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16. Abstract

This research aims to advance the state of the art in daily activity-travel modeling. It represents one of the first attempts to comprehensively model the activity-travel patterns of workers as well as non-workers in a household. The activity-travel system will take as input various land-use, socio-demographic, activity system, and transportation level-of-service attributes. It will provide as output the complete daily activity-travel patterns for each individual in the household.

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REPRESENTATION AND ANALYSIS PLAN AND DATA NEEDS ANALYSIS FOR THE ACTIVITY-TRAVEL SYSTEM

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"Activity-Based Travel Demand Modeling for Metropolitan Areas in Texas"

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CHAPTER 1. INTRODUCTION

ACTIVITY-BASED TRAVEL DEMAND MODELING

Since the beginning of civilization, the viability and economic success of communities have been, to a major extent, determined by the efficiency of the transportation infrastructure. To make informed transportation infrastructure planning decisions, planners and engineers have to be able to forecast the response of transportation demand to changes in the attributes of the transportation system and changes in the attributes of the people using the transportation system. Travel demand models are used for this purpose; specifically, travel demand models are used to predict travel characteristics and usage of transport services under alternative socioeconomic scenarios, and for alternative transport service and land-use configurations. The need for realistic representations of behavior in travel demand modeling is well acknowledged in the literature. This need is particularly acute today as emphasis shifts from evaluating long-term investment-based capital improvement strategies to understanding travel behavior responses to shorter-term congestion management policies such as alternate work schedules, telecommuting, and congestion-pricing. The result has been an increasing realization in the field that the traditional *statistically-oriented* trip-based modeling approach to travel demand analysis needs to be replaced by a more *behaviorally-oriented* activity-based modeling approach.

The trip-based approach uses individual trips as the unit of analysis and usually includes four sequential steps: trip generation, trip distribution, mode choice, and traffic assignment. In the trip-based approach, the time of day of trips is either not modeled or is modeled in only a limited way. Most commonly, time is introduced by applying time-of-day factors to 24-hour travel volumes at the end of the traffic assignment step or at the end of the trip generation step. A fundamental conceptual problem with the trip-based approach is the use of trips as the unit of analysis. Separate models are developed for home-based trips and non-home based trips, without consideration of dependence among such trips. Further, the organization (scheduling) of trips is not considered; that is, there is no distinction between home-based trips made as part of a single-stop sojourn from home and those made as part of a multiple-stop sojourn from home. Similarly, there is no distinction between non-home based trips made during the

morning commute, evening commute, from work, and as part of pursuing multiple stops in a single sojourn from home. Thus, the organization of trips and the resulting inter-relationship in the attributes of multiple trips is ignored in all steps of the trip-based method. This is difficult to justify from a behavioral standpoint. It is unlikely that households will determine the number of home-based trips and the number of non-home based trips separately. Rather, the needs of the households are likely to be translated into a certain number of total activity stops by purpose followed by (or jointly with) decisions regarding how the stops are best organized. Similarly, the location of a stop in a multistop sojourn (or tour) is likely to be affected by the location of other stops on the tour. Such multistop tours are becoming increasingly prevalent (see Refs 1, 2) and ignoring them in travel analysis means *"discarding an element that is doubtless important in the individual's organization of time and space"* (Ref 3). Also, in a multistop tour, the trip-based approach fails to recognize that the travel mode for all constituting trips will be the same. The travel mode chosen will depend on various characteristics of all trip legs (and not any one single trip) and, consequently, these trips cannot be studied independently.

The behavioral inadequacy of the trip-based approach, and the consequent limitations of the approach in evaluating demand management policies, has led to the emergence of the activity-based approach to demand analysis.

