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Sequential Model of Interdependent Activity and Destination Choices

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ABSTRACT

A sequential model of daily travel patterns that consists of activity and destination choice submodels is developed in this study. The model development takes into account the interdependencies among the choices and the constraints imposed on the movement in time and space. The empirical analysis indicates that non-home-based destination choice is critically dependent on the residence location of the individual and that activity choice is influenced only marginally by the accessibility of the origin location. As a practical and immediate modification of non-home-based destination choice models, it is proposed in this study that destination-to-home travel time be included as a factor that enables a more realistic depiction of spatial travel patterns.

In previous efforts (1,2) the authors have examined the properties of activity choice that are directly related to generation of trips and their temporal distribution over a 1-day period. The results have revealed the characteristics of time-of-day dependencies of activity choice and revealed patterns in sequencing activities in trip chains. Analysis of the dependence of activity choice on its own history indicated that activity history may be represented in a simple manner for use in travel behavior analysis. This study draws on the previous efforts and expands it by introducing the spatial dimension into its scope.

The ultimate objective of this continuing effort is to develop a practical model system that makes possible a more realistic depiction of complex daily travel behavior. The effort and the resulting models can be characterized by the following two aspects. The first is its explicit recognition and incorporation into the model structure of the fact that trips made by an individual are linked to each other. This leads to the emphasis in this study of the interdependencies among choices that underlie the entire daily travel and activity pattern. In other words, this study does not isolate a trip or a travel choice from the rest to be analyzed independently. Second, the effort acknowledges that the movement of an individual is constrained in time and space because of various factors, including the social commitments, obligations, limited transportation capabilities, and physiological needs of the individual (3-8). The constraints are most typically associated with activities that allow little scheduling flexibilities such as work, chauffeuring children to school, or having lunch during a lunch break. This study therefore emphasizes, among others, time-of-day dependencies of activities and trips.

A system of models is developed in this study. It consists of home-based and non-home-based destination choice models that incorporate the effects of trip continuity together with those of time of day. The activity choice models of this study are expanded to include, in addition to the variables used in the previous study (2), spatial factors such as the travel time between the home base and the origin activity location and the accessibility from that location.

The objective of this study is, first, to identify the extent to which destination choice is influenced by factors other than the traditional variables (i.e., the origin-destination travel time and the attributes of alternative destination locations). More specifically, the study is an endeavor to show that the location of an individual's home and the locations of alternative destinations relative to the home location critically influence non-home-based destination choice. The second objective is to identify the effects that spatial factors have on activity choice, either independently or jointly with other factors, including time of day, activity history, and socioeconomic characteristics of the individual. Note that the effects of the latter group of variables have been studied earlier (2), and accessibility indices as spatial factors have often been used in previous travel behavior analyses (9,10). The intention of this study is to achieve a more comprehensive treatment of these factors in analyzing daily travel patterns. Their intricate interactive effects are examined through statistical hypothesis testing that involves specification and estimation of alternative destination and activity choice models. Based on the results of the study, a practical modification that can be made to destination choice models for improved depiction of spatial travel patterns is proposed.

BACKGROUND

Formulations of destination choice models are typically based on the assumption that the trip is made from the home base and that only one destination location will be visited after the individual leaves home. Non-home-based choice, where the origin of the trip is not the home base, is analyzed while isolating the trip from the rest as an independent unit of analysis. Accordingly, the behavior of linking trips into a multiple-sojourn chain is not appropriately taken into consideration in the conventional analyses. This simplification is implicit in the behavioral or statistical derivations of commonly used trip distribution models such as the gravity model (11-13). The simplification also makes possible formulation of spatial choice models while using as explanatory variables only the attributes of respective destination alternatives and the spatial separation between the origin and destination. The models thus developed appear to capture the observed tendencies in spatial travel patterns with their simple model structure and with a relatively small set of explanatory variables. Nevertheless, this simplification may impose serious limitations when attempting to expand the scope of the analysis to include multiple-sojourn trip chains. Further discussions of the limitations and problems arising from the assumption can be found in Hanson (14,15). [This study focuses on trip linkages and constraints in its effort of extending the framework of destination choice analysis. Possible alternative developments are discussed elsewhere (16-18), with emphases on additional factors and behavioral aspects.]

