DYNAMIC MODELLING USING PANEL DATA WITH TRAVEL INFORMATION ON MULTI-ROUTE

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abstract : This study analyzed commuters' route choices among three main routes towards their downtown workplaces on a Stated Preference Survey. After stating their initial preference, information about routes that would take less time to traverse appeared to greatly influence drivers' choices, often provoking them to choose the faster route. Past experiences, including the number of times a route had been chosen, prior preferences and the positive or negative results of previous route choices also exerted a strong influence on drivers' decisions.

1. INTRODUCTION

Intelligent Transport Systems (ITS) are a group of rapidly developing high-technology applications combining innovations in electronics, information science, and communications to reduce traffic-associated problems such as traffic jams, accidents and air pollution. One of the key components of ITS technology is the Advanced Traveler Information System (ATIS), which enables information exchange between or among automobiles on roads and traffic control centers, thus minimizing traffic congestion, enhancing road safety, and enabling an efficient use of the road network.

For ATIS technology to be effective, it has to present the driver with that information most likely to be utilized in route decision choices, hence the rationale for this study. The subjects of our research were commuters in the city of of Chunju who drove to workplaces in the downtown core. This was chosen as the sample population because: (i) business functions in Chunju are concentrated in the downtown area which lies at the heart of commuting traffic, (ii) the amount of time spent while driving to downtown workplaces is more significant than for other areas in the city, and (iii) the downtown area is most crowded because commuting traffic concentrates on the area in a shorter time, and more heavily than traffic outside the main commuting hours. In order to analyze commuting drivers' choices between three main routesto the dowtown core, we conducted a Stated Preference Survey while varying the subjects' access to travel information, and analyzed which factors most influenced route choice.

Our analysis was based on the Disaggregate Behavioral Model (DBM), a model in which the behavior of the individual units of analysis, in this case communters, is preserved in the final representation. In analyses based on the Aggregate Model, by contrast, the behavior of individual commuters would disappear from the representation of group choices, making the Disaggregate Model more suitable for this study from both theoretical and practical viewpoints. In order to work with the DBM, we first had to study the its theoretical background. Then we established a model for the analysis of route choosing behavior over three main routes to the downtown core using the Logit Model, which is very adaptable to practical situations due to its ease of calculation and quick coefficient estimation. Next, we estimated the model of the route choosing behavior of downtown road users in the morning rush hours based on the data collected through the survey. Finally, we analyzed influential factors and their degrees of influence on route choosing behavior.

2. SURVEY OUTLINE

There are many factors which could possibly influence a driver's choice of route: eg., travel time, expense, detour distance, past experiences with a route, the amount of traffic information drivers have access to, and the crowdedness of the route the driver is currently on. Since some of these factors are determined by spatial, social and circumstantial factors which are dificult to manipulate, we chose travel time information about the three main routes as the comparative data, and we examined the route choosing behaviors of drivers as that information varied. When this on-route information was given, drivers would re-evaluate and often change their route choices, integrating the given travel time information with their past road experiences and current traffic circumstances.

A conceptual map of the test area for this research is given in Fig. 1. For the Stated Preference Survey, we presented drivers with a hypothetical situation in which travel time information was given to them as they were driving downtown on one of the three main inbound roads: Kirin-ro, Paldal-ro, and Chunbyun-ro. We profiled each Stated Preference Survey response, based on the travel time supplied for each route as given in Table 1.

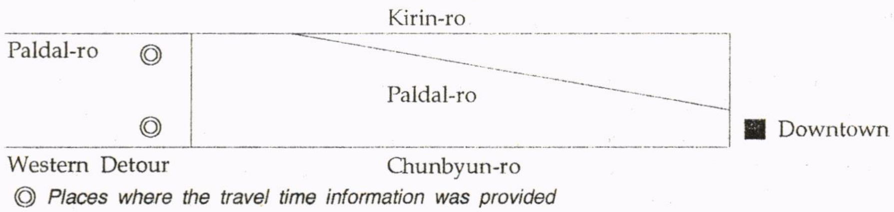

Figure 1. Concept Map of the Survey Area

Table 1. Primary Factor and Level of Profile

Primary Factor	Level			
Current Route	Kirin-ro / Paldal-ro / Chunbyun-ro			
Travel Time Info	Kirin-ro	10 min	20 min	30 min
	Paldal-ro	15 min	25 min	35 min
	Chunbyun-ro	10 min	20 min	30 min