The activity-based approach to travel demand analysis views travel as a derived demand; derived from the need to pursue activities distributed in space (see Ref 4 or Ref 5). The approach adopts a holistic framework that recognizes the complex interactions in activity and travel behavior. The conceptual appeal of this approach originates from the realization that the need and desire to participate in activities is more basic than the travel that some of these participations may entail. By placing primary emphasis on activity participation and focusing on sequences or patterns of activity behavior (using the whole day or longer periods of time as the unit of analysis), such an approach can address congestion-management issues through an examination of how people modify their activity participations (for example, will individuals substitute more out-of-home activities for in-home activities in the evening if they arrived early from work due to a work-schedule change?).

The shift to an activity-based paradigm has also received an impetus because of the increased information demands placed on travel models by the 1990 Clean Air Act Amendments (CAAAs). These amendments require the inclusion of transportation control measures (TCMs) in transportation improvement programs for MPOs in heavily polluted non-attainment areas and, by state law, for all non-attainment areas in California. Some TCMs, such as high occupancy vehicle (HOV) lanes and transit extensions, can be represented in the existing modeling framework; however, non-capital improvement measures such as ridesharing incentives, congestion pricing, and employer-based demand management schemes cannot be so readily represented (Ref 6). The ability to model both individual activity behavior and interpersonal linkages between individuals, a core element of activity modeling, is required for the analysis of such TCM proposals. The CAAAs also require travel demand models to provide (for the purpose of forecasting mobile emission levels) link flows at a high level of resolution along the time dimension (for example, every 30 minutes or an hour as opposed to peak-period and off-peak period link flows) and also to provide the number of new vehicle trips (i.e., cold starts) which begin during each time period. Because of the simplistic, "individual-trip" focus of the trip-based models, they are not well-equipped to respond to these new requirements (see Ref 7). Since the activity-based approach adopts a richer, more holistic approach with detailed representation of the temporal dimension, it is better suited to respond to the new requirements.

The activity-based approach requires time-use survey data for analysis and estimation. A time-use survey entails the collection of data regarding all activities (in-home and out-of-home) pursued by individuals over the course of a day (or multiple days). Travel constitutes the medium for transporting oneself between spatially dis-located activity participations. The examination of both in-home and out-of-home activities facilitates an understanding of how individuals substitute out-of-home activities for in-home activities (or vice-versa) in response to changing travel conditions. This, in turn, translates to an understanding of when trips are generated or suppressed.

It is important to note that administrating time-use surveys is similar to administrating household travel surveys, except for collection of in-home as well as out-of-home activities. The information elicited from respondents is a little more extensive in time-use surveys compared to travel surveys, but experience suggests that the respondent burden or response

rates are not significantly different between time-use and travel surveys (see Ref 8 for an extensive discussion). On the other hand, such intensive scrutiny of data helps identify data inconsistencies, which might go unchecked in the trip-based approach (for example, there might be “gaps” in an individual's travel diary because of non-reporting of several trips; these will be identified during data preparation for activity analysis, but may not be identified in the trip-based approach since it highlights individual trips and not the sequence between trips and activities).

COMPREHENSIVE DAILY ACTIVITY-TRAVEL SYSTEMS

Activity-based travel analysis has seen considerable progress in recent years. Several studies have focused extensively on the participation of individuals in single activity episodes, and on one or more accompanying characteristics of the episode such as duration, location, or the window of time in which the episode occurs. The effect of household interdependencies on individual activity choice is represented in these models in the form of simple measures such as presence of working spouse, number of adults, and household structure.

Researchers have also made significant attempts to broaden the scope of earlier studies to examine activity episode patterns; that is, multiple activity episodes and their sequence over a particular time-span, typically a day. Some of these studies focus only on activity episode scheduling and consider the generation of activity episodes and their attributes as exogenous inputs. Other studies analyze both activity episode generation and scheduling, yielding more comprehensive activity-travel models. Such comprehensive models can potentially replace the conventional trip-based travel demand models.

This research aims to advance the state of the art in daily activity-travel modeling. It represents one of the first attempts to comprehensively model the activity-travel patterns of workers as well as non-workers in a household. The activity-travel system will take as input various land-use, socio-demographic, activity system, and transportation level-of-service attributes. It will provide as output the complete daily activity-travel patterns for each individual in the household.