An alternative approach is to acknowledge that choices underlying daily travel and activity patterns are interdependent (19). This can be done by analyzing travel choices as a simultaneous decision that is concerned with the entire daily activity and travel pattern (20-22), or by analyzing the series of choices sequentially (23,24). In the latter case, interdependencies can be accounted for by specifying the choices as dependent on the past history of activities (1,2), by viewing them as dependent on possible future behavior (25), or possibly on both. The interdependencies are reflected in the models of this study through activity choices that are assumed to be history dependent, and destination choices that are specified as, to an extent, dependent on the future.

By viewing the destination choices in an individual's daily travel pattern as interrelated choices and recognizing the fact that his travel pattern develops around the home base, it is hypothesized that the residence location of the individual is of critical importance in explaining the non-home-based destination choice. Note that the residence location has not been included in previous analyses of destination choice. However, the very fact that the individual sooner or later returns home in the future suggests that the choice is influenced by the location of the home.

For example, consider the choice of a shopping opportunity by a worker on the way back to home from the work place. This destination choice for the non-home-based shopping trip is influenced by the location of the home because it is dependent on the intended future behavior, in this case, returning home. Accordingly, the choice cannot be explained by the conventional factors alone, but its explanation requires that additional factors be introduced into the analysis. The distance between the alternative destination and home appears to be a promising candidate variable that may well explain this type of future dependency.

The importance of the residence location as a factor in non-home-based destination choice models can be seen in the following discussion, which emphasizes the constrained nature of urban travel choice. Individuals are typically subjected to certain constraints as to the locations where they can be at various time periods of the day. In other words, the range of locations where the individuals can exist is confined within a limited region in the time-space coordinates, which is often called a prism (3). This constraint will affect the choice of both activities and their locations.

Suppose that an individual located outside the home wishes to visit another location for an out-of-home activity, but he must return home by time T. The time available for the out-of-home activity and travel is T - t, where t is the present time. Let i be the location where the individual is currently located, and j be the potential destination. Then the following relation must be satisfied for location j to be accessible:

$$d_{ij} + d_{jh} \leq T - t \quad (1)$$

where d_{ij} is the travel time between locations i and j, and d_{jh} is the travel time between j and the home base. The inequality indicates that the destination-to-home travel time (d_{jh}) is an important element in destination choice under the prism constraint.

Additional evidence for the importance of the residence location is given by the following empirical observation of the series of destination choices in a trip chain. By applying the log-linear model of contingency table analysis to a large-scale origin-destination survey data set, Kermanshah (26) found that there exists a predominant pattern into which a set of destination locations to be visited are frequently arranged in a trip chain: The individuals tend to visit farther locations first, and subsequent destinations tend to be closer to home or cluster in the vicinity of the preceding locations. The finding implies that the home location is again of critical importance in adequately capturing the pattern of sequencing the locations visited in a trip chain.

MODEL FORMULATION

The activity and destination choice models of this study are formulated by using a two-stage approach, where activity choice and destination choice are separately modeled; choice of destinations given the out-of-home activity type is first modeled, and then activity choice models are developed. Accordingly, the destination choice models include as alternatives only nonhome destination opportunities. The structural framework of the model system of this study is described in detail elsewhere (24). It is worthy to note that a similar activity-location model system has been developed by van der Hoorn (27) with emphasis on determining trip generation based on temporal tendencies in activity engagement and also on differentiating in-home and out-of-home activities.

The non-home-based destination choice model of this study is formulated as

$$\left.\begin{aligned} P_a(i,j,t) &= \exp[V_a(i,j,t)]/\Sigma_k \exp[V_a(i,k,t)] \\ V_a(i,j,t) &= V(d_{ij}, d_{jh}, A_j, t, y) \end{aligned}\right\} \text{for } j = 1 \ldots, J \quad (2)$$

where

- J = number of destination alternatives,
- a = type of the activity for which the choice is made,
- $P_a(i,j,t)$ = probability that destination j will be chosen by individual i at time t to pursue an activity of type a,
- $V_a(i,j,t)$ = measure of attractiveness of destination j when visited from i at time t to pursue an activity of type a,
- A_j = vector of attributes of destination j,
- t = time of day,
- y = activity history,
- d_{ij} = travel time between origin i and destination j, and
- d_{jh} = travel time between home h and location j.

