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EFFECT OF CENTRAL PARKING SERVICE ON SHOPPING BEHAVIOR BY USING THE 4-LEVEL NESTED LOGIT MODEL

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The objective of this study is to examine the effect of central area parking service on shopping travel behavior in order to help make a decision for parking policies of a local city. This paper describes the estimation of a disaggregate nested logit model for frequency, destination, mode, and parking place, being parking place choice the first level and frequency choice the last level of the nested structure. The data used for model estimation were obtained from the questionnaire survey of shopping trips on holidays in the city of Nagaoka, Niigata. The sensitivity analysis of the model reveals that the improvement of parking service in the central area contributes to the increase of car mode, but not so much to the shift of destination and the increase of trip frequency.

1. INTRODUCTION

In recent years owing to the high motorization in Japan, particularly in local cities, a private car is the primary mode of transport. Parking and congestion problems in central areas make it difficult in some degree to get access to commercial areas, and consequently create changes on the individual behavior of shopping.

The expansion of a shopping center located in the suburbs may produce a decline in the retail sales of central areas. On the other hand, the provision of central parking facilities possibly obtains a contrary effect on them. Both situations can induce changes of individual travel behavior. Parking policies now form an important element in the transport strategies of many local authorities, especially those responsible for congested urban centers.

It is desirable to examine the effects produced on travel behavior by some relevant quantitative analysis in order to make adequate policies that solve a specific problem. Travel behavior can be represented satisfactorily by the disaggregate behavioral models[2]. There exist many applications for destination choice, mode choice and parking place choice of shopping trips, but a few applications for frequency choice.

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A nested structure of choice is usually applied to two levels, such as mode and destination choice[7], or parking and destination choice[3], etc. There are a few cases of three levels, such as frequency, destination and parking place choice[6], but so far no applications of four levels.

In order to evaluate the overall impact of parking policies on shopping travel behavior, the four-level nested logit model should be applied. Following the technique developed by Yoshida and Harata[6], this paper tries to estimate a reasonable four-level structure of choice alternatives, possibly in the sequence of frequency, destination, mode and parking place.

Hence, this paper deals with shopping travel to buy grocery and non-grocery goods on holidays in a local core city. Travel behavior is represented by the four-level nested logit model which considers choice alternatives of frequency, destination, mode and parking place. Then, the overall effects of central area parking policies on shopping travel behavior are evaluated by making a sensitivity analysis of the model.

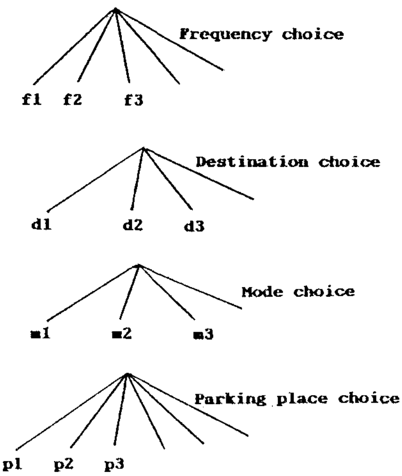


Fig. 1 Structure of the model

2. MODEL

The model selected for use in the study is the Nested Logit (NL) model, which has four dimensional choice alternatives of frequency, destination, mode and parking place. Fig.1 shows schematically four levels of the NL model, being the first level of this nested structure parking place choice and frequency choice the last one.

Based on the typical formulation of the NL model, the probability of the simultaneous choices for each level is given by the product of probabilities such as

$$P(f,d,m,p)=P(f)\cdot P(d/f)\cdot P(m/d,f)\cdot P(p/m,d,f) \qquad \text{...............(1)}$$

where,

$P(f,d,m,p)$ = joint choice probability,
$P(f)$ = marginal probability of frequency,
$P(d/f)$ = conditional probability of destination,
$P(m/d,f)$ = conditional probability of mode and,
$P(p/m,d,f)$ = conditional probability of parking place.

As known, the utility function of the NL model can be specified by including the natural logarithm of utility sum, a variable typically named as LOGSUM. In each level of the nested structure the variable LOGSUM can be expressed as follows:

$$\Lambda f= \frac{1}{\mu_d} Ln \sum_d \exp[\mu_d(\Sigma\beta_d X_d+\Lambda_d)] \qquad \text{...............(2)}$$

$$\Lambda d = \frac{1}{\mu_m} \mathrm{Ln} \sum_m \exp[\mu_m(\Sigma\beta_m X_m + \Lambda_m)] \quad \text{.............. (3)}$$

$$\Lambda m = \frac{1}{\mu_p} \mathrm{Ln} \sum_p \exp[\mu_p(\Sigma\beta_p X_p)] \quad \text{.............. (4)}$$

where

X_d, X_m, X_p = explanatory variables related to the choice of destination, mode and parking place respectively,

β_d, β_m, β_p = coefficients related to the choice of destination, mode and parking place respectively, and

μ_d, μ_m, μ_p = scale parameters for the choice of destination, mode and parking place respectively.