We presented our subjects with only 9 travel time conditions, using the $L_9(3^4)$ array of cross-relationship to present 4 factors in 9 experiments, by showing 9 cards with trip duration information on them to each individual respondent. The Stated Preference Survey filled out voluntarily by workers in the downtown offices visited by the examiner collected data on the items listed in Table 2 (demographic information, normal commuting route in the morning, preferred route, number of times per week other specific non-preferred routes were chosen, and estimated travel time). Out of 1,100 questionnaires distributed, 464 were returned, giving a 42.18% rate of return.

Table 2. Survey Outline

Survey Subjects	Chŏnju workers who drive to downtown worksites
Survey Items	Demographic information, normal commuting route in the morning, preferred route, number of times per week other specific non-preferred routes were chosen, estimated travel time, SP questions
Survey Method	Office Visitation

3. COMPARISON OF PREFERRED ROUTES AND ROUTE CHOOSING BEHAVIOR

We investigated drivers' likelihood of deviating from their preferred route based on the provision of traffic information. Before seeing the traffic information, drivers made guesses about approximate travel time based on their previous driving experiences. Once they got information about travel times that differed from their expectations, they tended to revise their initial choices. We also examined how persistent the initial route preference was, after information about transit times on other routes was given.

We noted that the first wave of morning commuters tended to prefer Kirin-ro, prior to receiving information on transit times. Commuters who travelled during later waves of morning rush hour traffic showed progressively less initial preference for Kirin-ro, and progressively more for Paldal-ro and Chunbyun-ro (Table 3).

Table 3. Route Choice by Traffic Wave Before the Provision of Travel Time Information

Wave \ Route	Kirin-ro	Paldal-ro	Chunbyun-ro
Wave 1	100 (26.8%)	54 (14.5%)	219 (58.7%)
Wave 2	27 (11.0%)	45 (18.3%)	172 (69.9%)
Wave 3	21 (11.2%)	38 (20.2%)	129 (68.6%)

Table 4. Route Choice by Traffic Wave After the Provision of Travel Time Information

Wave \ Route	Kirin-ro	Paldal-ro	Chunbyun-ro
Wave 1	1638 (39.3%)	1026 (24.6%)	1509 (36.2%)
Wave 2	850 (38.4%)	494 (22.3%)	870 (39.3%)
Wave 3	552 (32.6%)	388 (22.9%)	752 (44.4%)

After the provision of travel time information, choices were more evenly distributed across Kirin-ro, Paldal-ro and Chunbyun-ro, showing that drivers responded to the given travel time information (Table 4).

We also found out that in the latter stages of the morning rush, drivers were more likely to stick with their preferred routes after the provision of travel time information. In other words, as can be seen in Table 5, the correlation between the preferred routes and the chosen routes grew higher with later waves of traffic. But the provision of information still influenced route choice, as can be deduced from the fact that there were differences between the overall route choices and the route choices per preferred route.

Table 5. Route Choice Per Each Preferred Route After the Provision of Information

Preferred Route \ Chosen Route		Kirin-ro	Paldal-ro	Chunbyun-ro
Wave 1	Kirin-ro	388 (43.1%)	218 (24.2%)	294 (32.7%)
	Paldal-ro	189 (38.9%)	150 (30.9%)	147 (30.2%)
	Chunbyun-ro	744 (37.7%)	440 (22.3%)	787 (39.9%)
Wave 2	Kirin-ro	122 (50.2%)	48 (19.8%)	73 (30.0%)
	Paldal-ro	158 (39.0%)	121 (29.9%)	126 (31.1%)
	Chunbyun-ro	563 (36.4%)	320 (20.7%)	665 (43.0%)
Wave 3	Kirin-ro	94 (49.7%)	46 (24.3%)	49 (25.9%)
	Paldal-ro	104 (30.4%)	117 (34.2%)	121 (35.4%)
	Chunbyun-ro	354 (30.5%)	225 (19.4%)	582 (50.1%)

