TOPIC 15
TRAVEL CHOICE AND
DEMAND MODELLING

ANALYSIS OF PERSONAL ACTION SPACE USING A MODEL SYSTEM WITH MULTIPLE CHOICE STRUCTURES

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Abstract

The concept of heterogeneity in choice structure is applied in this study to examine individuals' action space, which is defined in terms of the reported frequencies of visits. A disaggregate model system that predict the frequency of visit is condensed using nested logit model with multiple choice structures

INTRODUCTION

Heterogeneities in travel behavior across individuals can not be ignored in travel behavior analysis. The most basic approach to account for heterogeneity in travel behavior has been to introduce demographic and socio-economic variables with the premise that personal and household attributes account for heterogeneity. Perceptions of time or costs, values and beliefs affect travel behavior as well. To consider heterogeneities in these elements, Golob *et al.* (1979) and Keppelman & Pas (1980) used psychological variables. On the other hand, based on the assumption that unobserved variables expressed as error terms in multiple equations representing travel behavior are inter-related, Tischer and Phillips (1979) estimated the covariance matrix of error terms. An approach used to account for unobserved heterogeneity when multiple observations are available from each behavioral unit is the use of individual-specific random error components (eg, Kitamura & Bunch, 1990). Random coefficients have been used when behavioral sensitivities to the explanatory variables are assumed to vary across individuals. Heterogeneity in choice sets are addressed in Kitamura & Lam (1984) and Swait & Ben-Akiva (1987).

Heterogeneity in choice structure, however, has rarely, if at all, been incorporated into the analysis of travel choice. For example, it has been often discussed whether travel choice is "sequential" or "simultaneous". Do individuals choose a travel mode, then, given the mode they have chosen, choose a destination? Or do they choose the mode and destination simultaneously from among available mode-destination pairs? If the former is the case, is the mode chosen before the destination, or is the destination chosen first? Past studies have not addressed the possibility that multiple choice structures may exist and different individuals adopt different choice structures, or that even the same individual may adopt different structures from time to time. In the sense that the joint choice probability can be expressed either as a simultaneous, joint probability, or as a series of sequential, conditional probabilities, these questions may be neither practically significant nor statistically testable. Yet, it has been shown that inconsistent coefficient estimates will be obtained if a single choice structure is applied when in fact multiple choice structures exist (Pendyala, 1992).

In this study, individuals' action space is examined while recognizing the possibility that multiple choice structures exist, and by estimating a model system that allows for heterogeneity in choice structure. Personal action space is defined in terms of the reported frequencies per month of visits by an urban resident at respective destination zones in the study area. It is well established that an individual exhibits habitual behavior in his/her action space. Understanding what factors affect this action space is critical for assessing the individual's responses to changes in the travel environment, therefore for policy analysis and demand forecasting. The model system used here assumes that individuals probabilistically adopt one of two possible choice structures: choose a travel mode first then choose a destination, or choose a destination then a mode.

The study involves the following: urban residents in the Osaka-Kobe area are surveyed; the data gathered are analyzed; and a desegregate model system that predicts the frequency of visits is constructed. The model system comprises: 1) a Tobit simultaneous equations model system of the total number of trips by purpose, per month, and 2) mode and destination choice models that incorporate multiple choice structures. Input data for each model consist of the attributes of the individual, trips, destinations, and output from the other models. The frequency of visits at each destination zone per month is estimated by mode, and the personal action space is determined by the model system. The objective of the study is to use this model system to identify the factors which determine the spatial expansion and amount of personal travel.

SURVEY

The data used in this study were collected in a two-wave panel survey that aimed at understanding the effect of a new freeway, Hansin Expressway Wangan (Bayshore) Route, completed in April

1994 (Figure 1). The first wave was carried out in November 1993, before the opening of the freeway. The second wave was carried out in October 1994, after the freeway opened, and before the earthquake which hit the Kobe area in January, 1995. This survey involved self-administered, mail-back questionnaires. The first wave survey comprised two stages. In the first stage, simple questionnaires were distributed to: (a) an address-based, geographically-stratified sample of households with different levels of accessibility to the freeway, and (b) drivers passing several survey points located along the highways that ran parallel to the freeway. In the second stage, detailed questionnaires were distributed to the respondents of the first stage by mail. This two stage procedure was adopted largely because of the limited monetary resources available to the study. The response rate of the first stage was 16.9% (of 24,500 questionnaires distributed), and that of the second stage was 38.5% (of 4,450 questionnaires distributed). In the second wave, questionnaires were distributed to the households who responded to the first stage of the first wave. The response rate was 15.6% (of the 4,450 households questionnaires were distributed to). In both waves, all household members of at least 16 years old were requested to complete the questionnaire.