The model system will be based on ongoing activity-based modeling efforts at the University of Texas at Austin. In this report, the structure of an initial framework is discussed, along with data needs for implementing the model system. Possible ways of extending and refining the frameworks are also presented.

OUTLINE OF REPORT

This report is organized as follows. Chapter 2 reviews the relevant literature to provide an understanding of the state of the art in the activity-travel modeling. The chapter identifies common modeling approaches. It reviews existing operational systems for modeling daily activity-travel patterns. Their commonalities and differences in modeling scope, features and methodologies are discussed.

Chapter 3 describes a possible framework for modeling the activity-travel patterns for workers and for non-workers. The chapter further discusses how these two frameworks compare to each other and to the models reviewed in Chapter 2. The data needs for the integrated framework is also discussed.

Chapter 4 summarizes the report and concludes by outlining the next steps in estimating the components of the framework.

CHAPTER 2. LITERATURE REVIEW

MODELING APPROACHES

Econometric Models

The econometric modeling approach involves using systems of equations to capture relationships among macroscopic indicators of activity and travel, and to predict the probability of decision outcomes. These models explore how activity and travel patterns are related to land use and socio-demographic characteristics of the traveler. The main criticism of the econometric approach is that it does not explicitly model the behavioral mechanisms underlying activity engagement and travel. This limits the richness of the behavior theories that can be incorporated into the model system (Ref 9). Nevertheless, the family of econometric models - ranging from discrete choice models, hazard duration models and limited-dependent variable models - remains a powerful approach to activity-travel analysis. Its strength lies in allowing the examination of alternative hypotheses about the causal relationships among behavioral indicator. The approach has led to the development of several operation model systems that will be reviewed later in the report.

Computational Process Models

Computational process models (CPM) have been proposed as an alternative approach to modeling the complex activity-travel behavior. A CPM is basically a computer program implementation of a production system model, which is a set of rules in the form of condition-action (IF-THEN) pairs that specify how a task is solved (Ref 10). The modeling approach focuses on the process of decision-making and captures heuristics and short-cuts that are involved, as opposed to assuming overriding paradigms such as utility maximization. Hence, the modeling approach offers more flexibility than econometric models in representing the complexity of travel decision making.

A major drawback of CPM is that they lack a statistical error theory, which makes it more difficult to generalize their outcomes and apply them to policy evaluation (Ref 11). In addition, the models generally have very challenging data requirements for model estimation,

application and validation, and the assumptions they make about the search process have not been validated (Ref 12).

REVIEW OF OPERATIONAL DAILY ACTIVITY-TRAVEL MODELS

BB System

Bowman and Ben-Akiva (Ref 13) develop a model (hereafter referred as the BB system) in which they consider the daily activity-travel pattern as a set of tours, where a tour is defined as the travel from home to one or more activity locations and back home again. Tours are sub-divided into "primary" and "secondary" tours based on activity priority. Activities are prioritized based on the purpose of the activity, with work activities having the highest priority, followed by work-related, school, and all other purposes. Within a particular purpose, activities with longer durations are assigned higher priorities. The tour of the day with the highest priority activity (the "primary" activity) is designated as the "primary" tour and others are designated as "secondary" tours.

Based on the notion of activity priority and the assumption that people use a priority-based decision process, the BB framework represents the daily activity-travel pattern by three attributes: the "primary" activity, the "primary" tour (characterized by the number, purpose and sequence of activity stops), and the number and purpose of "secondary" tours. The tours are represented by the time of day (categorized broadly into a.m. peak, p.m. peak, mid-day, and other), destination (discrete traffic analysis zones) and mode. The spatial and temporal resolution of the model is, therefore, quite limited. Furthermore, the model's four-way classification of activity purposes (home, work, school, other) is also somewhat arbitrary and limited. As the authors acknowledge, a more customary classification distinguishing subsistence, maintenance and leisure may be more appropriate.