The multinomial logit model, which has been used in many previous analyses of spatial choice (28-30), is used here as the model structure. The representative utility or attractiveness measure of destination j $[V_a(i,j,t)]$ is time-of-day dependent and is formulated with the distance measure (d_{jh}), the travel time between the home base and destination j. This is in addition to the conventional origin-destination travel time (d_{ij}). Other factors considered in the model development are activity history, time of day, attributes of destination locations, and socioeconomic attributes of the individual. The variables used are summarized in Table 1. Not all of the variables in the table appear in the final models selected in this study.

Noting that the individual's time budget for activity and travel becomes tighter as the day proceeds, it is expected that the valuation of travel time varies depending on the time of day; presumably the individual is less willing to take a long trip at the end of the day than in the beginning of the day. Such a time-dependent nature in destination choice can be represented in the model by introducing an interaction term that involves time-of-day and travel time variables. Similar terms can be used to represent a possible history dependency in destination choice.

The emphasis placed in this study on temporal dependencies of activity and travel requires that time of day be explicitly incorporated into the framework of the model. This leads to the formulation of the model where the attraction measure of a destination is defined as a function of the time of day as well as its attributes, such as retail employment. This is based on the belief that activity

TABLE 1 Variables Considered in Model Development

Variable Group	Abbreviation	Definition
Destination attributes (A_j)		
Population	POP	ln[(zonal population)/1,000]
Retail employment	REMP	ln[(zonal retail employment)/1,000]
Nonretail employment	NREMP	ln[(zonal nonretail employment/1,000]
Travel time (d)		
Origin-destination travel time	d_{ij}	Time (min) obtained from off-peak network skim trees
Home-origin travel time	d_{ih}	
Home-destination travel time	d_{jh}	
0-1 dummy for $d_{ih} - d_{jh}$	d_s	1 if $d_{ih} - d_{jh} > 0$; 0, otherwise.
Accessibility index (I_a)		
Accessibility of zone i for activity type a at time t	$I_a(i,t)$	$\ln \Sigma_j \exp[V_a(i,j,t)]$
Time of day (t)		
Function of time of day		$t, t^2, \exp(t), \exp(-t), \ln(t)$; t is in hours
Store hours (0-1)	$D_s(t)$	1 if t is between 9:00 a.m. and 9:00 p.m.; 0, otherwise
Business hours (0-1)	$D_b(t)$	1 if t is between 8:00 a.m. and 5:00 p.m.; 0, otherwise
Activity history (y)		
Activity engagement in previous chains in		Binary variable: 1 if activities of the indicated type were pursued in the trip chains previously made
Personal business	PBNS01H	
Social recreation	SREC01H	
Shopping	SHOP01H	
Serving passengers	SRVP01H	
Activity engagement in the current chain in		Binary variable: 1 if an activity of the indicated type has been pursued in the current trip chain
Personal business	PBNS01C	
Social recreation	SREC01C	
Shopping	SHOP01C	
Serving passengers	SRVP01C	
Current activity		Binary variable: 1 if the current activity is of the indicated type
Personal business	PBNS	
Social recreation	SREC	
Shopping	SHOP	
Serving passengers	SRVP	
Out-of-home time	OHTIME	Cumulative amount of time spent so far outside home for both trips and activities
No. of chains	CHAINS	Cumulative number of home-based trip chains made so far
Socioeconomic attributes (e)		
School-age children	SCHLAG	Binary variable: 1 if the age of youngest child in the household is between 5 and 12; 0, otherwise
Household role	ROLE	Binary variable: 1 if an individual is female and not employed; 0, otherwise
No. of children	CHLDRN	Number of household members who are 17 years old or younger and not married
Household income	INCOME	Median value of the household's annual gross income category ($)
No. of cars	CARS	Number of cars available to the household

and destination choices are made on the basis of the availability of functions that accommodate and facilitate the pursuit of intended activities, but not the physical existence of the facilities themselves (31). For example, a department store after it has closed in the evening should not be counted as a destination opportunity. In order to represent such temporal variations in the availability of opportunities, variables were developed that represent typical business and store hours. Note that the inclusion of the time-of-day-dependent attraction measures in the model offers a mechanism for evaluating the changes in activity and travel patterns that correspond to changes in the availability over the 1-day period.