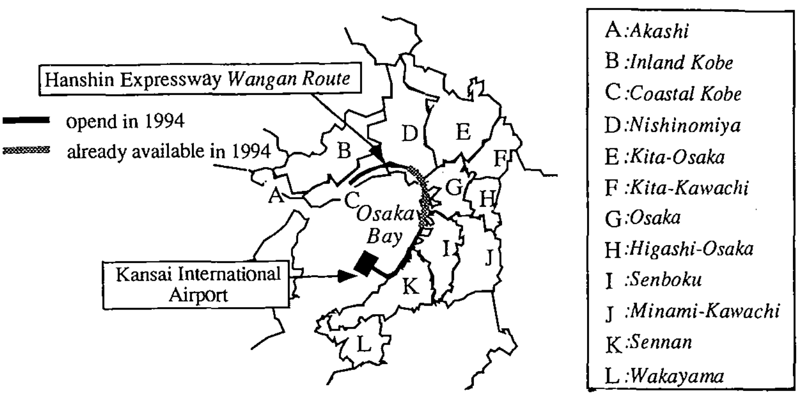

Figure 1 Survey area

The following data were collected in each wave:

1. demographic and socio-economic attributes,
2. the frequency of visits at each destination zone (zone A through zone L as shown in Figure 1) per month for the purposes of routine activities (shopping, eating out and others) and non-routine activities (sightseeing, leisure, recreation, taking a drive and others),
3. the mode chosen to go to each destination zone for each purpose,
4. the perceived attraction level of each destination and the psychological distance measure between home and the destination, and
5. whether destination choice preceded mode choice or mode choice preceded destination choice (in the second wave only).

IMPACT OF THE WANGAN ROUTE FREEWAY ON ACTION SPACE

The effects of the new freeway on area residents' action space can be assessed by comparing the frequency of visits collected by the two-wave survey. Figure 2 shows the monthly average of the frequency of visits by residents in zone K (Sennan) to each destination zone for the purpose of non-routine activities before and after the freeway opening. The area with a darker shade of gray is visited more frequently by the residents. After the new freeway became available for use, the residents in the Sennan area visited all zones more frequently, except zone K itself (Sennan), zone L (Wakayama) and zone B (inland Kobe). Especially, the frequency of visits to zone C (Kobe) has increased substantially. In 1993, the average frequency of visits to zone C was 0.24, while in 1994 after the freeway opening it has increased to 1.15. The reason for the decrease of visits to zones K and L is probably because the respondents in zone K have chosen areas whose accessibilities increased as a result of the new freeway. The change of the frequency of visits to each destination zone implies that the personal action space of the residents has changed. In this case, the action space of residents in zone K has expanded along the new freeway.

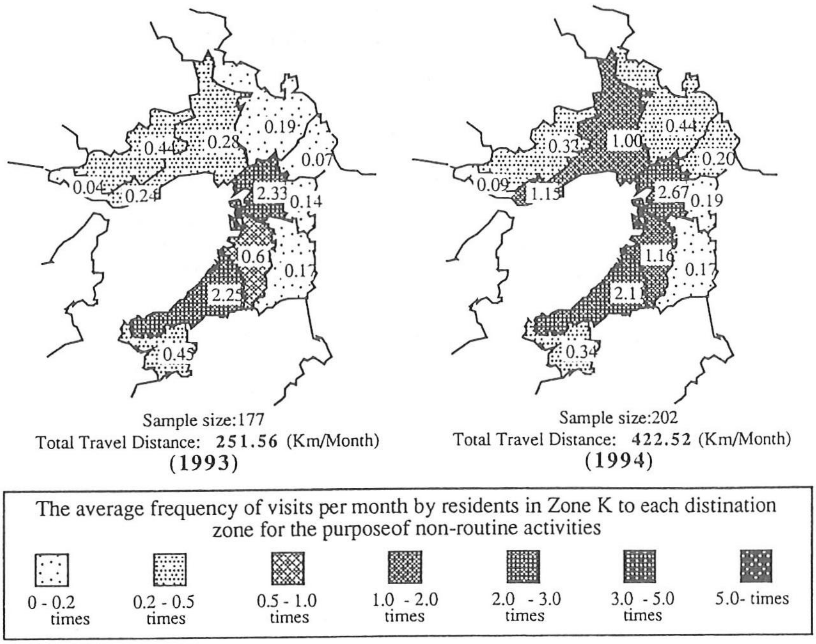

Figure 2 The effect on frequency of visits of Hanshin Expressway Wangan Route

Total travel distance for a month can be calculated as:

$$M_i = \sum_j D_{ij} K_{ij}$$

where

M_i = total travel distance per month of resident i (km/month),

K_{ij} = frequency of visits to zone j of resident i, and

D_{ij} = distance between home of resident i and zone j.

Using above equation, the average of total travel distance of respondents in zone K for non-routine activities is 251.6 (km/month) in 1993, which increased by 68% to 422.5 (km/month) in 1994. In this area which was not served by freeways before the opening of the Wangan Route, the new freeway appears to have led to a substantial increase in vehicle-miles traveled (VMT).

FRAMEWORK OF THE MODEL SYSTEM

Structure of the model system

The framework of the model system proposed in this study is shown in Figure 3. The exogenous variables of the model system are:

1. demographic and socio-economic attributes of the respondent and his/her household,
2. attributes of the destination zone, and
3. measures of accessibility between the home zone and the destination zone.

