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Identifying Time and History Dependencies of Activity Choice

RYUICHI KITAMURA AND MOHAMMAD KERMANSHAH

In this study a sequential model of activity patterns is formulated that consists of time- and history-dependent models of activity choice. This analytical framework is used to identify time-of-day and history-dependent characteristics of activity choice by statistically testing a series of hypotheses. The results indicate that the simplest expression of the history of activity engagements is an adequate descriptor, and also that non-home-based activity choice is conditionally independent of the activities in the previous chains, given the activities pursued in the current trip chain. Interdependencies of activity types across trip chains are also characterized by estimated model coefficients. The results of the study indicate that the decisions associated with the entire activity pattern can be decomposed into interrelated activity choices whose conditional dependencies can be statistically evaluated.

The way individuals schedule their daily activities and organize their itineraries has immediate impacts on the spatial and temporal distribution of trips, or needs for trips, in an urban area. Therefore, representing how the choice and scheduling of activities are done and how travel patterns are formed are critical elements in travel-demand forecasting as well as in basic travel-behavior research (1-3). This is especially so when attempting to forecast the impacts of novel changes in the travel environment or when seeking a transportation policy that will accomplish given objectives most effectively.

The mechanism by which trips as induced demand are generated is complex. Even when only scheduling is considered (i.e., when and in what order a given set of locations is visited and how these visits are arranged into trip chains), there are numerous scheduling possibilities. Choice of activities and their locations further complicates the problem. Constraints that govern the behavior are not limited to monetary and time budgets as in the classical utility maximization framework in economics, but include spatial and temporal fixity constraints associated with the respective activities (4), interpersonal linkage constraints (5), and other types of constraints that portray the travel environment of each individual (6). The interrelated activity choices underlying an activity-travel pattern are dependent on the time of day, as many previous studies on time use have indicated (7,8). Previous empirical evidence (9, and paper by Kitamura elsewhere in this Record) at the same time indicates that the choices are dependent on history, i.e., the set of activities already pursued on that day.

These aspects of daily activity and travel behavior are all of particular importance for the understanding and forecasting of the behavior. In particular, the time-of-day and history dependencies of activity choice may be viewed as the most fundamental elements, whose adequate representation will lead to representation of other important aspects of the behavior as well. For example, the preferences in forming a set of activities in a trip chain can be described by sequential probabilities of activity choice when their history dependencies are appropriately incorporated (see paper by Kitamura elsewhere in this Record). By specifying the structure of the time-of-day and history dependencies and estimating the model statistically, an important objective can be accomplished: characterization of activity and travel patterns along the time dimension. When the model includes exogenous factors that are related to changes in the travel environment or in the population characteristics, then the model serves as a tool for forecasting possible changes in activity and travel behavior.

An extension of a previous sequential analysis of activity linkages is described in this study (see paper by Kitamura elsewhere in this Record), and an attempt is made to identify the structure of time and history dependencies of activity choice. The objective is to demonstrate that the conditional dependency of activity choice can be properly represented by a simple model structure that can be statistically estimated and conveniently applied to practical problems. The dependency is examined by testing a set of hypotheses and by inferring its characteristics. Alternative model specifications are examined, and home-based and non-home-based activity-choice models are estimated.

The results of hypothesis testing and model estimation indicate that a simple indicator of the history of the behavior--a set of binary variables each representing whether an activity of a given type has been pursued--best explains the activity choice. Home-based choice that determines the first activity in a trip chain is shown to be dependent on the past activity engagement, but non-home-based choice is conditionally independent of the activities in the previous chains, given the activities pursued in the present chain. Strong time-of-day dependencies in activity choice, whose temporal variations are well captured by the model, are also shown in the study. The results of the study consistently indicate that the time and history dependencies of the behavior can be represented by a simple model structure, and suggest that a set of sequential activity-choice models can be developed to represent and forecast the characteristics of daily activity and travel behavior.

BACKGROUND

Because individuals develop their daily itineraries while considering the set of activities to be pursued during a certain period, activity choices (or travel choices) cannot be analyzed individually, but the interdependencies among them must be adequately accounted for. Such interdependencies have been noted across different time periods of a day (9), or among activity choices in a trip chain (see paper by Kitamura elsewhere in this Record). Another aspect of activity and travel behavior is the existence of various types of constraints that govern behavior (5,6,10). Many constraints are unobservable if typical survey data are the only information sources. All these characteristics of tripmaking make causal representation of the behavior quite complex.