To describe the nested choice behavior of destination and frequency, it is necessary to recognize that the feasible number of destination alternatives may affect the generation of trips. Ben-Akiva and Lerman[1] have proposed the logit model utility with known sizes of the (aggregate) destination alternatives. But, this model requires a special estimation procedure. This paper uses the following utility function to formulate the destination choice model.[3),6]

$$U_j = V_j + \ln(A_j) + \sum_k \alpha_k \ln(A_{jk}/A_j) \quad \text{.............. (5)}$$

where

U_j= expected utility for destination j,

V_j= utility component excluding the size variables for destination j,

A_j= one basic size variable which determines the size of destination alternatives,

α_k= the coefficient of the k-th size variable, and

A_{jk}= the k-th size variable for destination j.

To formulate the generation of shopping trip, Yoshida and Harata[6] applied and recommended the Ordered Logit (OL) model which was originally developed by Sheffi[4]. This paper uses the OL model with constrained coefficients [5]. The OL model can be estimated by first estimating a simple binary logit model of the choice of one trips against two or more trips, then estimating a binary logit model of the choice of two trips against three or more trips. The coefficients of independent variables are constrained to be constant across alternatives, whereas constant terms are alternative specific.

3. DATA

The data used for model estimation were obtained from the questionnaire survey carried out in October 1989 for the of householders living in Nagaoka city. Nagaoka is a local core city situated in Niigata Prefecture with a population of about 180,000. The survey included 1260 persons of households, and 1184 persons answered effectively. The travel information in the survey consists of questionnaire detailing frequency, destination, mode and parking place used for shopping activities on holidays. Questionnaire responses are separated into the shopping travel to central areas and the one to suburban shopping centers.

Destination zones in the study are indicated in Fig. 2, where A is the central area and B, C and D are suburban shopping zones.

People going for shopping only to the center were 8.1%, and people going only to the suburbs were 6.4%, and the rest of them (85.5%) chose both areas. The share of destination among suburban zones was 41% for Kawasaki (C in Fig. 2), 30.0% for Kitamachi(B), 20.1% for Miyauchi(D) and 8.5 % for other places.

Table 1 shows the share of mode used for shopping travel destined for center or suburbs. As expected, a car is the preference mode for shopping travel toward both areas of center and suburbs.

Fig. 3 shows the five destination zones and the location of parking places in the central area. The destination of shopping trips were identified by the five zones in the survey. There locate 17 parking places in the central area, but 11 parking places are selected to be the choice alternatives in the estimation sample.

Table 2 shows the choice distribution of destination zone and parking place for the central area. In each of the zone 1 and 3, there is a big supermarket managing its own parking place. The station building of Nagaoka holds a fashionable shopping center. Zone 1 and 3 are highly preferred shopping districts in comparison to the other ones.

4. ESTIMATION OF UTILITY FUNCTIONS

4.1 Parking choice model

The choice model of parking place is applied only to the car trips destined for the central area, and choice alternatives are 11 parking places shown in Table 2. It is assumed that the user makes his choice from alternative parking places which are rather close to his destination of shopping. So, the possible parking places to be chosen are defined by the criteria that the distance between parking place and destination is less than or equal to 300 m.

The choice of parking place is specified as type captive for the suburbs, since suburban shopping

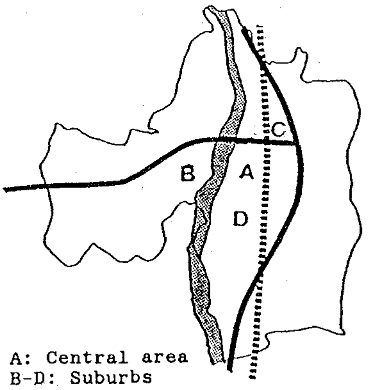
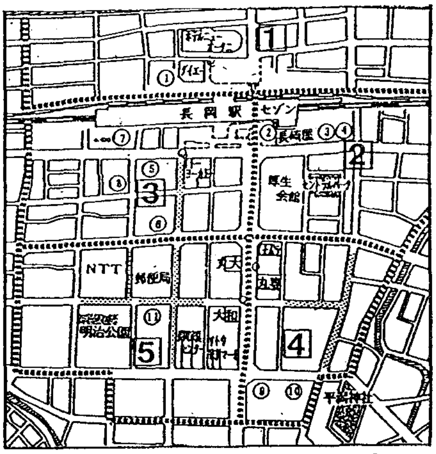