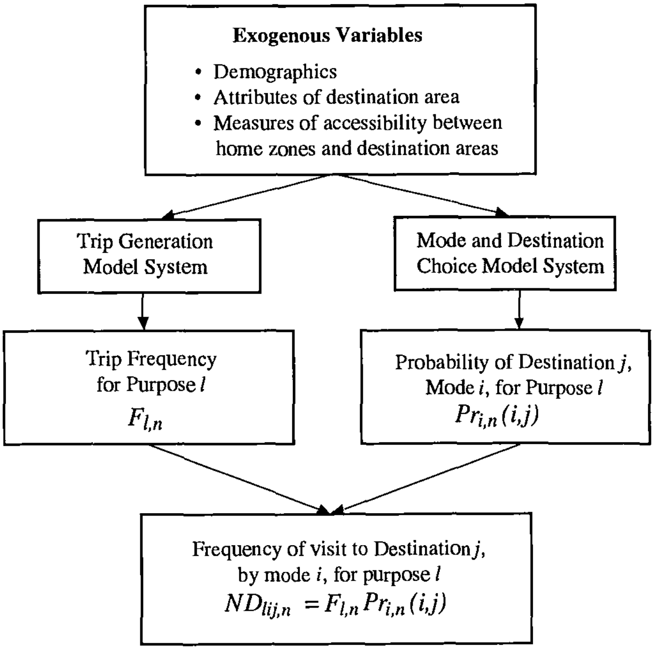

Figure 3 Framework of the model system

This model system is composed of two sub-models, the trip generation model system and the mode and destination choice model system. The former estimates the trip frequency per month by purpose, and the latter estimates by purpose the simultaneous probability that an alternative mode and destination zone pair will be chosen. In this study, trip frequency and mode-destination choice are assumed to be conditionally independent given the exogenous variables. Based on the assumption, frequencies of the routine and non-routine visits to each destination zone by each mode per month are calculated according to equation (1),

$$ND_{lij,n} = F_{l,n} Pr_{nl}(i,j) \qquad (1)$$

where

l = trip purpose (1 = routine activity; 2 = non-routine activity),

$ND_{lij,n}$ = the frequency of visits by individual n, to destination j, by mode i, for purpose l, per month; n=1, ..., N, j=1, ..., J, and i=1, ..., I,

$F_{l,n}$ = the trip frequency of individual n, for purpose l, per month (estimated by the trip generation model system), and

$Pr_{nl}(i,j)$ = the probability that individual n will choose mode i and destination zone j.

Trip generation equations system

The trip generation model system estimates the trip frequencies for routine activities and non-routine activities. Since those two classes of trips are generated as a result of the individual's activity scheduling effort over a span of time, it is theoretically anticipated that their frequencies are inter-related. To capture this inter-relationship the trip generation model system is constructed as a simultaneous Tobit equations system and estimated using a LISREL software package (Jorsekog & Sorbom, 1984). Since the frequency of trips is never negative, it is treated in the model system as a left-censored variable. The model system is specified as follows.

$$F_{l,n} = \left\{ \begin{array}{ll} F^*_{l,n} & \text{if } F^*_{l,n} > 0 \\ 0 & \text{if } F^*_{l,n} \leq 0 \end{array} \right\} \forall l,n \qquad (2)$$

where

$F_{l,n}$ = the frequency of trips generated by individual n, for purpose l, per month, and

$F_{l,n}{}^*$ = the latent variable corresponding to $F_{l,n}$,

and

$$\begin{pmatrix} F^*_1 \\ F^*_2 \end{pmatrix} = B \begin{pmatrix} F^*_1 \\ F^*_2 \end{pmatrix} + \Gamma t + \pi \qquad (3)$$

where

$F_1{}^*$ = 1 X N vector of the $F_{1,n}{}^*$,

$F_2{}^*$ = 1 X N vector of the $F_{2,n}{}^*$,

B = 2 X 2 matrix of coefficients,

Γ = 2 X k matrix of coefficients (k = the number of exogenous variables),

t = k X 2 matrix of 1 X N vector of exogenous variables, and

π = 2 X N matrix of error terms whose distribution is assumed to be multivariate normal.

In the nomenclature of LISREL analysis, equation (2) is called the measurement equation, and equation (3) is called the structural equation. Equation (2) is introduced to guarantee that the frequencies are always non- negative. Equation (3) implies that the latent variables are functions of themselves as well as the exogenous variables. The parameters in equations (2) and (3) are estimated by a weighted least square method.

The framework of mode and destination choice model system

The mode and destination choice model estimates the simultaneous probability that each mode and destination zone will be chosen. One approach to modeling multi-dimensional choice is through the use of the nested logit model which assumes a hierarchical choice structure (Cramer, 1991). Two alternative structures can be specified for mode and destination choice as shown in Figure 4. Structure 1 is based on the assumption that destination choice precedes mode choice for all individuals, while choice structure 2 is based on the assumption of the opposite sequence. However, there is the possibility that different individuals adopt different choice structures or that the same individual may adopt different structures from time to time.