A possible representation of activity- and travel-choice behavior uses the concept of optimization together with the assumption that the observed activity-travel pattern is the one preferred the most by the individual (11). Let a_n be the type of nth activity, t_n be its starting time, d_n be its duration, and ℓ_n be the location where the activity is pursued. For simplicity, only these four aspects are considered here. By letting $a = (a_0,\ldots,a_{N+1})$, and so forth, the activity- and travel-scheduling behavior can be formulated as follows:

$$\text{Maximize } U = U(a,t,d,\ell) \tag{1}$$

$$\text{Subject to } t_{n+1} - (t_n + d_n) = s(\ell_n, \ell_{n+1}, t_n + d_n)$$

$$0 \leq t_0, \ldots, t_{n+1} \leq T; \quad \ell_0 = \ell_{N+1} = \text{home}$$

$$0 \leq d_n$$

$$a_n \in C, \ell_n \in E \quad n = 1, \ldots, N$$

$$g_i(a,t,d,\ell) = 0 \quad i = 1, \ldots, G$$

where

s(i,j,s) = travel time between locations i and j when the trip begins at time s,

N = total number of sojourns (including intermediate sojourns at home),

C = set of activity types, and

E = set of opportunity locations.

The first constraint simply represents the temporal continuity condition, the second represents the condition where the individual's path must originate and terminate at home within time T, and the third condition is the nonnegativity of activity durations. Additional constraints are represented in a general form by function g in this formulation. Function U, which may be called a utility function, includes not only the type and duration of each activity but also its starting time. This is because the regularity and rhythms in time use patterns strongly suggest that the utility of an activity of a given type is a function of the time when it is pursued.

Not quite obvious from this formulation is the discrete nature of the optimization problem, i.e., resources are not always allocated to all activities and some activities simply may not be pursued at all during a given period. Accordingly, the classical constrained optimization approach (12,13) is not applicable to this problem if this formulation is to be applied to disaggregate data where behavior during a relatively short period (e.g., 1 day) is recorded. The problem is also much more complex than that of a traveling salesman. Not only the order of visits, but also the number of visits, their locations, the way these visits are organized into trip chains, and their timing must be endogenously determined. When this complexity as a mathematical programming problem is combined with the additional constraints, the task involved in representing the behavior as an optimization problem and obtaining its solution appears to be prohibitive. Perhaps the number of possible activity-travel patterns recognized by the individual is relatively small (2) because of the constraints and limited information the individual has, but this is not the case for the observer who attempts to analyze and predict the behavior without comparable knowledge on microscopic factors that influence each individual.

[The approach taken by Adler and Ben-Akiva (14) avoids these difficulties and at the same time retains the simultaneous structure of analysis by modeling the behavior as a discrete choice among alternative activity-travel patterns. The approach is quite effective in analyzing characteristics of activity-travel choice. Determining the probability with which a given pattern will be chosen, however, requires that all feasible patterns be enumerated.]

An alternative approach to the analysis of activity and travel patterns is a sequential one, which is based on the following identity:

$$\Pr(a,t,d,\ell) = \prod_{n=0}^{N} \Pr[a_{n+1}, t_{n+1}, d_{n+1}, \ell_{n+1} | a_{(n)}, t_{(n)}, d_{(n)}, \ell_{(n)}] \tag{2}$$

where $a_{(n)}$ is a vector of the first (n + 1) elements of a, i.e., $a_{(n)} = (a_0,a_1,\ldots,a_n)$; and $t_{(n)}$, $d_{(n)}$, and $\ell_{(n)}$ are similarly defined. This approach, where choices are analyzed one by one in a sequence, represents the preferences in choosing patterns given that, if $U(a,t,d,\ell) \leq U(a',t',d',\ell')$, then $\Pr(a,t,d,\ell) \leq \Pr(a',t',d',\ell')$. The approach has an advantage in that it reduces the size of the problem to a manageable one, and the preferences to the entire pattern can be correctly represented if the conditional dependencies of the sequential probabilities are properly incorporated. A recent study indicated that the sequence of activities in a trip chain can be adequately represented by a simple sequential model, whereas failure to capture the conditional dependency leads to erroneous results (see paper by Kitamura elsewhere in this Record).

An interesting example of a sequential approach can be found in Horowitz (15), where the concept of time-dependent utility is used. A similar concept is used in the present study, but emphasis is on the identification of time and history dependencies of the behavior. The works by Damm (9), Damm and Lerman (16), and Jacobson (17) are noted here because certain facets of the complex behavior are carefully selected in these studies so that the size of the problem can be reduced and the analysis can be carried out meaningfully and effectively by using econometric methods.

There are two tasks involved in developing a sequential model of activity and travel for forecasting purposes. The first is the identification of the structure of the conditional dependency, which is a prerequisite for proper functioning of the model. Because representing the history as in Equation 2 will not serve practical purposes because of its excessive information requirements, some simple yet accurate forms must be sought. The second task is to relate the sequential probabilities to exogenous factors, especially those that closely represent planning options and policies.

The time factor is of critical importance in developing such a probabilistic model of activity choice because of the strong correlation between time of day and activity, as noted earlier. Incorporating the time variable is also important because it will make probabilistic representation of the constraints that affect the behavior more meaningful and accurate. In particular, the effect of time constraints cannot be appropriately represented without the time variable [e.g., Hagerstrand's prism is approximated by time-dependent probabilities of spatial choice (18)]. A previous study (19) indicated that married women who are not employed and who are in the childbearing stage tend to return home early in the evening; this can be viewed as being a result of the constraints imposed by family responsibilities. The sequential probabilities can depict such constraints when they are specified as time-of-day dependent and when they include appropriate variables that represent individuals' attributes.