4. DYNAMIC ROUTE CHOICE BEHAVIOR MODEL

4.1 Markov Model

The primary Markov process can be represented in terms of the probability vector P of an individual situation i (i = 1, 2, . . . , s) at certain point of time, t, and the probability matrix R of multiple rows s × s (Table 6):

Table 7 represents the route choices from the first and second waves of traffic. The transition probability estimation is obtained by a conversion into a ratio which makes the sum of the frequencies in each row in Table 7 equal to 1.
In other words,

$$R = \begin{bmatrix} .73 & .12 & .16 \\ .21 & .61 & .19 \\ .16 & .07 & .77 \end{bmatrix}$$

Table 6. Markov's Link Coefficient

	time $t+1$ situation	
Situations at time t	$\begin{matrix} & 1 & 2 & \cdots & s \\ 1 \\ 2 \\ \vdots \\ s \end{matrix} \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1s} \\ r_{21} & r_{22} & \cdots & r_{2s} \\ \vdots & \vdots & & \vdots \\ r_{s1} & r_{s2} & \cdots & r_{ss} \end{bmatrix} = R$	$\sum_{j=1}^{s} r_{ij} = 1.0 \quad (i=1,2,\cdots,s)$
Situation i probability	$[\, p_1 \ \ p_2 \ \cdots \ p_s \,] = P$	$\sum_{i=1}^{s} p_i = 1.0$

Table 7. Route Choices (Wave 1 - Wave 2)

Wave 1 \ Wave 2	Kirin-ro	P'aldal-ro	Ch'ŏnbyŏn-ro	Total
Kirin-ro	605	96	133	834
P'aldal-ro	115	338	103	556
Ch'ŏnbyŏn-ro	129	59	633	821
Total	849	493	869	2,211

The matrix R above means that if a person chose Kirin-ro at a certain time t, the probability of choosing the same route at $t+1$ is 73%; the probability of a person who chose P'aldal-ro at t to choose P'aldal-ro again at $t+1$ is 61%; and the probability of a person who chose Ch'ŏnbyŏn-ro at t to choose Ch'ŏnbyŏn-ro again at $t+1$ is 77%. The probability of a person who chose P'aldal-ro at t to choose Kirin-ro at $t+1$ is 21%, and the probability of a person who chose Ch'ŏnbyŏn-ro at t to choose Kirin-ro at $t+1$ is 16%. When these data are given, the primary Markov process can predict the probabilities of route choices among Kirin-ro, P'aldal-ro and Ch'ŏnbyŏn-ro at time $t+2$. As the result of route choice at time $t+1$ (Wave 2) in Table 7, the circumstantial rates are :

$$R = [\ .38\ \ .22\ \ .39]$$

The probabilities at time $t+2$ can be obtained from the aboves above by using matrix calculus :

$$PR = [\ .38\ \ .22\ \ .39] \begin{bmatrix} .73 & .12 & .16 \\ .21 & .61 & .19 \\ .16 & .07 & .77 \end{bmatrix} = [\ .39\ \ .21\ \ .40]$$

We can evaluate the appropriateness of the above calculus by examining the assumption that the change transition matrix from $t=1$ to $t=2$ is equal to the matrix based on the data from $t=2$ and $t=3$. When the ordinary χ^2 test is done on split table following Goodman (1962), the actual measurements of the changes from Wave 2 to Wave 3 appear as presented in Table 8.

Table 8. Route Choices (Wave 2 ~ Wave 3)

Wave 1 \ Wave 2	Kirin-ro	Paldal-ro	Chunbyun-ro	Total
Kirin-ro	449	78	146	673
Paldal-ro	44	258	69	371
Chunbyun-ro	59	52	537	648
Total	552	388	752	1,692

The values of χ^2 calculated from Table 9 are χ^2 = 29.77 for Kirin-ro, χ^2 = 22.66 for P'aldal-ro, and χ^2 = 17.25 for Ch'ŏnbyŏn-ro. When we compared those values with the table of χ^2 statistics, each value of χ^2 was statistically significant (α<0.05). Since the Markov process is not appropriate due to differences in the route choices among waves, one of the following two modifications of the Markov model is necessary : (i) to raise the order of the Markov process, (ii) to divide the sample into subparts and to develop a model in which each subpart has its own transition matrix.