The alternatives of the non-home-based activity choice model include four activity types (personal business, shopping, social recreation, and serving passengers) and two returning-home options (i.e., returning home temporarily, and returning home permanently). The last alternative implies that the out-of-home activity schedule of the day will be terminated. This study hypothesizes that choice of activity type depends on the distribution of opportunities around the origin location. For example, if the individual who has just completed an out-of-home activity is located in an area with intense commercial development, the individual may be more likely to pursue additional shopping activities. This effect is represented by the following accessibility index defined for location i (9,10):

$$I_a(i,t) = \ln \left\{ \Sigma_j \exp\left[V_a(i,j,t)\right] \right\} \quad (3)$$

where the $V_a(i,j,t)$'s are obtained from the non-home-based destination choice models. This index represents the expected maximum utility; that is, the expected utility of that destination that is most attractive to the individual who intends to pursue activity of type a and is located at i at time t. Inclusion of the $I_a(i,t)$'s for all activity types would indicate the relative attractiveness of the respected types of activities. Note that the accessibility measure is a function of the travel time to opportunities from i, and may be viewed as a proxy variable for travel cost for activity engagement from that location. Also note that the measure is time-of-day dependent, and that the activity choice model takes on the form of the nested logit model. Another spatial factor considered in the non-home-based activity choice model is the distance of the origin location from the home base.

The home-based destination choice model has the same logit form. The model development effort considers the traditional factors (d_{ij} and A_j) and also the variables representing the past history of activity and travel as well as time of day. The home-based activity choice model is similar to the one developed in the earlier effort (2). The types of variables included in the four types of activity and destination choice models are given in Table 2.

TABLE 2 Variables Examined in Development of Activity and Destination Choice Models

	Destination Choice Model		Activity Choice Model	
Variable Group	Home Based	Nonhome Based	Home Based	Nonhome Based
Destination attributes (A_j)	X	X		
Travel Time				
d_{ij}	X	X		
d_{ih}				X
d_{jh}		X		
Accessibility index $[I_a(i,t)]$			X	X
Time of day (t)	X	X	X	X
Activity history (y)	X	X	X	X
Socioeconomic attributes (e)	X	X	X	X

Note: X indicates that the variable group is examined in the model development.

DATA SET

The statistical analysis of this study uses a subsample of the 1977 Baltimore travel demand data set. The subsample is almost identical to the one used in the previous effort of activity choice model formulation (2), and includes adult individuals whose daily trip records are complete and consistent, and whose households had access to a car. Only those individuals who did not make work trips on the survey day are analyzed in this study. The activity choice analysis excludes weekend trip records because of the obvious differences in time use patterns between weekdays and weekends. The sample screening criteria, which are similar to the ones used in previous studies (1,2,6,8,26,32), are used here with the intention of controlling the sample so that the travel environment within which the individuals' activity and travel patterns develop will be relatively homogeneous. Such a controlled sample and the resulting internal homogeneity are believed to aid in the effort of interpreting the results and inferring causal relationships by simplifying these tasks. The current sample is slightly smaller than the one used in the previous study (2) because a new set of screening criteria, which are concerned with the consistency of spatial information, is introduced in this study. Because only aggregate measures of the attributes of destination alternatives are available in the data file, the analysis uses 70 planning districts as the alternatives of destination choice.

The resulting sample used in the development of activity choice models includes 343 home-based choices and 550 non-home-based choices in 343 trip chains made by 209 individuals. Unfortunately, the sample size is not large enough for estimating destination choice models by activity types, and weekend observations had to be included in order to facilitate the estimation process. The sample used for the development of the destination choice models of this study includes 647 home-based choices and 354 non-home-based choices with nonhome destinations.

ESTIMATION RESULTS

The key question in the empirical analysis is whether the traditional destination attraction measures and origin-destination travel time adequately explain destination choice behavior, or whether additional factors, such as the distance between an alternative destination and the home base, should be introduced into the model. Another interesting aspect to be examined is the interplay of temporal and spatial factors. The temporal variables may influence destination choice, and the temporal and spatial factors may jointly or independently affect activity choice.

Non-Home-Based Destination Choice Models

The model coefficients are estimated by using, as the choice set, 12 randomly selected destination alternatives and the destination that was actually

TABLE 3 Non-Home-Based Destination Choice Models

	Activity Type					
	Personal Business[a]		Social-Recreation		Shopping	
Variable	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
d_{ij}			-0.0824	-3.87		
$\ln(t)d_{ij}$	-0.0592	-6.02			-0.0640	-6.29
d_{jh}	-0.1391	-5.89			-0.1792	-6.46
$\ln(t)d_{jh}$			-0.0617	-7.38		
POP	0.3363	1.55	0.5410	2.85		
(REMP)$D_s(t)$	0.3557	2.37			0.6871	5.18

Note: Variables are defined in Table 1.
[a]Includes serving passengers.