APPROACH

In this study the activity choice along the time dimension is analyzed, and the main focus of the study is on the identification of the time- and history-dependent nature of the choice. The spatial aspect is suppressed in this study. The model specification and estimation effort is based on the following formulation of the sequential probability:

$$
\begin{aligned}
&dPr[a_{n+1}, t_{n+1} | a_{(n)}, t_{(n)}] \\
&\quad = Pr[a_{n+1} | t_{n+1}; a_{(n)}, t_{(n)}]\ dPr[t_{n+1} | a_{(n)}, t_{(n)}] \\
&\quad = Pr[a_{n+1} | t_{n+1}; a_{(n)}, t_{(n)}]\ dPr[t_{n+1} \\
&\qquad - t_n | a_n, t_n; a_{(n-1)}, t_{(n-1)}]
\end{aligned}
\tag{3}
$$

where $a_{(n)} = (a_0, a_1, \ldots, a_n)$ as before, and $t_{n+1} - t_n$ is called the sojourn duration in the nth state that, in this formulation, includes the duration of the nth activity and trip time to its location (the activity duration and trip time are treated separately in the empirical analysis presented in later sections). The sequential probability is expressed as a product of activity-choice probability given the time of the choice and the probability density of the duration of the nth sojourn. The focus of this study is on the first element: time- and history-dependent activity-choice probability.

The activity-choice probability is formulated as a function of time, history, and other factors by using the multinomial logit structure, i.e.,

$$
\begin{aligned}
&Pr[a_{n+1} = j | t_{n+1} = t; a_{(n)}, t_{(n)}, y] \\
&\quad = \exp\{V_j[t, a_{(n)}, t_{(n)}, y]\} / \sum_k \exp\{V_k[t, a_{(n)}, t_{(n)}, y]\}
\end{aligned}
\tag{4}
$$

where y is a vector of socioeconomic attributes of the individual and t is the time of day. The conditional dependence in Equation 3 is now represented in the model by its explanatory variables that represent the history of the behavior and the time of day. It is therefore assumed that the random error terms of the model possess all the desirable properties, including their statistical independence across the choices in the sequence. Although it is possible to use more elaborate formulations of the random elements (20,21), which may lead to an interesting examination of history dependence, this study does not extend its scope to analysis of the dependence structure of the unobservables. [Note that the validity of the error term specification depends on model specification, and it is an empirical issue in that sense (22).]

The time dependency of activity choice is represented by introducing time variables into the logit function. For example, suppose that the effect of time of day on relative activity-choice odds can be expressed by gamma functions, i.e.,

$$
\begin{aligned}
&\exp[V_j(t, \ldots)] / \exp[V_i(t, \ldots)] = [K t^a \exp(-bt)] \\
&\quad \div [t^c \exp(-dt)] \qquad a,b,c,d,K \geq 0
\end{aligned}
\tag{5a}
$$

(Note that neither the numerator nor the denominator is necessarily a distribution function.) Then,

$$
V_j(t, \ldots) - V_i(t, \ldots) = \ln K + (a - c)\ln t - (b - d)t \tag{5b}
$$

Although it is not possible to determine these parameter values uniquely, the time effects can be represented simply by introducing t and $\ln(t)$ into function V. The model specification effort in the following sections also considers polynomial and exponential functions of t.

By using this framework, various hypotheses regarding the nature of the conditional dependencies can be examined statistically and the model can be specified subsequently. This study rejects without examination the null hypothesis that activity choice is independent of time of day. The critical hypotheses that need to be examined statistically include the following:

1. Activity choice is independent of the set of activities pursued in the past;
2. Activity choice is conditionally independent of the set of activities pursued in previous trip chains, given the activities pursued in the current chain;
3. Given whether activities of respective types have been pursued or not, activity choice is conditionally independent of the number of times the activities were pursued;
4. Given whether activities of respective types have been pursued or not, activity choice is conditionally independent of the amount of time spent in the past for each type of activity;
5. Activity choice is independent of the number of trip chains made in the past; and
6. Activity choice does not depend on the time spent since the individual left home.

An appropriate representation of the history of an activity pattern is sought through the examination of these hypotheses, and the nature of history dependency is inferred from the results.

DATA SET AND VARIABLES

In this study the statistical analysis of a sample from the 1977 Baltimore travel demand data set is used. Analysis of nonwork activities is the main subject of this study, and only those individuals who did not make work trips on the survey day are analyzed. The records in the data set are screened, and individuals who were younger than 18 years old, who did not hold a driver's license, and whose households did not have a car available are eliminated. A detailed description of the screening criteria used can be found in Kitamura (see paper elsewhere in this Record). The screened sample used in this study includes 927 activity choices in 356 trip chains made by 217 individuals.