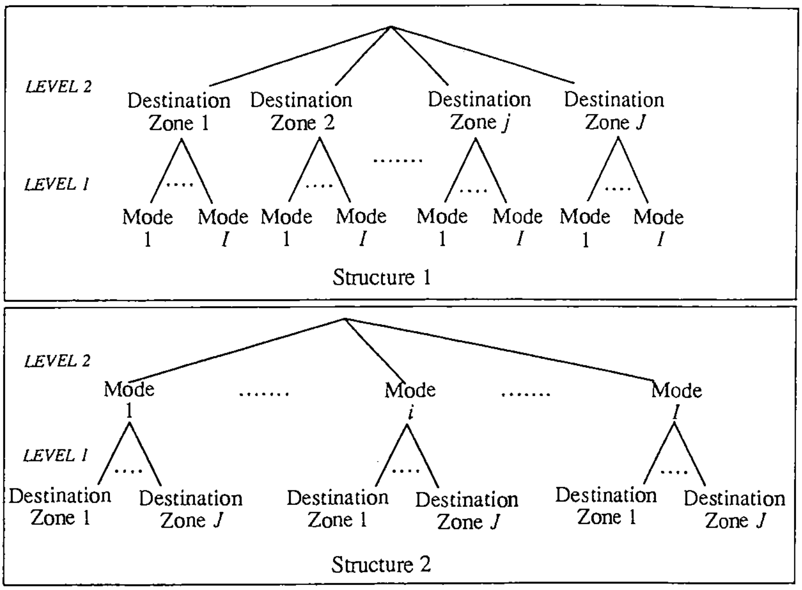

Figure 4 **Hierarchical choice structures in modeling mode and destination choice**

In this study, in order to consider the heterogeneity in choice structures, the two structures are both assumed for the choice of travel mode and destination. It is assumed that an individual adopts one of the two structures for the trip he/she is marking, and that which of the two structures is adopted is probabilistically determined. Let the simultaneous probability that an individual chooses mode i and destination j be

$$Pr_{l,n}(ij) = \sum_{k} Pr_{l,n}(ij|k)P_{l,n}(k) \quad (4)$$

where,

$Pr_{l,n}(i,j)$ = the probability that an individual n chooses mode i and destination j for activity l,

$Pr_{l,n}(i,j|k)$ = the probability that an individual n chooses mode i and destination j for activity l, given choice structure k (k=1,2), and

$P_{l,n}(k)$ = the probability that individual n has choice structure k for activity l.

$P_{l,n}(k)$ represents the assumption that an individual has either structure 1 or structure 2 when he/she chooses a mode and a destination. In this paper, this switching between the structures is called structure choice behavior, and $P_{l,n}(k)$ is called the structure choice probability.

If the parameters of $Pr_{l,n}(i,j|k)$ and $P_{l,n}(k)$ are to be estimated by the maximum likelihood method, the log-likelihood function LLl would be

$$LL_l = \prod_{n} Pr_{l,n}(ij) \quad (5)$$

In this study, rather than using this likelihood function, the parameters of $Pr_{l,n}(i,j|k)$ and $P_{l,n}(k)$ are estimated separately in stages, assuming that these two probabilistic terms are conditionally independent of each other given the exogenous variables, and that no parameters are structurally related between the two. There are two reasons for this. Firstly, the likelihood function is highly non-liner. Secondly, the survey included questions that asked the respondent whether he/she chose the destination first or the mode first for the respective destination zones, facilitating the estimation of $P_{l,n}(k)$ on its own. In other words, information exists to determine which structure segment each respondent belonged for each destination zone.

By the staged estimation method, the parameters contained in $P_{l,n}(k)$ are estimated. Based on the parameter estimates, $\hat{P}_{l,n}(k)$ is then calculated. Secondly, using $\hat{P}_{l,n}(k)$, the parameters contained in $P_{l,n}(k)$ are estimated by maximizing

$$LL_l' = \prod_n \sum_k Pr_{l,n}(ij|k)\,\hat{P}_{l,n}(k) \tag{5'}$$

Bivariate Probit structure choice sub-model

The structure choice probabilities for routine and non-routine activities are anticipated to be correlated to each other. In order to consider this correlation, the set of two probabilities is formulated using the bivariate probit structure in this study. Let

$$d_{n,l} = \begin{cases} 1 & \text{if } d^*_{n,l} \le \theta_l \\ 2 & \text{if } d^*_{n,l} > \theta_l \end{cases} \tag{6}$$

where

$d_{n,l} = \begin{cases} 1 \\ 2 \end{cases}$ if Structure 1 is chosen by individual n, if Structure 2 is chosen by individual n,

$d_{n,l}{}^*$ = latent variable corresponding to $d_{n,l}$, and

θ_l = threshold.

Let the latent variables be specified as:

$$\begin{pmatrix} d_1^* \\ d_1^* \end{pmatrix} = HX + \begin{pmatrix} \gamma_1 \\ \gamma_2 \end{pmatrix} \tag{7}$$

where

$d_l{}^*$ = 1 x N vector of the $d_{n,l}{}^*$,

H = 2 x m matrix of coefficients (m = the number of exogenous variables),

X = m x 2N matrix of exogenous variables, and

γ_l = error term whose distribution is assumed to be multivariate normal distribution.