TABLE 4 Summary Statistics for Table 3

	Activity Type		
	Personal Business[a]	Social-Recreation	Shopping
L(0)	-307.79	-266.76	-333.44
L(β)	-151.84	-153.58	-134.79
Sample size	120	104	130
$\rho^2 = 1 - L(\beta)/L(0)$	0.507	0.424	0.596
χ^2	311.90	226.36	397.30
df	4	3	3

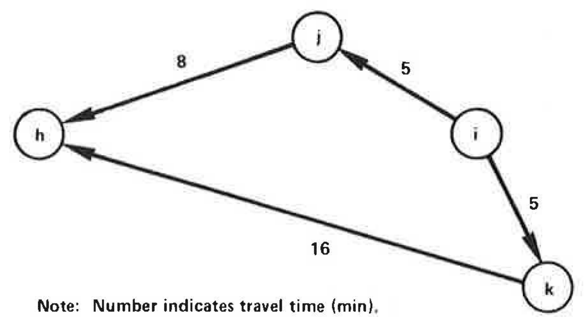
Note: L(β) = log-likelihood with the model coefficients; L(0) = log-likelihood without any coefficients; and the chi-square values presented are defined as -2[L(0) - L(β)].
[a]Includes serving passengers.

chosen. Because of the insufficient sample size, two activity types--personal business and serving passengers--had to be grouped together in this non-home-based destination choice modeling.

The final models selected (Tables 3 and 4), after examination of a large number of alternative model formulations, are rather simple and involve only three groups of variables: time of day, travel time, and attraction measures of the destination. Models with interaction terms consisting of travel time measures and history variables or socioeconomic attributes were estimated to evaluate the effects of the latter variables on destination choice, especially on the trip length. Effects of the socioeconomic attributes and activity history, however, were not evident from the model specification effort of this study.

The estimation results confirm the hypothesized importance of the travel time between the destination and home. Inspection of the t-statistics indicates that this variable is at least as significant as the traditional origin-destination travel time. Its significance is especially notable for the social-recreation activity. The same conclusion can be obtained from the data in Table 5. The table presents another set of destination choice models that were estimated without the time-of-day effects in order to make the comparison of the relative effects of d_{ij} and d_{jh} easier. It can be seen that d_{jh} has a coefficient value and t-statistic close to those of d_{ij} in the models for personal business and shopping. In the model for social-recreation, both its coefficient and t-statistic are twice as much as those of d_{ij}.

The estimated effect of this variable is illustrated here by using the example discussed earlier. Suppose that an individual at a nonhome location (i) is making a destination choice for shopping. There are two opportunities, j and k, with identical attributes (i.e., $A_j = A_k$) and the same distance away from i ($d_{ij} = d_{ik}$). Opportunity k, however, is twice as far from the home base as opportunity j (d_{kh} = 16 min, and d_{jh} = 8 min). This is shown in Figure 1. The conventional destination choice model would predict the identical choice probability for the two opportunities. The estimated shopping des-



Note: Number indicates travel time (min).

FIGURE 1 Effect of residence location on non-home-based destination choice.

TABLE 5 Alternative Non-Home-Based Destination Choice Models Without Time-of-Day Effects

	Activity Type					
	Personal Business		Social-Recreation		Shopping	
Variable	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
d_{ij}	-0.1532	-6.01	-0.0814	-3.83	-0.1674	-6.27
d_{jh}	-0.1367	-5.79	-0.1684	-7.38	-0.1803	-6.49
POP	0.3423	1.59	0.5493	2.90		
(REMP)$D_s(t)$	0.3548	2.37			0.6888	5.26

Note: Variables are defined in Table 1.

tination choice model of Table 3, on the other hand, yields the predicted choice odds of

$$P_a(i,j,t)/P_a(i,k,t) = \exp[-0.1792(8 - 16)] = 4.2,$$

namely, the opportunity closer to home is more than 4 times likely to be chosen than the other.

The way the individual chooses his destinations in a series of trips cannot be characterized as the movement of a frog jumping between lily pads, and the location of the destination relative to the home base is an important concern to the individual. This conjecture, now supported by the empirical result, has not been incorporated into the standard destination choice or trip distribution analysis. It is proposed in this study that the destination-to-home travel time be considered in formulating non-home-based destination choice models, such that the individuals' movements can be characterized appropriately as human behavior, not as the random movement of a frog.