The BB framework uses the pattern and tour as joint units of analysis, but does not accommodate stop-level attributes such as activity duration of a stop and travel time to a stop. It also does not model number of stops in a tour. Attributes of "secondary" activities in a tour are not modeled either. Furthermore, the BB framework does not accommodate space-time

interactions since it does not model the temporal dimension of activity participation, except for the departure time to/from the primary activity of a tour.

The BB system models various tour/pattern attributes using a joint nested logit model. The nested logit model has been used quite extensively in travel demand modeling. But its use in the BB system has limitations. First, a particular hierarchy of decisions has to be selected from among several possible structures. Unfortunately, different hierarchal structures can produce quite different estimation results. Second, when there are several layers (nests) of decisions, the logsum parameters associated with the nests have to conform to an increasing ordering from the bottom to the top and should all be bounded in the 0-1 interval. In general, these consistency requirements can often be violated. Third, the BB system is estimated sequentially because simultaneous estimation becomes cumbersome when there are several nests. However, it is now well established that the sequential estimation can produce substantially different estimates than a simultaneous full-information method. Also, the standard errors using the sequential estimation technique underestimates actual standard errors, which may lead to incorrect conclusions about the effect of variables. Finally, the BB system adds nests as more activity pattern attributes are included in the modeling structure. The current BB model system includes only a part of the attributes characterizing the entire daily activity-travel pattern. It does not include the modeling of the time of day, mode and destination of the secondary stop in tours. The nesting complexity increases as these dimensions of the activity pattern are included or as the number of stops/tours in the daily activity pattern increase.

STPG

Kitamura et al. (Ref 14) present a sequential, simulation approach to the generation of daily activity-travel patterns. The model, referred as the Synthetic Travel Pattern Generator (STPG), considers an individual's daily activity-travel pattern as a series of activities, each characterized by the type of, the duration of, the location of, and the mode of travel used for the activity. Every pair of successive activities implies the presence of a trip.

The STPG system assumes that the variation in an individual's activity-travel pattern is random and that each possible pattern occurs with a certain probability. This probability is expressed as a product of a series of conditional probabilities, each representing the

dependency of the attributes of an activity on the past history of activity engagement and travel. This dependency reflects, for instance, that the mode choice for a trip starting from a non-home origin is strongly conditioned by the mode used for the preceding trip. It is therefore likely that the destination of the trip is dependent on the mode used.

The STPG system comprises a number of model components for computing the probabilities. A group of multinomial logit models are designed to determine the work or school location for each individual who is employed or a student. Two separate models, which are simple probabilistic models, are used to determine the departure timing and the location choice of the first trip of the day. The activity type choice models are formulated as multinomial logit models. The activity durations models take on the form of Weibull distribution models. The destination choice models are formulated as multinomial logit models by activity type and by trip origin. The choice is zone based. The mode choice models comprise a series of mode transition matrices. After establishing the probabilities from these models, the system sequentially generates the activities according to the probabilities through Monte Carlo simulation.

The STPG has been estimated and validated using results of the 1991 home interview travel survey conducted by the Southern California Association of Governments (SCAG), along with accompanying land use and network data defined for 127 traffic analysis zones. Approximately half of the data are used for estimation and the other half for validation. The validation results suggest that overall the models perform well for nonworkers. Higher discrepancies are found for workers and students. This is attributed to the fact that the STPG does not incorporate any mechanism to represent fixities in individuals' daily activity patterns, such as work and school schedules. Another major drawback of the STPG is the absence of mechanisms for accommodating space-time constraints that govern individuals' movement. The authors note this problem as one challenge for the future extension of the system.

AMOS

SAMS (Sequenced Activity-Mobility System) (Ref 15), is an integrated dynamic micro-simulation system that aims to endogenously forecast socio-demographic change, land use development, vehicle holdings, as well as travel demand, network performance, and air

quality. At the heart of SAMS is AMOS, the activity-mobility simulator, that simulates household activities and travel over time and space. The other model components of SAMS include: a dynamic network simulator (NET), a vehicle transactions simulator (VTS), a socio-demographic simulator (SEDS), an urban systems simulator (USS), and an emissions module.