Fig. 2 Area of study (Nagaoka city)

Table 1 Observed choice of mode

	bicycle	bus	car	Total
Center	171 (15.9)	182 (16.9)	724 (67.2)	1077 (100.0)
Suburbs	111 (10.9)	33 (3.2)	875 (85.9)	1019 (100.0)



○:Parking place

Fig. 3 Parking place of central area

Table 2 Observed choice of zone and parking place (central area)

Parking	Zone 1	2	3	4	5	Total
P1	123	6	17	1	0	147
P2	1	6	7	1	1	16
P3	3	11	9	2	0	25
P4	3	11	4	3	2	23
P5	3	3	23	0	1	30
P6	3	2	11	1	2	19
P7	4	23	14	15	2	58
P8	1	0	45	1	0	47
P9	7	6	14	6	9	42
P10	2	2	3	5	0	12
P11	2	1	3	0	1	7
Total	152	71	150	35	18	426

centers and shops usually hold their own parking places.

Variables used to model the parking place choice include parking capacity (CAPAC), the distance between parking place and destination of shopping (DIST), and parking fare (FARE). The location dummy variable (LOCADU) indicates that the parking place is located on a principal urban road. The monthly rental dummy variable (MONTDU) is 1 if the parking place is managed to be rented monthly, and is 0 otherwise. Parking fare (FARE) was the actual price paid by the user; shopping centers and stores discount parking fare for customers who purchase goods of more than a certain amount of price.

The specification of the model are given in Table 3 and 4. Parking capacity is represented in a logarithmic form, which means that parking

Table 3 Variables used

Characteristic	Variable name	Explanation
Social & economic attribute of household	INC	Annual income of householder
	LICD	1 for driving license holder, 0 otherwise
	FAM	Numbers of persons in household
	CHILD	Number of children
	NBC	Numbers of bicycles per person in household
Destination variable	NBIG	Number of big stores
	FLR	Selling floor area of big stores
	NCD	1 for central area, 0 for suburbs.
Transportation service level	TRAVEL	Travel time (min.)
	COST	Travel cost (yen)
	RD	Distance (d) from house to destination ($d \leq 2$ km. RD=1; $d > 2$ km. RD=0)
Parking service level	DIST	Distance from destination to parking place (m)
	CAPAC	Parking capacity (car)
	FARE	Parking fare (yen)
	MONTDU	Monthly rental parking dummy
	LOCADU	Location of parking place dummy
Shopping articles dummy	ATCL1	1 for shopping to buy foods, 0 otherwise
	ATCL5	1 for shopping to buy gifts, 0 otherwise
Mode specific dummy	ALT1	1 for bicycle, 0 otherwise
	ALT2	1 for bus, 0 otherwise

Table 4 Estimated coefficients

PARKING PLACE		MODE		DESTINATION	
DIST	-0.0150	TRAVEL	-0.02338	LN(NBIG)	1.000
	(-10.64)		(-1.692)		(-)
FARE	-0.0027	COST/INC	-0.6610	LN(FLR/NBIG)	0.5613
	(-3.510)		(-4.123)		(3.493)
MONTDU	0.2903	LICD	1.194	ATCL1	0.5121
	(1.363)		(6.764)		(2.308)
LOCADU	0.680	RD	1.248	ATCL5	-0.4714
	(3.252)		(4.957)		(-1.206)
LN(CAPAC)	0.6169	NBC	0.4380	LOGSUM	0.4360
	(4.938)		(4.001)		(2.535)
		LOGSUM	0.2745	NCD	-2.04
			(3.682)		(-7.391)
		ALT1 (bic.)	-1.549		
			(-4.721)		
		ALT2 (bus)	-0.9122		
			(-3.885)		
$L(\theta)$	-383.1	$L(\theta)$	-533.7	$L(\theta)$	-275.4
ρ^2	0.297	ρ^2	0.441	ρ^2	0.478
Per. correctly predicted	55.7	Per. correctly predicted	82.1	Per. correctly predicted	64.3

Numbers in brackets are "t" statistics.