Another new feature of the models developed here is the inclusion of time-of-day variables. This is based on the belief that the time of day influences not only activity choice (2,31) but also the choice of the location to pursue the activity. Only few studies (33) have examined the temporal dependencies of destination choice behavior. The present estimation results indicate that, as the day proceeds and the time constraint becomes tighter, the negative effect of origin-destination travel time increases for personal business (including serving passengers) and shopping. In other words, the individuals tend to make shorter non-home-based trips for these two activity types toward the end of the day. For the social-recreation activity, the time variable is combined with the destination-to-home travel time, implying a somewhat different effect of time that social-recreational activity locations tend to cluster around the home base in the later part of the day.

Non-Home-Based Activity Choice Model

As activity choice models have been developed in the previous study in an aspatial context (2), the present effort concentrates on the introduction of spatial elements into the model and examination of their effects on activity choice. The discussion on the estimated coefficients of those variables that are included in the previous model development effort is not repeated in this paper. The interested reader is referred to the work by Kitamura and Kermanshah (2). The spatial variables considered in modeling the non-home-based choice are accessibility indices [$I_a(i,t)$'s] and the distance from the origin to home (d_{ih}). The model specification effort is summarized in Table 6, and the final model is given in Table 7.

The set of four accessibility indices evaluated according to Equation 3 for the respective activity types is first added to the previously developed base model (2). The indices as a group have a chi-square value of 7.08, with degrees of freedom (df) of 4, and not significant at $\alpha = 0.05$. Inspection of the individual coefficients indicated that the coefficient of the index for personal business alone was significantly different from zero, but its sign was negative, thus contradicting the hypothesis that higher accessibility induces activity engagement. The final model (Table 7) was developed by eliminating insignificant accessibility indices while adding the origin-to-home travel time variable to the two alternatives--temporary return to home and permanent return to home. These variables are significant as a group ($\chi^2 = 13.04$, with df = 4) and the coefficients of the accessibility indices are positive and lie between 0 and 1 in agreement with the derivation

TABLE 6 Development of Non-Home-Based Activity Choice Models

Model	Log-Likelihood	χ^2 of Added Coefficients	df
Constant terms alone	-872.45		
Base model[a]	-763.43	220.04	29
Base model + $I_a(i,t)$	-759.89	7.08	4
Final model [with d_{ih} and $I_a(i,t)$]	-756.91	13.04	4

[a]See paper by Kitamura and Kermanshah (2).

TABLE 7 Non-Home-Based Activity Choice Model

	Activity Type											
	Personal Business		Social-Recreation		Shopping		Serving Passengers		Temporary Home		Permanent Home	
Variable	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic	Coefficient	t-statistic
Constant	-1.1103	-1.95	-4.0188	-4.03	-3.4003	-3.79	-4.0440	-4.01	1.2745	1.50		
PBNS	1.6092	1.78	1.5712	1.89	2.6850	2.50			1.0873	1.34	1.0873	1.34
SREC	1.1335	1.90			1.6292	1.99			0.3576	0.74	0.3576	0.74
SHOP					0.8279	1.15			-0.4479	-1.26	-0.4479	-1.26
t			0.2336	3.85	0.1055	1.96	0.2020	3.19				
exp(-t/10)									0.4610	0.26		
exp(t/10)											0.0561	6.09
CHLDRN			-0.2398	-1.82								
SCHLAG							0.7363	1.86				
CARS									0.0672	0.66	-0.2486	-2.30
PBNS01C	1.1346	2.26			0.3966	1.04						
SREC01C			0.4855	1.12	0.7013	1.79						
SHOP01C					1.4350	3.36						
SRVP01C							1.1578	2.68				
OHTIME											-0.0002	-0.28
CHAINS											-0.1987	-1.60
$I_{srec}(i,t)$[a]			0.2727	1.42								
$I_{srvp}(i,t)$[b]							0.3115	1.69				
d_{ih}									-0.0500	-2.51	-0.0561	-3.14

Note: $L(0) = -985.46$; $L(C) = -872.45$; $L(\beta) = -756.91$; $\rho^2 = 0.132$; N = 550. [Note that L(C) is the log-likelihood with constant terms alone.]
[a]Accessibility index for social-recreation.
[b]Accessibility index for serving passengers.

of the nested logit model (9,10). The result indicates, however that the accessibility variables provide rather marginal improvement to the goodness-of-fit of the model, and the socioeconomic, time-of-day, activity history variables and origin-to-home travel time are the major factors that explain non-home-based activity choices.