By setting the covariance between γ_1 and γ_2 not to be 0, unobserved associations between structure choice behaviors for routine activity and non-routine activity can be considered. The model parameters are estimated using LISREL.Based on estimated parameters, the marginal probability that individual n chooses choice structure k (= 1 or 2), $P_{l,n}(k)$, is calculated as follows on the assumption that distribution of γ_l is normal:

$$Pr_l(1) = \Phi\left(\frac{\theta_l - d^*_{n,l}}{\sigma_{\gamma l}}\right) \tag{8}$$

where

$\Phi(\bullet)$ = standard cumulative normal distribution function, and

$\sigma_{\gamma l}$ = standard deviation of γ_l.

Nested logit models of mode and destination choice

The probability that an individual chooses a particular mode and destination pair, given a choice structure, is formulated as the nested logit model. Let the utility function for an individual n, of choice i at level 1 and choice j at level 2 for activity l, given choice structure k, be,

$$U_{l,nij,k}=V^1_{l,nij,k}+V^2_{l,nj,k}+\varepsilon_{l,nij,k} \qquad \forall\ i,j,k,l,n \tag{9}$$

$$V^1_{l,nij,k}=\alpha^1_{l,k}X1l,nj,k \qquad \forall\ i,j,k,l,n \tag{10}$$

$$V^2_{l,nij,k}=\alpha^2_{l,k}X^2_{l,nj,k} \qquad \forall\ j,k,l,n \tag{11}$$

where

$V^v_{l,nij,k}$ = a systematic component of the random utility at level v of choice structure k,

$\varepsilon_{l,nij,k}$ = a random disturbance at level v of choice structure k, which has a generalized extreme value distribution,

$X^v_{l,nj,k}$ = $s_{v,k}$ x 1 vector of exogenous variables, where $s_{v,k}$ = the number of exogenous variables at level v of choice structure k, and

$\alpha^v_{l,k}$ = 1 x $s_{v,k}$ matrix of coefficients.

And let

$$Pr_{l,n}(i,j|k) = Pr_{l,n}(j\mid k)\, Pr_{l,n}(i\mid j,k) \tag{12}$$

$$Pr_{l,n}(j|k) = \frac{\exp\left(V^2_{l,nj,k} + \lambda_{lk}\Lambda_{l,nj,k}\right)}{\sum_s \exp(V^2_{l,ns,k} + \lambda_{lk}\Lambda_{l,ns,k})} \tag{13}$$

$$Pr_{l,n}(i|j,k) = \frac{\exp\left(V^1_{l,nij,k}\right)}{\sum_s \exp(V^1_{l,nsj,k})} \tag{14}$$

$$\Lambda_{l,nj,k} = \ln\left\{\sum_s \exp\left(V^1_{l,nsj,k}\right)\right\} \tag{15}$$

where λ_{lk} = a scale parameter.

Maximizing log-likelihood function derived from equation (9)—(15), (4) and (5), $\alpha_{vl,k}$ and $\gamma_{l,k}$ are estimated.

ESTIMATION RESULTS

Trip generation equations system

The parameter estimates for the trip generation model system of eqs. (2) and (3) are shown in Table 1. The exogenous variables of the model system are defined in Table 2. The sample consists of 420 respondents who had complete data for all the variables in the model system. The R^2 are low, which is not uncommon for trip generation equations. The GFI (Goodness-of-Fit Index), AGFI (Adjusted GFI) and the chi-square statistic (which is a measure of discrepancy between the model and data) all indicate that the model system fits the data well.

The latent variable for routine trip frequency affects that for non-routine trip frequency statistically significantly; evidently routine activities affect non-routine activities, not vice versa. The significant coefficients of TerMode, TerTime and NRamps indicates that trip frequencies are affected by mode accessibility. The results also show that if an individual has his/her own vehicle, his/her trip frequency for non-routine activities increases. Thus the travel environment, especially the availability and convenience of travel modes, affects the trip frequency for routine and non-routine activities.

Table 1 Parameter estimates of trip generation model system

	Trip frequency for routine activities*		Trip frequency for non-routine activities	
Variables	Parameter	T-Statistic	Parameter	T-Statistic
Routine Frequency*			0.33	9.24
Non-routine Frequency*				
Sex	-0.113	-2.79		
FreqD	-0.069	-1.70	-0.072	-2.41
FreqH			0.123	3.58
PIncome	-0.104	-3.01		
MainUser			0.058	1.91
NChildren			-0.069	-2.24
NFamily	-0.087	-2.78	-0.132	-4.22
HHIncome	0.080	2.72		
TerMode	-0.309	-6.08		
TerTime	-0.195	-6.09		
NVehicles	0.121	3.85		
DYears	-0.051	-1.95	0.094	2.68
Sales	-0.057	-4.20	0.023	3.58
NRamps	0.097	3.15		
R^2	0.122		0.172	

Notes

Sample size = 420 * Latent variable GFI = 0.9997
X2(df=22) = 11.29 (p=0.97) AGFI = 0.9962