Activities are defined in terms of the trip-purpose categories in the data set, which are grouped into four types: personal business, social-recreation, shopping, and serve passengers. Home-based activity-choice models are estimated with these activity types as alternatives. Two additional categories enter models of non-home-based choice: temporary return to home and permanent return to home for the day [similar binary classification of the home state can be found in Lerman (23)]. Accordingly, the non-home-based models are estimated with six alternatives.

As variables representing individuals' attributes, the age, sex, education, employment status, household income, household size, number of children, family life cycle, household role, and car ownership are examined in this study. The household-role variable is defined in terms of the sex and employment status of the individual. The life-cycle-stage variable is defined in terms of the marital status of the adult members, their ages, and the age of the youngest child. The definitions of those variables that appear in the models presented in this paper are given in Table 1.

Table 1. Definition of explanatory variables in activity-choice models.

Variable and Abbreviation	Definition
School-aged children (SCHLAG)	Binary variable: 1 if the age of the youngest child in the household is between 5 and 12, 0 otherwise
Household role (ROLE)	Binary variable: 1 if the individual is a female and not employed, 0 otherwise
No. of children (CHLDRN)	No. 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)	No. of cars available to the household
Time of day (t)	Time of days in hours; the study period begins at 4:00 a.m. when t = 4.0, and ends at 4:00 a.m. the next day when t = 28.0
Activity engagement in previous chains in	
Personal business (PBNS01H)	Binary variable: 1 if activities of the indicated type were pursued in the trip chains previously made
Social-recreation (SREC01H)	
Shopping (SHOP01H)	
Serve passengers (SVPS01H)	
Activity engagement in the current chain in	
Personal business (PBNS01C)	Binary variable: 1 if activities of the indicated type have been pursued in the current trip chain
Social-recreation (SREC01C)	
Shopping (SHOP01C)	
Serve passengers (SVPS01C)	
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
Current activity	
Personal business (PBNS)	Binary variable: 1 if the current activity is of the indicated type
Social-recreation (SREC)	
Shopping (SHOP)	
Serve passengers (SVPS)	

HOME-BASED ACTIVITY-CHOICE MODEL

Because the examination of alternative hypotheses regarding the structure of time and history dependencies is an important concern of the study, a series of models, each being developed to test a specific hypothesis, is presented in this section. The first in the series involves only socioeconomic attributes of the individual as its explanatory variables (model 1 of Table 2). The model as a whole is significant with $\alpha = 0.005$, but the amount of variation explained by the model is relatively small ($\rho^2 = 0.0256$). Nevertheless, meaningful relationships are found from the estimation result. The coefficient of the variable that represents the presence in the household of children aged between 5 and 12 (SCHLAG) indicates a positive contribution of this variable to the engagement of serve-passenger trips. The role variable (ROLE), which has a value of 1 when the individual is female and not employed, indicates that these individuals carry out shopping and serve-passenger trips more often than do the others. The coefficient of the number of children (CHLDRN) indicates the negative effect that the presence of children has on the engagement in social-recreation by the adult members.

The fit of the model improves when time variables are introduced into the model with six additional coefficients (model 2). The log-likelihood ratio statistic has a value of $\chi^2 = 46.14$, with degrees of freedom (df) = 6 for the six new coefficients. Clearly the time of day has a substantial influence on activity engagement. The nature of the time dependency of activity choice is presented later in this section by using a history-dependent model.

Examination of the history dependence of home-based choice uses the following variables to represent the past history of activities: 0-1 binary variables, each representing whether an activity of a given type has been pursued in the past; the number of sojourns made for each activity type; and the cumulative amount of time spent for each activity type. These variables are used because of their conciseness as summary variables of the history. The possible effects on activity choice of the exact sequence of the past activities, their respective durations, and their occurrence times are considered to be negligible.

Each set of history variables is tested, and on the basis of its significance the nature of history dependence is inferred. The results indicate that the simplest representation of the history--the set of binary indicators of activity engagement--explains the choice better than any other sets examined here (model 3). Although the other sets of variables are all significant, they do not explain as large a portion of variations as does the set of binary variables. Whether the individual has pursued an activity of a given type or not does affect the home-based activity choice, but how many times and how long the activities were engaged in do not have as decisive an effect. This rather unexpected result is encouraging because of its implication that the history of behavior can be expressed in quite a simple manner in representing the condi-

Table 2. Home-based activity-choice models.