AMOS adopts the concept of adaptation as the governing behavioral principle in activity-travel making. The model simulates the adaptation process of individuals to a change in the travel environment by modifying his or her activity-travel pattern.

AMOS comprises five major components. First, the Baseline Activity-Travel Pattern Analyzer reconstructs the sample individuals' travel patterns from travel diary data. It also develops indicators of travel patterns characteristics that feed into the Response Option Generator. Given these indicators, together with household and personal attributes, and network and land use characteristics of the change in the travel environment, the Generator simulates the cognitive process in which each individual devises alternative travel options, prioritizes them and selects possible options. Once the individual sorts out the available options, the next step is to experiment with the options. For each option that might be exercised, the Activity-Travel Adjuster modifies the baseline pattern by activity re-sequencing, activity re-linking, mode and destination assignment, and trip timing adjustment. The Modifier then examines the feasibility of the resulting modified activity-travel pattern using a rule base. Knowing the consequences of an option, the individual would proceed to decide how good a particular adjusted activity-travel pattern is. This is implemented in the Evaluation Module by assigning a utility measure to the modified pattern using time-use utility functions. Finally, the Acceptance Routine compares the patterns generated and determines whether the search should continue or one of the patterns generated should be adopted. The output of the AMOS micro-simulation is the modified and accepted travel patterns that represent individuals' response to travel environment changes.

Bowman and Ben-Akiva (Ref 12) identify a number of weaknesses in AMOS. First, since the Response Option Generator is policy specific, the system requires custom development for each policy to be studied. Second, validation is needed for each specific policy response model, yet the availability of revealed preference data for this validation is very unlikely.

Third, the system does not forecast long run effects. Fourth, each application of the model would require the exogenous forecast of a baseline schedule. The structured search sequence implemented in the system may inadequately represent the actual search process undertaken by individuals.

PCATS

PCATS (Prism Constrained Activity-Travel Simulator), proposed by Kitamura and Fujii (Ref 16), is a micro-simulator of individuals' activity engagement and travel within Hagerstrand's prism. In defining the prisms for each individual, the framework divides a day into periods of two types: "open" periods and "blocked" periods. "Blocked" periods represent times when an individual is committed to performing "fixed" activities, such as work. The complement of a set of "blocked" periods is a set of "open" periods, in which an individual has the option of traveling and engaging in "flexible" activities.

PCATS first determines the "blocked" periods for each individual. Given the speed of travel, the ending time and location of a "blocked" period and the beginning time and location of the subsequent "blocked" periods, an individual's activity and travel are contained within a time-space prism. The individual is assumed to judge whether or not there is enough time to perform any free activities at the beginning of the current open period. If there is enough time, the person makes a decision about the type of activity to pursue and, then, the location and mode. The person then determines whether to engage in another activity. If the person decides to engage in another activity, he or she will determine the time to stop the current activity or will engage in the current activity until the latest time in the prism. If there is not enough time for free activities, he goes to the location of the next fixed activity.

In PCATS, the probability associated with a daily activity-travel pattern is decomposed into a series of conditional probabilities, each associated with an activity episode or trip. In this sense the current version of PCATS has a sequential structure. The conditional probability of an activity episode is further decomposed to yield the following three model components: the Activity Type Choice Models, the Destination and Mode Choice Models, and the Activity Duration Model.

The Activity Type Choice model is a two-tier nested logit model. The upper tier comprises three categories of activity bundles: (A) in-home activities, (B) activities at or near the location of the next fixed activity, and (C) general out-of-home activities. Nested under the first category are two lower-level alternatives: (A-1) engage in out-of-home activities subsequently in the prism, and (A-2) do not engage in out-of-home activities within the prism. The alternatives nested under (C) include six activity types. Exactly which alternatives can be included in the choice set is determined considering prism constraints.