Table 2 Definition of exogenous variables

Variable	Definition
Sex	1 if the individual is a woman; 0 if a man
Age	age of the individual
Occupation	1 if the individual is not employed; 0 otherwise
License	1 if the individual has a driver license; 0 otherwise
MainUser	1 if an automobile is always available to the individual; 0 otherwise
FreqD	1 if the individual drives a car more than twice a week; 0 otherwise
FreqH	1 if the individual uses freeways more than twice a week; 0 otherwise
PIncome	1 if the personal income exceeds 10 million yen; 0 otherwise
NChildren	the number of children in the household
NFamily	the number of household members
HHIncome	1 if the household income exceeds 10 million yen; 0 otherwise
TerMode	0 if going to nearest railway station on foot; 1 otherwise
TerTime	time from home to nearest railway station
NVehicles	the number of vehicles in the household
DYears	the number of years lived in the residence zone
Sales	the total number of all stores in the residence zone
NRamps	the number of freeway ramps in the residence zone
TAcc	a train accessibility index in the residence zone (summation of the inverse of the travel times to all zones from residence zone using train)
CAcc	a car accessibility index in the residence zone (summation of the inverse of the travel times to all zones from residence zone using car)
TTime	travel time from the residence zone to the destination zone by train
Time	travel time from the residence zone to the destination zone by level 2 mode
NXfers	the number of transfers by train
CTime	travel time from the residence zone to the destination zone by car
SMarkets	the number of super-markets in the residence zone
Hotels	the number of hotel in the zone
Workarea	1 if the individual's work place is located in the destination zone; 0 otherwise

Table 3 Parameter estimates of structure choice model system

	Routine Activities		Non-Routine Activities	
Variables	Parameter	T-Statistic	Parameter	T-Statistic
Age	0.043	2.30		
Sex	-0.20	-7.43	-0.24	-9.54
Occupation			-0.165	-4.72
License	-0.16	-7.22	-0.078	-3.18
FreqH	0.12	5.49	0.072	3.14
PIncome	-0.162	-6.22	-0.24	-10.24
MainUser	-0.057	-2.34	-0.162	-6.34
NChildren	0.11	5.12	0.22	10.02
NFamily			-0.16	-9.16
HHIncome	0.052	3.42		
TerTime			-0.082	-4.98
NVehicles	0.086	4.07	0.13	6.46
DYears	-0.060	-3.63		
TAcc	0.099	5.52		
CAcc			-0.174	-9.91
NRamps	-0.14	-8.35	-0.11	-8.56
R^2	0.085		0.124	

Notes
$Cov(\gamma_1, \gamma_2) = 0.61$ $Var(\gamma_1) = 0.92$ $Var(\gamma_2) = 0.88$
Sample size = 420 GFI = 0.9995
χ^2 (df=16) = 25.30 (p=0.064) AGFI = 0.9923

Structure choice sub-model

The parameter estimates for the structure choice model of eqs. (6) and (7) are shown in Table 3. As equation (6) indicates, a positive estimate implies that as the variable increases the probability of having structure 2 also increases. The exogenous variables of the model system are defined also in Table 2. The estimated covariance of the error terms is large, yielding a correlation coefficient of $\rho = 0.76$. The structure choice probabilities for routine and non-routine activities are positively correlated with each other.

Significant coefficient estimates indicate that, for both routine and non-routine activities, women, license holders, individuals with high personal incomes, those who always have a car available, and those living in areas with sparse freeway ramps, tend to have structure 1. In the study area the last variable is highly correlated with residential density. The results therefore suggest that suburban, automobile-oriented individuals tend to have a choice structure where destination is placed above travel mode. Households with more children and those with more vehicles, on the other hand, tend to have structure 2, suggesting that households in child-rearing stages (which may often necessitate ownership of multiple vehicles) tend to have a pre-determined travel mode and choose destinations given the mode. The results also suggest that higher transit accessibility increases the likelihood of structure 2 for routine activities, while higher car accessibility leads to structure 1 for non-routine activities.

The mode and destination choice model system

The coefficients of the nested-logit, mode-destination models are estimated first assuming a single choice structure. The utility of using train is set to 0 for normalization for both routine and non-routine activities, regardless of choice structure or choice level. The variable, *Time*, in the utility function for the lower level (level 1) of structure 2 is the travel time to each destination zone by the mode chosen at the higher level (level 2), both for routine and non-routine activities .

Table 4 **Parameter estimates of the mode and choice model system for routine activities**

Routine Activities, Structure 1				Routine Activities, Structure 2			
	Variables	Parameter	T-Statistic		Variables	Parameter	T-Statistic
Level 2 Destination Choice	SMarkets	0.31	4.29	Level 1 Destination Choice	SMarkets	-0.22	-2.02
	Workarea	0.0057	0.0045		Workarea	-0.45	-4.97
	logsum	0.28	3.47 (8.92)		logsum	-0.27	-3.39
Level 1 Mode Choice	Intercept	-2.48	-8.98	Level 2 Mode Choice	Intercept	-0.43	-4.33
	Age	-0.67	-6.50		Age	0.85	6.20
	Sex	0.041	0.82		Sex	-0.19	-4.18
	TTime	-0.31	-0.61		TTime	-0.069	-7.61
	NXfers	-0.42	-1.39		NXfers	-0.55	-6.67
	CTime	0.17	0.25		CTime	0.10	0.95 (8.55)

Notes

Structure 1		Structure 2	
Sample size	= 282	Sample size	= 282
L(0)	= -896.21	L(0)	= -896.21
L(B)	= -766.91	L(B)	= -775.22
-2[L(0)-L(B)]	= 258.6	-2[L(0)-L(B)]	= 241.98
ρ^2	= 0.14	ρ^2	= 0.14

( ): t-statistic for the null hypothesis is that the coefficient is 1.