Variable	Activity Type: Personal Business Coefficient	t-Statistic	Social-Recreation Coefficient	t-Statistic	Shopping Coefficient	t-Statistic	Serve Passengers Coefficient	t-Statistic
Model 1[a]								
Constant			-0.5797	-0.86	-0.0485	-0.08	0.0698	0.11
SCHLAG							0.8583	2.76
ROLE					0.4968	1.99	0.5702	1.92
CHLDRN			-0.1895	-2.02				
ℓn (INCOME)	0.2877	1.23	0.5893	2.37	0.2801	1.23		
Model 2[b]								
Constant			-3.3830	-5.55	-10.984	-2.01	5.0561	1.01
SCHLAG							0.8585	2.76
ROLE					0.4787	1.89	0.5743	1.93
CHLDRN			-0.2469	-2.52				
ℓn (INCOME)	0.3299	1.37	0.5063	2.02	0.2136	0.92		
t	-0.4240	-1.57	-0.2050	-0.76	-0.7928	-2.85		
ℓn (t)	4.1127	1.21	0.4227	1.18	10.498	2.90		
Model 3[c]								
Constant			-3.7499	-0.65	-11.876	-2.10	4.8241	5.25
SCHLAG							0.6289	1.89
ROLE					0.3895	1.44	0.6413	1.96
CHLDRN			-0.2086	-2.07				
ℓn (INCOME)	0.3542	1.42	0.5169	1.97	0.2093	0.87		
t	-0.3522	-1.22	-0.1310	-0.46	-0.7315	-2.56		
ℓn (t)	3.7260	1.04	4.0236	1.08	10.634	2.89		
PBNS01H			-0.8605	-1.98	-1.6576	-3.34	-1.0187	-1.90
SREC01H			0.6166	0.91	0.8793	1.25	1.5780	2.20
SHOP01H			-0.2300	-0.47	-0.5662	-1.09	-0.2014	-0.36
SVPS01H			0.3252	0.52	0.9638	1.67	1.8125	3.14

Note: Sample = 356 home-based activity choices. $L(\beta)$ = log-likelihood with the model coefficients, $L(C)$ = log-likelihood without explanatory variables (constant terms alone), $L(0)$ = log-likelihood without any coefficients, and $\rho^2 = 1 - L(\beta)/L(C)$. The chi-square values presented are defined as $-2[L(C) - L(\beta)]$.

[a] $L(0) = -493.52$, $L(C) = -490.27$, $L(\beta) = -477.70$, $\chi^2 = 25.14$ (df = 7), and $\rho^2 = 0.0256$.
[b] $L(\beta) = -454.63$, $\chi^2 = 71.29$ (df = 13), $\rho^2 = 0.0727$, and χ^2 for the set of time variables = 46.14 (df = 6).
[c] $L(\beta) = -434.36$, $\chi^2 = 111.81$ (df = 25), $\rho^2 = 0.114$, and χ^2 for the set of activity indicators = 40.54 (df = 12).

tional dependency of activity choice. Another history descriptor--the number of chains completed in the past--was found to be insignificant.

These models are developed primarily to examine alternative hypotheses; thus the selections of explanatory variables are not necessarily finalized as they are presented in Table 2. A similar model is estimated after eliminating some of the insignificant variables of model 3, and its coefficients for the binary variables are given in Table 3 to indicate how the past engagement in an activity of one type affects the choice of another activity type. In the table the estimated set of coefficients is adjusted by adding a constant to the coefficients for each activity type. The value of the constant is arbitrary, and that value that makes the row sum of the adjusted coefficients zero is used in developing the table.

The result indicates that engagement in personal

Table 3. Effects of activity engagements in previous chains on home-based activity choice.

Activity Engagement in Previous Chains[a]	First Activity of Current Chain: Personal Business	Social-Recreation	Shopping	Serve Passengers
Personal business	0.8278	0.0602	-0.7564	-0.1317
Social-recreation	-0.4109	-0.4109	0.0612	0.7606
Shopping	0.1024	0.1024	-0.3072	0.1024
Serve passengers	-0.6059	-0.6059	0.1782	1.0336

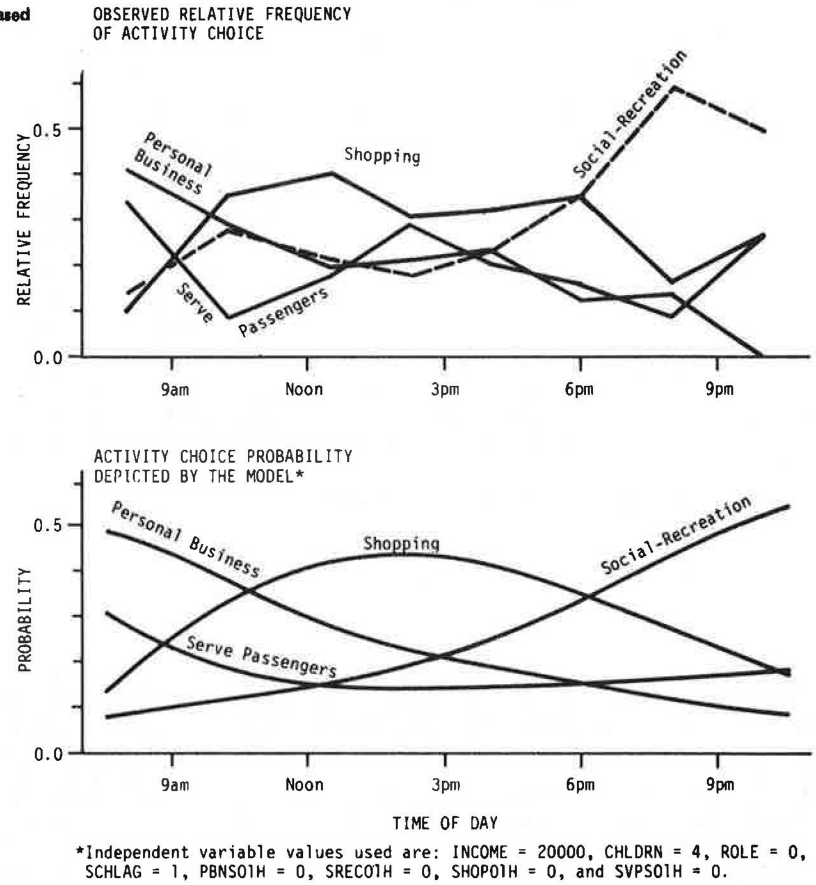
[a] 1 if engaged, 0 otherwise.