The origin-to-home travel time has a significant negative coefficient for both temporary and permanent returns to home. It appears that the variable reflects the sequencing tendency that the locations visited after a completion of nonhome activity tend to be closer to home. Accordingly, the individuals exhibit a higher probability of returning home from a location closer to home. The analysis, which used a large-scale data set from the Detroit metropolitan area (26), showed the same tendency of sequencing. The finding obtained from the two data sets may imply risk-averse planning behavior of the individuals. Locations closer to the home base require less time to visit, and the visits can be arranged with flexibility because they will fit into short time slots available during the day. On the other hand, visiting locations farther from home requires more time and allows less scheduling flexibility. Presumably individuals prefer to make less flexible visits first because of the uncertainty involved in trip making and activity engagement (e.g., it may not be possible to visit farther locations later because of tightened time constraints). A previous study (1) suggested similar planning behavior under uncertainty in sequencing activities in a trip chain. Daily time-use patterns reported in the literature (34) also suggest that less flexible activities tend to be pursued first during the day.

Home-Based Choice Models

Unlike the case of the non-home-based model, the time-of-day variables played less important roles in the home-based destination choice models and the model for personal business alone included the variable. Accordingly, the models gave the appearance of the traditional destination choice models. Inclusion of the accessibility indices in the home-based activity choice model resulted in a small improvement of the log-likelihood value and the indices as a group were not significant at $\alpha = 0.05$. The final model excluded the index for shopping because its sign was negative and insignificant. The other three indices had coefficient values between 0 and 1. However, as in the non-home-based activity choice model, these spatial variables played only marginal roles. It can be concluded that the choice of activity types, whether home based or nonhome based, is largely determined by factors other than the accessibility to opportunities [the estimation results of the home-based choice models can be found elsewhere (26)].

Residual Analysis

Underlying the use of the system of the logit models in this study is the assumption that the random disturbance terms associated with respective alternatives are statistically independent across the alternatives in a choice and also across the choices made by an individual. It appears appropriate to adopt this assumption for the destination choice models when they are formulated by activity types. Also note that the logit model is the only choice model that has been applied successfully to empirical destination choice analysis. The assumption, however, may be less appropriate when applied to a series of activity choices. For example, an individual may have a positive or negative preference for certain activities throughout a day, which can be represented only by disturbance terms that are correlated across choices. Inferring from the known results of linear-regression analysis (35), this by itself does not impose any serious estimation problems. However, the activity choice models of this study contain the history variables that may be viewed as a class of the lagged dependent variable. Presence of the correlation then may lead to inconsistent estimates when the ordinary logit estimation procedure is applied. Although it is beyond the scope of this study to develop an improved estimation procedure, an analysis was carried out to examine possible correlations of the residuals of the choice models. The results are summarized in the following paragraph [further discussions can be found elsewhere (26)].

Presence of correlations among the random disturbance terms across choices were examined by using weighted residuals (36). The residuals were evaluated for up to the sixth activity choice for each individual in the sample with more than one out-of-home activity record. The residuals were then regressed on the set of preceding residuals in order to examine the existence of correlations. The results indicated that the correlations were overall weak and were at the level that would have been expected with independent residuals. The result supports the model development effort of the study and indicates that interrelated choices can be adequately modeled by introducing variables that represent the history of the choices without assuming a complex distributional structure for the disturbance terms of a series of choices.

DISCUSSION OF RESULTS

The results of this study can be discussed from two different perspectives. One is concerned with the improvement of destination choice models toward more appropriate representation of spatial travel patterns of urban residents. The other is concerned with the development of a model system that is capable of evaluating the daily travel pattern as a whole rather than as a collection of isolated and unrelated trip segments.

The empirical analysis of this study has clearly shown that there exists a modification of destination choice models that will lead to better depiction of complex travel patterns. By introducing into the model formulation the travel time between a destination alternative and the home base, it becomes possible to represent the patterns in sequencing activity locations in a trip chain and also to better describe individuals' movement patterns that center around their residence locations. Representation of interrelated destination choices involved in a trip chain can be made by applying the destination choice models in a sequential manner.