Table 9. Mobility Data for the Examination of Equivalence in Transition Matrix

Choice of Kirin-ro at Time t	Response at Time $t+1$ Kirin-ro	Paldal-ro	Chunbyun-ro	Total
$t=1$ (Wave 1)	605	96	133	834
$t=2$ (Wave 2)	449	78	146	673
Total	1,054	174	279	1,507
Choice of Paldal-ro at Time t	**Kirin-ro**	**Paldal-ro**	**Chunbyun-ro**	**Total**
$t=1$ (Wave 1)	115	338	103	556
$t=2$ (Wave 2)	44	258	69	371
Total	159	596	172	927
Choice of Chunbyun-ro at Time t	**Kirin-ro**	**Paldal-ro**	**Chunbyun-ro**	**Total**
$t=1$ (Wave 1)	129	59	633	821
$t=2$ (Wave 2)	59	52	537	648
Total	188	111	1,170	1,469

4.2 Dynamic Route Choosing Behavior Model

Under the assumption that individual choices are not independent of time, we examined the validity of route choosing behavior using disaggregate model. To predict the route preference of drivers at the time of information provision, we analyzed how much influence the results of past choices or initially preferred routes had on drivers' current route choices. Our prediction rested on the assumption, following the representative disaggregate method, that each route i for each driver has definite terms of utility which are represented by a linear formula.

The definite term of expected utility V_i of a driver's route i is represented as follows :

$$V_{ti}= \alpha_1 T_{ti}+ \alpha_2 S_{ti}+ \alpha_3 E_{ti}+ \alpha_4 R_{t-1i} \quad (1)$$

$$V_{ti}= \alpha_1 T_{ti}+ \alpha_2 S_{ti}+ \alpha_3 S_{t-1i}+ \alpha_4 E_{ti}+ \alpha_5 R_{t-1i}+ \alpha_6 \quad (2)$$

where

T_{ti} : travel time information given on the present route i

S_{ti} : a dummy variable relating the present route i to the preferred route before the information is given

S_{t-1i} : a dummy variable relating the past route i to the preferred route before the information is given

E_{ti} : a dummy variable relating the present route i to the number of drivings on the present route

R_{t-1i} : a dummy variable relating the past route i to the preferred route

$\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5, \alpha_6$: coefficients

It is thought that drivers consider the expected utility of each route and choose the route with greatest utility. The probability P_i of preference of route i over other routes is obtained by

$$P_i= \frac{\exp(V_i)}{\exp(V_i)+\exp(V_j)+\exp(V_k)} \quad (3)$$

The coefficients of this dynamic route-choosing behavior model which are roughly given by formulas (1) and (2) are presented in Table 10. Travel time on each given route was adopted as the common variable in our study, and preferred route, number of times having driven on certain route, the result of choice at *t-1* and the preferred route at *t-1* were adopted as unique variables for each route. The dummy variable 1 was used for the preferred route, and 0 for non-preferred routes. As for the chosen routes at time *t-1*, we used the dummy variable 1 for the chosen route and 0 for the routes not chosen. For the number of times drivers had previously used a route, we used the dummy variable 0 to represent fewer than two prior experiences with a route, and the dummy variable 1 for more than two experiences in the cases of Kirin-ro and P'aldal-ro. In the case of Ch'ŏnbyŏn-rŏ we used the dummy variables 0 for no prior experiences and 1 for at least one experience with the route.

Table 10(a) can be said to be a situation dependent model which includes the results of past choices in the current traffic condition, and Table 10(b) a serial correlation model which includes past error terms by including past preferred routes and the results of choice in the current traffic condition.

Model 1 in Table 10(a) took Wave 2 as the present time and modelled present travel-time information, present preferred route, current number of experiences driving on each route and the results of choices at Wave 1 as expanatory variables. Model 2 took Wave 3 as the present time and modelled the same explanatory factors, substituting Wave 2 choices for Wave 1 choices. Model 3 took Wave 3 as the present time and modelled the explanatory variables with the results of choices at both Wave 1 and Wave 2.