business in the past has a positive influence on the choice of the same activity type later. The same tendency can be found for serving passengers; choices of personal business or serve-passenger trips are positively correlated across trip chains. The negative diagonal value for shopping indicates that people tend not to pursue shopping in two or more trip chains; it suggests that people have been consolidating their shopping trips into fewer trip chains. A negative coefficient of social-recreation on personal business indicates that there are patterns in sequencing activities across trip chains, and personal business tends not to be pursued if the previous chains included social-recreation trips. The pattern found here is quite similar to that found earlier as to the sequencing of activities within a trip chain (see paper by Kitamura elsewhere in this Record).

The time-dependent nature of home-based activity choice can be seen in Figure 1, which presents against the time axis both the observed relative frequencies of chosen activity types and the choice probabilities depicted by the model. The observed shopping frequency coincides naturally with the typical stores' hours, and it peaks in the early afternoon. Personal business tends to be pursued in the morning, whereas the relative frequency of social-recreation increases toward the end of the day. The serve-passenger activity has a rather irregular pattern with peaks in the early morning (chauffeuring children or workers, perhaps), early afternoon, and late evening.

The data in the figure indicate that the observed tendencies are well replicated by the estimated

Figure 1. Observed and predicted probabilities of home-based activity choice.



activity-choice model. The activity-choice probabilities are evaluated by assuming the independent variable values, as shown in the figure; therefore, they are not readily comparable with the observed relative frequencies that represent the entire sample. Nevertheless, satisfactory agreement is shown in the figure between the observation and the prediction by the model. The irregularities in the probability of serve-passenger trips are not well represented by the model, although the overall tendency is captured. If it is shown that the observed irregularities are not caused by the small sample size, then the model specification must be altered to reflect them.

NON-HOME-BASED ACTIVITY CHOICE

Non-home-based activity choice is studied in a manner similar to home-based activity choice by examining hypotheses of history and time dependencies of the choice. Additional hypotheses that are included here are concerned with the relative magnitudes of the dependencies on the activities in the previous trip chains and on those in the current chain. Also of interest are the effects of elapsed time since the beginning of the chain and the total out-of-home time on the decision to return home. The variables used to represent the history of the behavior include 0-1 activity engagement indicators defined for the current chain and for the chains previously made, total activity time by activity type in the current chain and in the previous chains, number of sojourns made by activity type in the current chain and in the previous chains, number of chains made in the past, elapsed time since the individual left home, and the cumulative out-of-home time spent.

The models tested and their goodness of fit are given in Table 4 without presenting the estimated coefficients of the respective models. The conclusions of this hypothesis testing are summarized as follows:

1. Given the history of the current chain, activity choice is conditionally independent of the activity engagement in the previous chains;
2. The number of sojourns made and the time spent for each activity type in the current chain are correlated with the observed activity choice, but the 0-1 activity engagement indicators best explain the choice;
3. The elapsed time since the beginning of the chain is not a significant factor influencing the decision to return home;
4. The non-home-based choice is most closely correlated with the time of day, whereas activity history and socioeconomic attributes of the individual have less effects on choice; and
5. The choice of the next activity is affected by the type of current activity.

Perhaps the most significant finding is that non-home-based activity choice is conditionally independent of the history of activity engagement in the previous chains. (No sets of history variables for the previous chains were statistically significant when they were included in the model together with a set of history variables for the current chain.) This may appear to indicate that activity choice repeats itself and that all chains made by an individual are probabilistic replicas of each other. However, this is not the case because the home-based choice that determines the first activity of a chain

Table 4. Alternative specifications of non-home-based activity-choice models.