The destination-to-home travel time is an important factor that influences non-home-based destination choice as much as the traditionally used origin-destination travel time. Judging from the statistical significance of this variable, its inclusion in the model should contribute to its predictive accuracy. Moreover, this improvement does not require any additional information to be supplied; the model can be estimated by using the standard logit estimation procedure with small-scale survey results. The study results warrant the evaluation of the predictive capability of the proposed non-home-based destination choice model in comparison with that of the conventional model, and further the development of the procedure for model application.

Another result of the non-home-based model estimation is that the valuation of travel time varies depending on the time of day, presumably because of the tightening time budget constraint toward the end of the day. This constraint on destination choice can be expressed conveniently in destination choice models.

The difficulty of developing a model system of daily travel patterns is perhaps proportional to the complexity of the behavior itself, especially the magnitudes of interdependencies among the choices. This study, together with the previous effort (1,2), has shown that the dependencies can be incorporated into the model system by use of appropriately developed variables that represent the past history of activity. The significance of the variables suggests that their omission will result in serious errors. The endogenous nature of the history variables, however, may create estimation problems when the random disturbance terms of the choice models are correlated across choices. The residual analysis conducted in connection with this study (26) indicated that such correlations are not significant. Although the effort to develop and apply improved and more versatile estimation procedures should continue, it may be appropriate to conclude that the logit model can be used to represent a series of choices and that each choice model can be separately estimated. These results and also the finding from the previous studies (1,2)--that the activity history can be represented in a simple and convenient manner--all suggest that the model structure can be kept simple and that the model system can be applied in a practical manner.

The study findings also suggest that activity and destination choices are influenced by different types of factors, with only a few affecting both. Activity choice is influenced largely by time-of-day, activity history, and socioeconomic attributes of the individuals, whereas spatial factors play only minor roles. On the other hand, the socioeconomic and history variables influence destination choice behavior to a rather limited extent.

The sequential model system developed here, with further extensions and modifications, can be used in several ways. Daily travel patterns can be reconstructed by the system by using the stochastic simulation technique, and impacts of transportation planning options can be evaluated. This reconstruction is more realistic than one by the conventional procedure because the model system accounts for the interdependencies among choices and continuity of trips. The separability of the explanatory variables, together with the previous findings (2) that socioeconomic attributes play only small roles in non-home-based activity choices, may make possible aggregative treatment of individuals when simulating their non-home-based choices; model application may be able to avoid the bookkeeping difficulties that may otherwise arise. The model can also be used to evaluate the likelihood of alternative daily travel patterns that a person may take in response to changes in various elements in the travel environment. The model will serve as a useful supplementary tool to the in-depth game-simulation technique (37) used to evaluate such responses.

The model system, as it is formulated now, is sensitive to travel time, land use variables, as well as socioeconomic variables. The inclusion of time of day offered the possibility of evaluating the effects on travel patterns of the changes in time-related factors such as store hours. The destination attraction measures that are formulated as time-of-day dependent make the model system sensitive to such changes. The estimation results, however, did not show that the accessibility indices, which are also time-of-day dependent, have an important effect on activity choice. This may be caused by the physiological rhythms inherent in human activity patterns and also to the habitual, routine time-use patterns that may be insensitive to changes in the environment. It is quite conceivable that the temporal variations in the supply of opportunities are closely correlated with the time-use patterns, making it difficult to evaluate the sensitivity of activity choices to changes in the availability of opportunities over the 1-day period.

Although it is believed that the proposed sequential model system will resolve many problems of the conventional forecasting procedure, it is of course not devoid of limitations. The model system assumes the structure of (past) history dependency. As a result, the activity and travel patterns predicted by the system may not necessarily agree with the patterns that individuals, who conscientiously plan ahead and schedule future activities, would exhibit in a different travel environment. Theoretically speaking, a future-dependent model system can be obtained from a history-dependent system (1), but practical difficulties involved therein call for other solutions. One possibility is to model the respective model components such that they reflect the individuals' planning effort. An example of such a model can be found in a recent destination choice analysis (25). The activity choice models may be made future dependent by extending the accessibility index among the time dimension to reflect the availability of opportunities during the rest of the day. Note that the system structure can be kept as history dependent after these modifications. Another task that remains to be completed is the development of activity duration models. This is being undertaken while focusing on the relationship between activity durations and their locations, time of day, and history (38). Interrelationships among activity duration, activity choice, and activity sequencing also remain as a subject of future investigation.

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