Given the activity type, a destination-mode pair is next determined using the Destination and Mode Choice Model, which is also a nested–logit model. The first tier concerns the choice of destination, and the second tier the conditional choice of travel mode, given the destination. In the current version of PCATS, geographical zones are used to represent locations. As is the case for activity choice, only those destination-mode pairs that are feasible in light of prism constraints and coupling constraints (primarily for auto availability) are included in the choice set.

The duration of the activity is finally determined by the activity duration model, which is a split population survival model consisting of a binary logit model for activity-engagement and a hazard-based duration model for activity duration. Once the attributes of an activity are all determined, the procedure is repeated for the next activity in the same prism. Activity and travel in each open period is thus simulated by recursively applying these model components, while considering the history of past activity engagement. The procedure is repeated until each open period is filled with activities.

A major drawback of PCATS lies in its sequential structure for the estimation of activity attributes. A potential problem with this approach is that different modeling sequences may offer quite different estimation results. In addition, activity type, activity duration, and travel time duration (or, equivalently, activity location) may be jointly determined. Ignoring the jointness can lead to self-selection bias in the estimates of the activity duration and travel time duration (or location) models. The approach also does not adequately consider interaction effects in stop-making across multiple tours in a day.

SIMAP

The SIMAP (Refs 17, 18) is an activity-based micro-simulation model that synthesizes the individual, 24-hour activity-travel pattern for households. The modeling approach is based on the belief that groups of individuals from the population show similarities in their daily activity-travel patterns. The population is segmented into three broad lifestyle groups based on employment and age: children, adults employed full time, and adults not employed full time. A number of distinct representative activity patterns (RAPs) are identified for each of the three groups. For instance, the adults employed full-time are associated with six patterns, including Standard Work, Power Work, Late Work, Work-Maintenance, Work-Discretionary and Short Activities. The RAPs then serve as seeds for synthesizing activity-travel patterns for individuals belonging to each lifestyle segments.

The system operates as follows. Initially, a household is selected from the population. For each individual household member, identified RAP choice probabilities are assigned based on the individual's socio-demographic characteristics. The first stage of the simulation process assigns a RAP to the individual based on the likelihood that the RAP would match the person's lifestyle. Conditional on the distributions associated with the assigned RAP and the time step, activities are generated for a 24-hour period in a sequential manner. The activity type, duration and location are determined for each activity based on the corresponding probability distributions derived from observed data. One drawback of the approach is that the process could get "stuck" at a time step (unable to generate an acceptable location or duration). Another drawback is that noise or outliers may skew the simulation. In these cases, an individual's pattern would be ill specified and should be discarded. The entire pattern synthesis process would need to be repeated.

The activity-travel pattern output by the first stage of the simulation process is only provisional because distances are assigned only as general parameters. To update the general parameters with specific activity locations, a GIS is used in the second stage of the simulation process to assign specific locations for the generated activities based on the relevant spatial and temporal constraints. Given the household's location and starting from the beginning of each individual's activity-travel pattern, the activity locations reflecting the activity distribution

available to the household and satisfying the constraints of the assigned pattern (e.g., distance from home and distance from the last activity) are identified within the GIS. The potential locations, either zones or x-y coordinates, are assigned a likelihood, most likely proportional to the density of nearby land-use variables depending on the activity. A location is then randomly selected based on these likelihoods. The process is repeated for all activities in the synthesized pattern.

As a separate set of RAPs are defined a priori for each of the lifestyle segments, individuals of a segment are assumed to be homogenous. That is, they are assumed to have very similar patterns regardless of their socioeconomic attributes. Thus, the problem of identifying representative and appropriate number of clusters of patterns is critical to this method. This approach, while appealing from an application standpoint, is limited in a number of ways. First, the model, in its current form, considers each individual independent of other household members. Intra-household constraints such as joint activity participation, sharing of household vehicles and timing of activity patterns are not considered. Second, mode choice is not modeled as one of the activity attributes. Third, no procedures exist at this stage for validating the methodology.