Model No.	Origin Indicator	Time of Day	Socioeconomic	History Indicators Set 1	History Indicators Set 2	L(β)	χ^2 (df = 4)
1[a]	X	X	X			-813.585	_[b]
2	X	X	X	X		-810.396	_[c]
3	X	X	X	X	No. of sojourns, past	-807.659	5.474
4	X	X	X	X	Activity time, past	-806.258	8.276
5	X	X	X	X	0-1 activity, past	-808.649	3.494
6	X	X	X	X	No. of sojourns, cumulative	-803.366	14.060
7	X	X	X	X	Activity time, cumulative	-807.694	5.404
8	X	X	X	X	No. of sojourns, present	-800.499	19.794
9	X	X	X	X	Activity time, present	-805.467	9.858
10	X	X	X	X	0-1 activity, present	-797.013	26.766
11[a]	X		X	X	0-1 activity, present	-842.981	_[d]
12[a]		X	X	X	0-1 activity, present	-808.820	_[e]

Note: The origin indicator includes three binary variables: PBNS, SREC, and SVPS. Time of day is represented by three independent variables: t, exp(t), and exp(-t). The set of socioeconomics includes four variables: number of children, 0-1 binary variable for presence of school-aged children, income, and number of cars. The history indicators include two sets of variables: set 1 consists of cumulative out-of-home time, elapsed time, and number of chains made previously; and set 2 includes the variables indicated in the table. X indicates that the variable is included in the model.

[a]These models are tested against model 10; the other models are tested against model 2.
[b]Effect of history, χ^2 = 33.14, df = 7.
[c]Reference model.
[d]Effect of time of day, χ^2 = 91.94, df = 5.
[e]Effect of direct linkages, χ^2 = 23.61, df = 10.

is dependent of the past history, as discussed in the previous section. Thus the history dependence of the non-home-based choice is indirectly represented through the history dependence of the home-based choice.

The strong time dependency of non-home-based choice must be noted. The contribution of the five time coefficients to the explanatory power of the model is represented by a chi-square statistic of 91.9 (df = 5), whereas that of the socioeconomic variables is 16.1 (df = 4), and that of the history variables is 33.1 (df = 7). Obviously, time of day is the most critical determinant of the non-home-based choice.

The final form of the non-home-based activity-choice model that was selected on the basis of the hypothesis testing results is given in Table 5. A set of three binary variables (PBNS, SREC, SHOP) is used to represent the type of current activity, i.e., the activity just completed at the time of the transition to the chosen activity. Many of the nine coefficients that apply to these variables are significant and indicate the strength of direct linkages between activity types. Compared with the home-based choice models, fewer socioeconomic attribute variables are used in the model. The number of children and the presence of school-aged children have the same effects on activity choice as in the home-based choice model.

The coefficients of the car-ownership variable are positive (but not significant) for the temporary return to home, and they are negative for the permanent return to home. The indication is that the individuals from households with more cars tend to make more trip chains, but the number of sojourns in a chain may tend to be fewer. A similar tendency was found in a previous study that analyzed a 1965 Detroit data set (24). The negative coefficients of the cumulative out-of-home time and the number of chains are quite noteworthy, although they are not statistically significant at α = 0.05. The coefficients apply to the permanent return to home and imply that the more time the individual has spent outside home and the more chains he has made, the less likely he is to terminate his out-of-home activity pursuit of the day. The result suggests that

Table 5. Non-home-based activity-choice model.

Variable	Personal Business Coefficient	Personal Business t-Statistic	Social-Recreation Coefficient	Social-Recreation t-Statistic	Shopping Coefficient	Shopping t-Statistic	Serve Passengers Coefficient	Serve Passengers t-Statistic	Home Coefficient	Home t-Statistic	Absorbing Home Coefficient	Absorbing Home t-Statistic
Constant	-0.5306	-1.01	-2.4408	-3.08	-2.7799	-3.19	-2.5840	-2.89	0.9237	1.17		
PBNS	1.4074	1.59	1.7789	2.17	2.7420	2.57			1.1598	1.44	1.1598	1.44
SREC	1.1186	1.96			1.8215	2.25			0.5169	1.09	0.5169	1.09
SHOP					0.9220	1.29			-0.3812	-1.10	-0.3812	-1.10
t			0.1809	3.23	0.0884	1.74	0.1490	2.52				
exp(-t/10)									1.3261	0.77		
exp(t/10)											0.0520	6.04
CHLDRN			-0.2116	-1.66								
SCHLAG							0.4998	1.31				
CARS									0.0580	0.59	-0.2478	-2.32
PBNS01C	1.2327	2.62			0.4349	1.16						
SREC01C			0.6284	1.51	0.6789	1.76						
SHOP01C					1.4726	3.53						
SVPS01C							1.2009	2.83				
OHTIME											-0.0009	-1.30
CHAINS											-0.1498	-1.26

Note: L(0) = -1023.090, L(C) = -905.722, L(β) = -794.778, χ^2 = 221.89 (df = 26), and ρ^2 = 0.123. Sample is based on 571 non-home-based activity choices.

individuals pursue either very few or very many activities on a given day. This may be a result of activity scheduling over a longer time span, e.g., a week.

In summary, the hypothesis testing and model specification efforts presented in these two sections have indicated that the activity choice is dependent on both the time of day and the history of the activity. But the structure of the history dependency is rather simple. The binary history indicators that represent whether activities of respective types have been pursued in the past or not are correlated with the activity choice more strongly than is the number of sojourns or the time spent for each activity type in the past. Furthermore, non-home-based activity choice is found to be conditionally independent of the activity history in the previous chains, given the history in the current chain. It appears that activity choice is dependent more strongly on more recent activities. The significance of the variables that represent the direct linkages also indicates this.