Table 5 Estimated coefficients of the frequency model

VARIABLE	V 2/1	V 3/2	V 4/3	V 5/4	V 6/5	V 7/6
CONSTANT	-0.2486	-1.875	-3.742	-6.626	-9.762	-13.68
	(-0.8371)	(-1.096)	(-1.118)	(-1.483)	(-1.746)	(-2.036)
CHILD/FAM	-0.7431	-0.7431	-0.7431	-0.7431	-0.7431	-0.7431
	(-1.722)	(-1.722)	(-1.722)	(-1.722)	(-1.722)	(-1.722)
LOGSUM	0.5509	0.5509	0.5509	0.5509	0.5509	0.5509
	(3.292)	(3.292)	(3.292)	(3.292)	(3.292)	(3.292)
Sample	590		L(0)	-1713	ρ^2	0.366
Case	2471		$L(\theta)$	-1086	$\bar{\rho}^2$	0.365
Percentage correctly predicted			79.77			

capacity has a very similar effect to a singly constrained gravity model. The coefficients of all variables have the expected signs, but the log likelihood ratio ρ^2 and the percentage correctly predicted of sample estimated are lower than the satisfactory level.

4.2 Mode Choice Model

Choice alternatives of the mode choice model are car, bus and bicycle. Variables of service level used include total travel time (TRAVEL), total travel cost (COST), and a dummy variable of distance from house to destination (RD). The LOGSUM variable of parking service level is added to the utility function of the mode choice model to represent the nested structure of preference. ALT1 and ALT2 are mode specific dummy variables of bicycle and bus respectively.

Table 4 shows that the coefficient of LOGSUM has the expected plus sign and value. The log likelihood ratio and the percentage of correct prediction indicate a very good specification of the model.

4.3 Destination Choice Model

Choice alternatives of the destination choice model are five zones for the central area and three zones for the suburban areas. Variables used include the number of big shopping stores (NBIG) and the selling floor area of big stores (FLR), which represent the attractiveness of a destination. The variable of NBIG is considered as a size variable and its coefficient is set to be 1.0 to examine the effect of only NBIG separating from the effect of FLR. A dummy variable NCD is introduced to distinguish the central area from the suburbs. Dummy variables ATCL1 and ATCL5 are added to define a particular type of articles purchased.

Table 4 shows that the coefficients of ln(FLR/NBIG) and LOGSUM have the expected plus signs and values. The log likelihood ratio and the percentage of correct prediction indicate a satisfactory specification of the model.

4.4 Frequency Choice Model

As indicated previously, the partially constrained Ordered Logit (OL) model is applied for the frequency choice model. Coefficients and other information for this model are given in Table 5, where $V_{i+1/i}(=V_{i+1}-V_i)$ represents incremental expected utility of the chosen alternative (i) of frequency. Shopping frequencies are ranked from once monthly to seven and more times monthly. Variables used include the ratio of children to persons in household (CHILD/FAM) and the LOGSUM of the destination choice model. The coefficients of constant terms result in reasonable values, and the log likelihood ratio and the percentage of correct prediction indicate a very good specification of the model.

4.5 The 4-level nested logit model

Now that the estimation of the 4-level nested model have been completed, the whole value of log likelihood ratio can be computed to be 0.386. The ratio of scale parameters μ_m/μ_p, μ_d/μ_m and μ_f/μ_d (which are the values of coefficients of LOGSUM variables) are positive and less than 1. Therefore the scale parameters are μ_p=1.0, μ_m=0.274, μ_d=0.119 and μ_f= 0.065, which satisfy the condition of the nested logit model.

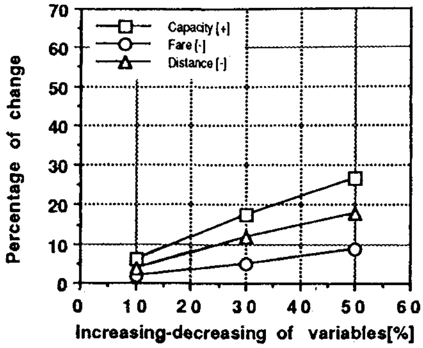


Fig. 3(a) Parking place 1

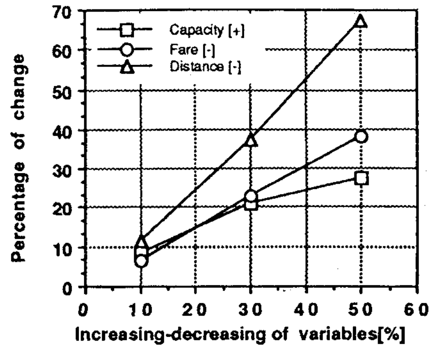


Fig. 3(b) Parking place 7

5. SENSITIVITY ANALYSIS

To investigate the effect of central area parking service on the shopping travel behavior, sensitivity analysis was carried out by simulating the changes of choice for each level when the variables of parking service changed.