In summary, SIMAP aims to replicate the observed behavior of individuals, without modeling the decision-making process by which individuals schedule or execute activities. Hence, it is only capable of replacing the trip generation and distribution stages of the conventional travel demand modeling process. The approach is therefore limited in its capability in performing policy analysis or forecasting changes in demand due to changes in the transportation system.

ALBATROSS

ALBATROSS (Ref 19) is a multi-agent rule-based model that predicts activity patterns. The system is based on using choice heuristics to simulate behavior. The choice heuristics are represented by an exhaustive set of mutually exclusive rules that link conditions (constraints, individual or household characteristics, characteristics of the physical environment, transportation system, institutional context, policies) to particular actions, preferences or decisions.

The system consists of a series of agents that handle the data, the derivation of choice heuristics from activity diary data, the simulation/prediction of activity patterns, the assessment and reporting of model performance, the calculation of various system performance indicators and descriptive analysis of activity patterns, and the evaluation of alternative model scenarios. The core of the system is the scheduling engine that controls the activity scheduling process. The process requires as input a so-called schedule skeleton containing the fixed activities that need to be conducted by an individual, and the start times and the locations of these activities. Taking into account the space-time constraints, the scheduling process then adds activities, if any, to the skeleton and determines the profile and schedule position of these activities. As the first step of the process, flexible activities (typically shopping, social and recreational activities) are added to the skeleton. The order in which activities are considered for adding is based on pre-defined priority of candidate activities. When an activity is added, the system first determines if it is a joint activity or not, and assigning a duration (discretized time range) for the activity. The schedule position of the activity is then determined based on two decisions: the start time of the activity and the option of trip-chaining. Finally, the transportation mode and activity location are identified. Mode decisions are made at the level of tours. Interactions between mode and location choices are captured by using location information in mode selection rules.

Albatross is focused on activity scheduling. It relies on diary data to derive the rules representing the scheduling decisions. No attempt is made to explicitly model the formation of activity agendas, which are assumed as given. This is a major shortcoming when the model is used for forecasting. A more recent study (Ref 20) attempts to extend Albatross to model the formation of activity agenda. A conceptual framework is proposed that decomposes the formation of activity agendas into a number of elementary decisions arranged in a hierarchy. Each decision is modeled by means of an agent that accepts constraints as well as individual preferences and receives feedback from the agent lower in the hierarchy. The framework, however, is not yet fully operational.

MODEL COMPARISON

This chapter closes with a summary comparison of the six model systems reviewed in the previous sections. The comparison is made based on three aspects: model features, model scope and data requirements.

Model Features

Table 2.1 lists the major features of each of the six systems. The BB system rests on the econometric modeling approach. A hybrid of econometric models and simulation techniques are found in STPG and PCATS. The econometric modeling approach used in the system considers utility maximization as the underlying decision making mechanism. AMOS and SIMAP are primarily micro-simulation-based, with the former simulating the satisficing principle and the latter focusing on reproducing the probability distributions uncovered from observed data. Only ALBATROSS is an operational computational process model system. Both AMOS and SIMAP use a daily activity pattern as the unit of analysis, which requires specific modules to re-construct/extract patterns from observed data. Both STPG and PCATS consider an individual's daily pattern as a series of activities. The probability associated with a pattern is determined as a product of a series of conditional probabilities, each representing an activity episode. This inherent sequential structure is the source of some of their model limitations. The BB system, on the other hand, is limited because it does not include all activity episodes in its analysis and therefore provides an incomplete representation of daily activity patterns.

Table 2.1. Major model features.