The positive coefficient of a mode choice component implies that the probability that the auto will be chosen increases with the variable.

Routine activities

Age has statistically significant coefficient estimates for both structure 1 and structure 2 (Table 4). Quite importantly, the signs are opposite between the two structures. In the model with structure 1, where destination is placed above mode, the *Age* coefficient is negative, implying that those who are younger tend to choose auto for a trip to a given destination zone. An opposite tendency is depicted by the positive coefficient estimate in the model with structure 2. The result offers empirical evidence that entirely different behavioral sensitivities to a variable may be indicated depending on the choice structure assumed for model estimation; the validity of a coefficient estimate must be determined while examining alternative choice structures that may be theoretically assumed.

SMarkets has statistically significant coefficient estimates in both structures. The negative sign in the model with structure 2, however, is theoretically not supported. The coefficients of *Time* and *NXfers* in this model are extremely significant and have expected signs. The estimation results thus suggest that, in mode-destination choice where travel mode is placed higher in hierarchy than is destination, destination attributes are of little importance.

ρ^2 values of structure 1 and structure 2 are both 0.14, and χ^2 values of structure 1 is slightly greater than that of structure 2. The coefficient of the log-sum term of structure 1 is 0.38 while that of structure 2 is 0.10, suggesting that the destination alternatives are highly correlated. The nested logit model with structure 1 can be preferred to the model with structure 2, because: 1) the goodness of fit is slightly better, and 2) its log-sum term indicates that the effect of trip attributes shown at the mode choice level is reflected in the destination choice level.

Non-routine activities

The parameter estimates for non-routine activities are shown in Table 5. Models which assume a single choice structure and a model with multiple structures are presented. The formulations of the utility functions with multiple structures are the same as that with a single choice structure.

The estimated coefficient values are often different among the models. These differences in coefficient estimates imply different elasticities between the two sets of models, again offering empirical evidence that assumptions about the choice structure significantly affect coefficient estimates, and therefore, predictions produced by the model.

Table 5 Parameter estimates of the mode and destination choice model system for non-routine activities

Non-routine Activities, Structure 1				Non-routine Activities, Structure 2			
	Variables	Parameter	T-Statistic		Variables	Parameter	T-Statistic
Level 2 Destination Choice	Hotels	0.37	3.93	Level 1 Destination Choice	Workarea	-0.082	-0.33
	Workarea	0.018	0.17		Time	-0.21	-1.84
	logsum	0.34	2.60 (5.05)		NXfers	-0.51	-1.18
Level 1 Mode Choice	Intercept	-1.42	-9.65	Level 2 Mode Choice	Intercept	-0.56	-4.11
	Age	0.56	6.14		Sex	0.15	2.11
	Occupation	0.12	2.12		Occupation	-0.27	-2.94
	TTime	0.05	0.42		Logsum	1.16	1.85 (0.26)
	NXfers	-0.19	-0.83				
	CTime	-0.27	-4.99				

Notes

Sample size	= 178	Sample size	= 178
L(0)	= -514.59	L(0)	= -514.49
L(B)	= -467.76	L(B)	= -489.22
-2[L(0)-L(B)]	= 93.46	-2[L(0)-L(B)]	= 50.53
ρ^2	= 0.091	ρ^2	= 0.049

Non-Routine Activities, Multiple Choice Structures							
Structure 1				Structure 2			
	Variables	Parameter	T-Statistic		Variables	Parameter	T-Statistic
Level 2 Destination Choice	Hotels	0.80	3.24	Level 1 Destination Choice	Workarea	-0.50	-1.29
	Workarea	0.61	2.44		Time	-0.44	-2.17
	logsum	0.68	3.52 (1.66)		NXfers	0.54	0.27
Level 1 Mode Choice	Intercept	-6.97	-2.11	Level 2 Mode Choice	Intercept	-0.66	-2.90
	Age	4.00	4.60		Sex	-4.52	-1.32
	Occupation	1.30	3.13		Occupation	-0.18	-1.76
	TTime	0.16	0.67		Logsum	0.32	0.46 (0.95)
	NXfers	0.076	0.49				
	CTime	-2.16	-4.92				

Notes

Sample size	= 178
L(0)	= -661.68
L(B)	= -540.07
-2[L(0)-L(B)]	= 243.24
ρ^2	= 0.18

( ): t-statistic for the null hypothesis that the coefficient is 1.

The positive coefficient of a mode choice component implies that the probability that the auto will be chosen increases with the variable.