When it came to the code condition of the overall model coefficients, the travel-time information coefficient was of negative value, the preferred-route coefficient was of positive value, the number of past route experiences coefficients were of positive value, and all coefficients were valid. In terms of significance, for Model 1 the travel time information coefficient, preferred-routes coefficient (Paldal-ro and Chunbyun-ro), the number of driving experiences coefficient (Kirin-ro) and chosen-route coefficient at time *t-1* were significant at 1%. For Model 2 as well, the travel-time information coefficient, preferred-routes coefficient (Kirin-ro, Paldal-ro and Chunbyun-ro), the number of driving experiences coefficient (Kirin-ro, Paldal-ro and Chunbyun-ro) and the chosen-route coefficient at time *t-1* (Kirin-ro, Paldal-ro and Chunbyun-ro) were significant at 1%. Again in Model 3, the travel-time information coefficient, the preferred-routes coefficient (Kirin-ro, Paldal-ro and Chunbyun-ro), the number of driving experiences coefficient (Kirin-ro, Paldal-ro and Chunbyun-ro), and the chosen-route coefficients at time *t-1* (Kirin-ro) and at time *t-2* (Kirin-ro, Paldal-ro and Chunbyun-ro) were significant at 1%. In Model 3, the value for the chosen route at time *t-1* had a bigger influence on time *t* than that at time *t-2*. The prediction accuracy rate and log-likelihood ratio for each coefficient was considerable. This indicates that not only the current traffic environment but also the driver's route-choice history affects immediate route choices. Looking at the prediction accuracy rates by route, predictions were most accurate for Chunbyun-ro, which explains drivers' preference for that route over others.

Model 4 in Table 10(b) took Wave 2 as the present time and modelled the same set of explanatory variables (present travel-time information, present preferred route, current number of experiences driving on each route, and the preferred route), and the results of choices at Wave 1. Model 5 took Wave 3 as the present time and modelled the explanatory variables plus the results of choices at Wave 2. Model 6 took Wave 3 as the present time and modelled the variables plus the preferred route and results of choices at both Wave 1 and Wave 2.

When it came to the code condition of the overall model coefficients, the travel time information coefficient was of negative value, preferred route coefficient was of positive value, the number of drivings coefficients on each route were of positive value and they were all valid. When it came to the significance of coefficients, in Model 4, the travel-time information coefficient, preferred-routes coefficient (Paldal-ro and Chunbyun-ro), number of drivings coefficient (Kirin-ro and Paldal-ro) and chosen route coefficient at time *t-1* were significant at 1%. Again for Model 5, the travel-time information coefficient, preferred-routes coefficient (Paldal-ro and Chunbyun-ro), number of drivings coefficient (Kirin-ro and Chunbyun-ro), preferred-route coefficient at time *t-1* (Chunbyun-ro), chosen-route coefficient at time *t-1* (Kirin-ro, Paldal-ro and Chunbyun-ro), and the constant-term coefficient of Paldal-ro were significant at 1%. In the case of Model 6, the travel-time information coefficient, preferred-routes coefficient (Kirin-ro and Chunbyun-ro), number of drivings coefficient (Kirin-ro), and both the preferred-route coefficient (Chunbyun-ro) and the chosen-route coefficient (Paldal-ro and Chunbyun-ro) at time *t-1*, as well as the preferred-route coefficient (Chunbyun-ro) and chosen-route coefficient (Kirin-ro) at time *t-2* were significant at 1%. In Model 6, the result of chosen route at time *t-1* had a bigger influence at time *t* than that at time *t-2*. This indicates that not only the current traffic environment conditions but also recent route choices and preferred routes influence immediate route choosing behavior. Hit-rates and log-likelihood rates were considerably for all variables. When it came to the hit-rates for each route, Chunbyun-ro showed the highest hit-rates, well explaining preference of Chunbyun-ro in drivers' route choosing behavior.

