in a subject trip is related to that of the preceding trip. Modal choice models of first generated trips and other orders of generated trip were also proposed.

(4) Modal choice models that consider a traveler's consciousness were constructed for first generated trips and other orders of generated trips. In comparison with the traditional

model, the proposed model was considered more precise and therefore more useful and meaningful.

(5) Application of the modal choice model based on the linked structure of trip purpose was proposed. By considering the linked structure of trip purposes in each group of personal attributes, it was possible to effectively and meaningfully apply the proposed modal choice model. In doing so, changes in travel behaviors with regards to personal attributes and the paradigm shift of society can be understood. Therefore, with this system an accurate understanding of the structural mechanism of travel behavior is possible.

References

1) Y. Kajita, T. Chishaki, W. Shih and H. Tatsumi, Modelling of model choice using the user's consciousness, Technology reports of Kyushu University, Japan, Vol.69, No.6, 763-770, 1996.
2) E. Kinoshita, T. Sasaki and S. Hirata, Evaluation of route choice characteristics of expressways using analytic hierarchy process, Expressways and automobiles, Japan, Vol. 11, No.31, 16-24, 1988.
3) K. Kouji, Y. Matsumoto and Y. Kurimoto, Quantitative analysis of the opinion of the elderly about transportation in medium and small cities, Papers on city planning, Japan, No.27, 379-384, 1992.
4) S. Matsumoto, S. Kumakura and K. Matsuoka, Joint-choice model for destination and travel mode for non-grocery shopping trips, Papers on city planning, Japan, No. 18, 469-474, 1983.
5) Y. Kajita, T. Chishaki, A. Matsuoka and T. Kohara, Construction of Modal Choice Model Considering User's Consciousness, Journal of the Eastern Asia Society for Transportation Studies, Vol.4, No.2, 319-334, 2001.
6) K.Tone, Introduction of Analytic hierarchy process, Kagiren Pub. Ltd., Japan, 1986.
7) T.Chishaki and N. Inoue, Traffic planning. Kyoritsu Pub. Ltd., Japan, 1993.
8) Person Trip Survey, Urban transport planning conference in Northern Kyushu area, Fukuoka, Japan, 1983.