The coefficient estimate for the log-sum term of the model assuming choice structure 2 exceeds 1, but not statistically significantly. Thus when it is assumed that the mode is above destination in the choice structure, then the destination alternatives associated with each mode have no correlated unobservables and the mode-destination choice may be represented by the standard multinominal logit model. The coefficient estimate is statistically significantly different from both 0 and 1 in the model with structure 1 in which destination is in the higher level. Thus there are strong correlations among unobservables for the mode alternatives associated with each destination.

The coefficient estimates of the log-sum terms of the model with multiple structures both fall between 0 and 1. The coefficient estimate for structure 2 in the multiple structures model, however, is significantly different from neither 0 nor 1. On the other hand, the estimate for structure 1 is again significantly different from both 0 and 1. The estimation results thus suggest that the nested logit applies to structure 1 while the multinominal logit is adequate for structure 2. It may be concluded that there are correlations in unobservables across travel modes but not across destination alternatives, and that, had the model system included more than two travel modes, the model with choice structure 2 would have to be formulated with a nesting of the travel modes.

The ρ^2 value of the model with multiple choice structures is considerably larger compared with the those of the models with a single choice structure. The model with multiple choice structures provides a better fit to the data than the models with a single choice structure. The results offer evidence for the existence of the heterogeneity in choice structure across individuals.

SUMMARY AND CONCLUSIONS

The personal action space is analyzed in this study while considering multiple choice structures. The data on the frequency of visits to each destination zone were collected by a two-wave panel survey that aimed at understanding the effect of a new freeway. Mapping of the monthly average of the frequency of visits by respondents to each destination zone has indicated that the new freeway has led to a substantial expansion in action space and increase in vehicle-miles traveled. With the intent of developing a quantitative model of individuals' action space, a model system to predict the frequency of visits to each destination zone by mode was formulated.

As noted earlier the sample used in the study is an enhanced random sample part of which is based on a choice-based sampling. No weighting was applied in the analysis of this study to correct for possible bias in estimates of alternative-specific constants. It is nevertheless believed that the following conclusions remain valid and can be generalized.

This model system comprises a trip generation equations system and a mode and destination choice model system. The trip generation model system considers the inter-relation between trip frequencies for routine and non-routine activities. The coefficient estimates imply that the trip frequency for routine activities affects that of non-routine activities.

The mode and destination choice model system takes into account the heterogeneity in choice structure by adopting nested logit models with multiple choice structures. In modeling structure choice behavior, the error terms of the bivariate probit structure choice sub model were assumed to be correlated between routine and non-routine activities. The covariance estimate was statistically significant and positive. Comparing the goodness-of-fit statistics of models with a single choice structure to that of a model with multiple choice structures, the model with multiple choice structures has been shown to provide a better fit to the data. The results offer evidence for the existence of heterogeneity in choice structure across individuals. In sum the following can be concluded from this study:

1. there is heterogeneity in choice structure across individuals,
2. the trip frequency for routine activities affects that for non-routine activities,
3. the unobserved factors affecting structure choice are correlated between for routine and non-routine activities, and
4. mode alternatives are highly correlated among themselves.

REFERENCES

Cramer, J. S. (1991) *The Logit Model for Economists.* Champam and Hall, New York.

Forinash, C.V. and Koppelman, F.S. (1992) Application and interpretation of nested logit models of intercity mode choice. *Transportation Research Record*, 1413, 98-106.

Golob, T.F., Horowitz, A.D. and Abraham, D. (1979) Attitude behavior relationships in travel demand modeling. In D. A. Hensher and P. R. Stopher (eds.) *Behavioral Travel Modeling*, Croom Helm, London, pp.739-757.

Joreskog, K. and Sorbom, D. (1984) LISREL VI-Analysis of Linear Structural Relation by Maximum Likelihood, Instrumental Variables, and Least Squares Methods, User's Guide. Department of Statistics, Univ. of Uppsala, Uppsala, Sweden.

Kitamura, R. and Bunch, D.S. (1990) Heterogeneity and state dependence in household car ownership: A panel analysis using ordered-response probit models with error components. In M. Koshi (ed.), *Transportation and Traffic Theory*, Elsevier, New York, pp.477-496.

Kitamura, R. and Lam, T.N. (1984) A model of constrained binary choice, In J. Volmoller and R. Hamerslag (eds.) *Proceedings of the Ninthe International Symposium on Transportation and Traffic Theory,* VNU Science Press, Utrecht, pp.493-512.

Koppelman, F.S. and Pas, E.I. (1980) Travel-choice behavior: Models of perceptions, feelings, preference, and choice. *Transportation Research Record*, 765, 26-33.

Pendyala, R.A. (1992) Causal Modeling of Travel Behavior Using Simultaneous Equations Systems: A Critical Examination. Unpublished Ph.D. thesis, Department of Civil Engineering, University California, Davis, California.

Swait, J. and Ben-Akiva, M. (1987) Incorporating random constraints in discrete models of choice set generation, *Transportation Research B*, 2, 91-102.

Tischer, M.L. and Phillips R.V. (1979), The Relationship between transportation perceptions and behaviors over time. *Transportation*, 8, 21-33.

Toyoda, H. (1992) *Covariance Analysis of Linear Structural Equations Using Statistical Analysis System*. Press Association of Tokyo University, Tokyo.