Table 10(a) Dynamic Route Choosing Behavior Model

Variables		Model 1 (Wave 2)		Model 2 (Wave 3)		Model 3 (Wave 3)	
		Coefficient	t value	Coefficient	t value	Coefficient	t value
Travel Time Info (min)		-0.132	-21.342	-0.142	-20.271	-0.126	-17.133
Preferred Route	Kirin-ro			0.803	3.480	0.696	2.942
	Paldal-ro	0.630	3.358	0.859	4.409	0.804	4.035
	Chunbyun-ro	0.582	5.031	0.701	4.106	0.745	4.293
Number of Driving Experiences	Kirin-ro	0.755	5.875	0.534	3.278	0.494	2.978
	Paldal-ro	0.367	2.550	0.424	2.607	0.459	2.770
	Chunbyun-ro			0.525	2.915	0.558	2.986
Chosen Route (Wave 1)	Kirin-ro	0.865	7.071			0.768	4.433
	Paldal-ro	0.709	5.052			0.399	2.102
	Chunbyun-ro	0.844	5.878			0.314	1.665
Chosen Route (Wave 2)	Kirin-ro			0.835	6.079	0.507	2.877
	Paldal-ro			1.155	7.153	1.099	5.688
	Chunbyun-ro			0.675	4.022	0.632	3.395
Number of Samples		1,836		1,692		1,692	
$\bar{\rho}^2$		0.437		0.475		0.486	
Hit-Rates	Overall	78.05		79.78		80.26	
	Kirin-ro	78.44		76.56		78.01	
	Paldal-ro	73.15		75.88		76.50	
	Chunbyun-ro	80.24		84.38		83.87	

Table 10(b) Dynamic Route Choosing Behavior Model

Variables		Model 4 Wave 2		Model 5 Wave 3		Model 6 Wave 3	
		Coefficient	t value	Coefficient	t value	Coefficient	t value
Travel Time Info (min)		-0.132	-21.040	-0.147	-20.300	-0.137	-16.615
Preferred Route	Kirin-ro			0.608	2.463	0.781	2.792
	Paldal-ro	0.633	3.185	0.719	3.417	0.523	2.044
	Chunbyun-ro	0.767	4.627	0.688	3.365	0.732	3.081
Number of Driving Experiences	Kirin-ro	0.596	4.341	0.505	2.973	0.559	2.909
	Paldal-ro	0.458	2.835	0.270	1.570	0.346	1.861
	Chunbyun-ro	1.036	6.267	0.803	3.294		
Chosen Route (Wave 1)	Kirin-ro	0.551	3.398			1.163	6.184
	Paldal-ro	0.914	5.253				
	Chunbyun-ro						
Preferred Route (Wave 1)	Kirin-ro						
	Paldal-ro						
	Chunbyun-ro					0.697	3.081
Chosen Route (Wave 2)	Kirin-ro			0.850	4.639	0.416	1.931
	Paldal-ro			0.959	5.068	1.012	4.806
	Chunbyun-ro			0.768	4.127	0.902	4.333
Preferred Route (Wave 2)	Kirin-ro			0.393	1.657		
	Paldal-ro						
	Chunbyun-ro			0.497	2.650	0.521	2.622
Constant Terms	Kirin-ro	0.501	2.503	0.600	1.965	0.083	0.270
	Paldal-ro	0.045	0.214	0.897	2.907	0.690	2.312
Number of Samples		1,836		1,683		1,422	
$\bar{\rho}^2$		0.429		0.482		0.507	
Hit-Rates	Overall	78.54		80.10		80.94	
	Kirin-ro	77.11		78.38		79.39	
	Paldal-ro	73.79		75.07		77.52	
	Chunbyun-ro	82.65		83.99		83.75	

5. CONCLUSION

This study carried out a panel survey of preferred routes between three alternative inbound routes, and analyzed the route preferences of drivers before and after the provision of traffic information. To summarize :

(1) The reason for the big differences between the preferred route before the provision of information and the chosen route after the provision of information is thought to be due to the importance of travel-time information on route choosing behavior.

(2) We discovered regular differences in initial route preference (before the provision of traffic information) depending on the gender of drivers and the number of experiences driving on the preferred routes. After the provision of information, the route-choosing behavior was most affected by age, used route, preferred route and the number of experiences driving on the route.

(3) In our dynamic route-choice behavior model, travel time information, preferred route, number of experiences driving per route, previous preferences and the results of route choices influenced the dynamic route choosing behavior, indicating that a driver's route-choice history still influences immediate route choosing behavior.

Based on these results, we find that drivers choose routes based not only on the current traffic information but also on past experiences and preferred routes.

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