Since the parking places of large demand and capacity may have a significant impact and the choice behavior of parking place can be understood to be the result of demand and supply equilibrium, the variables CAPAC, FARE and DIST of parking places 1, 7 and 8 only are changed. The capacity of the three parking places (480, 431 and 405 cars) is assumed to increase by 10%, 30% and 50%, while the fare or distance of the three parking places decrease by the same percentage.

Figs. 3(a), (b) and (c) show the percentage of share change of parking place 1, 7 and 8 respectively when the capacity, fare or distance of the three parking places change.

Capacity makes the similar effect on the share of three parking places, but the elasticities of fare and distance for the parking place 7 are much greater than the other two parking places. This is because that the capacities of the three parking places are almost the same. The parking place 7 is managed by the local authority and does not have a discount system. But, the parking places 1 and 8 are located near the supermarkets and give discount of fare to their customers.

Fig. 4 gives the percentage of share change of frequency when the capacity of three parking places change. (the capacity increase of 10, 30 and 50% of the three parking places corresponds to

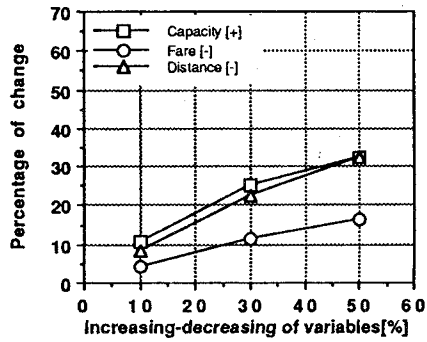


Fig. 3(c) Parking place 8

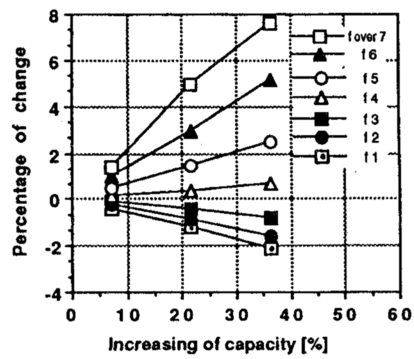


Fig. 4 Effect on frequency

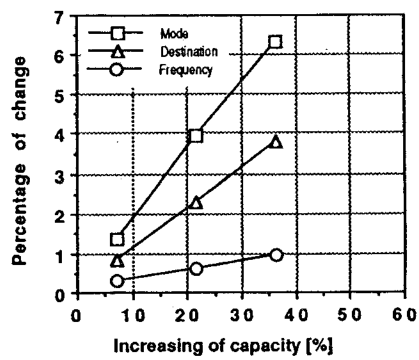


Fig. 5 Effect on mode, destination and frequency

the increase of 7, 22 and 36% of the whole parking places in the central area). The share of persons whose frequency of trips are more than 4 times monthly increases, and hence the average of frequency increases.

Fig. 5 shows the percentage of share change of mode, destination and frequency (average) when the capacity of three parking places changes. The simulated result that percentage of change is in the order of mode, destination and frequency indicates the characteristics of nested structure. Their elasticities are extremely smaller than that of parking place shown in Fig. 3.

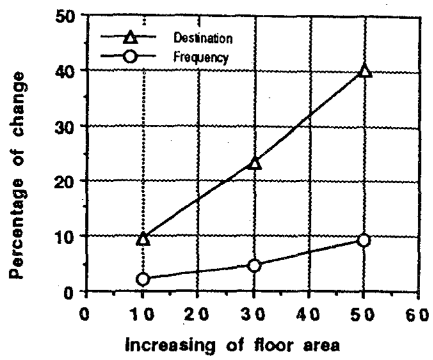


Fig. 6 Effect of floor area on destination and frequency

Next, let us compare the effect of parking place capacity with that of the selling floor area of big stores in the central area. Fig. 6 shows the percentage of share increase of destination (the central area) and of average frequency increase when the floor areas of big stores in the central area increase. The effect of the floor area is considerable compared with that of parking place capacity, as far as the percentage of change is concerned. This is because that the scale parameters μ_m, μ_d and μ_f (particularly μ_m) are far smaller than 1.0.

6. CONCLUSIONS

The estimation of the 4-level nested logit model are mainly based on the previous results of study, but an encouraging step in the development of a full set of shopping travel demand model. The 4-level model estimated, in the sequence of frequency, destination, mode and parking place, satisfies the condition of scale parameters and gives good statistical indexes. But, the value of scale parameters are smaller than expected. Then, the effects of parking place service in the central area on the shift of mode and destination, and the increase of frequency tend to be smaller than actually anticipated. This model does not seem to demonstrate the full effects of parking policies in the central area. Further works are needed, for example, to develop a more sensitive model of nested structure which may have a different sequence of choice dimensions.

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