DISCUSSION OF RESULTS

Identifying the dependencies across a series of activity choices is critically important for the development of a practical tool for analyzing and forecasting daily activity and travel behavior. In this study the structural form of a sequential model of activity patterns was formulated, and conditional probabilities of activity choice that used the multinomial logit structure were specified. This framework was then used to examine the nature of time and history dependencies in activity choice with the assumption that time of day and the history of the behavior are the most fundamental factors that influence activity choice.

The examination of a series of hypotheses indicated that the simplest representation of the history of the behavior--a set of binary activity engagement indicators--is an adequate descriptor and best explains activity choice. Non-home-based activity choice is strongly affected by time of day and also by current activity type, but socioeconomic attributes of the individual and history variables have less influence on non-home-based choice than on home-based choice. Non-home-based activity choice was also found to be conditionally independent of the activity history in the previous chains, given the activity history in the current chain, whereas home-based activity choice had interdependencies in the activity types across trip chains. The results of the study are encouraging and indicate that a set of simple models that can be conveniently estimated is capable of representing individuals' daily activity and travel behavior together with the interdependencies across the choices involved. The study has indicated that the decisions associated with the entire activity pattern can be decomposed into interrelated activity choices whose conditional dependencies can be statistically evaluated.

The models presented in this study, however, are not immediately applicable to practical problems because the types of exogenous variables included are limited. This limitation is mainly caused by the aspatial nature of the study. The models must be extended to spatial activity-choice models with land use and transportation network variables introduced as explanatory variables. Note that the land use variables in this context must be defined in terms of both the spatial distribution of opportunities and their availabilities along the time dimension. When land use variables are defined in this manner, then the activity choice can be related to the availabilities of various opportunities in different time periods of a day.

Such effort of modeling the activity choice in the spatial dimension will encounter a new problem: representation of the attractiveness of an opportunity, or a group of opportunities such as a zone. This is not a trivial task when the assumption of the conventional approach that a travel choice can be separated from the rest and can be analyzed independently is discarded, and when the interdependencies across the choices are acknowledged. The interdependencies imply that a choice of an opportunity is influenced by both the past and intended future behavior. The conventional formulation of the attractiveness of a zone that uses the attributes of that zone alone is not adequate when the individual has in mind additional activities to be pursued elsewhere. In other words, when trip chaining is considered, the traditional definition of the attraction becomes inadequate, and the attractiveness of a zone as an origin from which the next activity site will be reached must be evaluated and incorporated into the attraction measure. This can be done by using the concept of expected utility, in which the attractiveness of a zone is a function of not only its own attributes but also those of other zones. Another aspect, which was not emphasized in this study, is the structural relationship between the activity duration and activity choice. It may be the case that the relationship varies depending on the time of day or on the past history of the behavior. Examination of the interdependence structure of the unobservables also remains as a subject of future research.

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Equilibrium Traffic Assignment on an Aggregated Highway Network for Sketch Planning

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An application of the equilibrium traffic assignment algorithm on a simplified highway network, such as might be used for sketch planning, is described. Analysis zones in the assignment are also substantially larger than in most conventional traffic assignments. The algorithm for equilibrium traffic assignment is introduced, followed by a discussion of the problems with equilibrium traffic assignment in a sketch-planning application. Next, the network coding procedures for the case study are examined. Results of the sketch-planning assignment are then evaluated against a comparable regional assignment of the same trips. Finally, there is a discussion of how this research fits into the programs of a transportation planning agency.

An application of equilibrium traffic assignment to sketch planning is presented in this paper. Trips are assigned onto an aggregated network with a limited number of links, nodes, and zone centroids. One arterial link in the sketch-planning network is equivalent to a number of links in a conventionally coded regional highway network, and one sketch-planning zone is substantially larger than a zone in the regional assignment at the same location. The traffic assignment algorithm used in the study converges to approximately equal path travel times for multiple paths between origin-destination zone pairs. The algorithm is available to most transportation planning agencies.

A major portion of the paper is spent on a comparison of this sketch-planning assignment with a regional traffic assignment of a large trip table onto a detailed coded highway network. This comparison is complicated by the different number of intrazonal trips in the two traffic assignments; therefore, a procedure was developed to determine the significance of the additional intrazonal trips in the sketch-planning assignment. Vehicle miles of capacity and travel, vehicle hours, and average speeds predicted by the two assignments are summarized at the regional and zonal levels.

In the introductory sections of the paper the equilibrium traffic assignment algorithm and the network coding procedures for the sketch-planning network are documented. A simple method for aggregating links and summing regional link capacities into sketch-planning link capacities is then described. The question of the best network aggregation procedure is not considered. Moreover, a solution of this network aggregation problem was not an objective of the research, but rather a data requirement. The principal concern of this paper is to demonstrate a satisfactory correspondence between