	Modeling approach	**Unit of analysis**	**Decision mechanism**
BB system	Econometric modeling	Pattern and tour	Utility maximization
STPG	Hybrid simulation	Activity	Utility maximization
AMOS	Micro simulation	Pattern	Satisfying
PCATS	Hybrid simulation	Activity	Utility maximization
SIMAP	Micro simulation	Pattern	Observed probability replication
ALBATROSS	Computational process modeling	Pattern and activity	Heuristic

Table 2.2 summarizes a number of factors influencing a daily activity-travel pattern that some model systems capture, but others do not. First, the distinction between "fixed" and "flexible," or the prioritization of activities, are present only in BB system, PCATS and ALBATROSS. Such assumptions simplify the modeling framework; yet they may not necessarily reflect individuals' actual strategy in determining activity engagement choices. An individual's action space is confined by time use. This space-time restriction has not been incorporated in the BB system and STPG, and is only partially implemented in AMOS.

Table 2.2. Other model features.

	Activity priority/fixity	**Space/time constraints**	**Inter-stop dependency**	**Interpersonal dependency**
BB system	Yes	No	No	No
STPG	No	No	Yes	No
AMOS	No	Limited	No	No
PCATS	Yes	Yes	No	No
SIMAP	No	Yes	Limited	No
ALBATROSS	Yes	Yes	Yes	Limited

Inter-stop dependency refers to the substitutions between stops and also the consistency between stops (for example the mode used for stops on the same tour). This has not been considered in BB system, AMOS and PCATS. Inter-personal dependency refers to the effects of household members negotiating recourses, allocating tasks, and engaging in joint-activities. ALBATROSS is the only model system that takes this factor into account.

Model Scope

Table 2.3 identifies the scope of the model systems. The BB system integrates most activity-travel choice dimensions, but does to only primary stops. In addition, the system represents time in very coarse discrete categories. Both the micro-simulation models, AMOS and SIMAP, are missing some dimensions of an individual's decision-making process. Finally, all systems except SIMAP represent location choices by aggregate zones.

Table 2.3. Choice dimensions modeled.

	Activity participation	Purpose	Timing	Travel mode	Location	Sequence
BB system	Only primary stops	Only primary stops	Only primary stops	Only primary stops	Only primary stops (zonal)	Only primary stops
STPG	Yes	Yes	Yes	Yes	Discrete zones	Yes
AMOS	No	No	Yes	Yes	Yes	Yes
PCATS	Only flexible activities	Only flexible activities	Only flexible activities	Yes	Only flexible activities (zonal)	Yes
SIMAP	Yes	Yes	Yes	No	Yes	Yes
ALBATROSS	Only flexible activities	Only flexible activities	Only flexible activities	Yes	Only flexible activities	Yes

Model Application and Data Requirement

All six model systems have been implemented and tested to different degrees. A prototype of the BB system has been specified and estimated using separate data from workers and non-workers in Boston. A separate pilot implementation has also taken place in Portland, Oregon (Ref 21). As described earlier, the STPG has been estimated and validated using results provided by the SCAG. PCATS has been applied in a small validation study based on 374 sample individuals (Ref 9), and was subsequently implemented for Kyoto, Japan (Ref 22). A limited application of SIMAP using Portland data has been conducted to test the aggregate accuracy of synthesized activity-travel patterns. Activity diary data collected in 1997 in the municipalities of Hendrik-Ido-Ambacht in the Netherlands are used for developing ALBATROSS. The model is evaluated on the accuracy of reproducing (estimation) and predicting (holdout) observed patterns.

The data needs of these model systems are driven by the needs of their representation frameworks and modeling approaches. All the systems need information on person and household attributes, activity engagement records, zonal characteristics, land-use information, and transportation system level of service attributes. The activity-travel data are typically derived from cross-sectional activity travel surveys. Models that attempt to replicate the

decision making process of individuals are more data hungry than those adopting an econometric modeling approach. In order to model the adaptation behavior and longer term purchasing decisions, AMOS also requires longitudinal panel surveys. In addition, it requires stated preference data to estimate behavioral responses to system changes and new technology that have not yet been implemented.

CHAPTER 3. PROPOSED REPRESENTATION FRAMEWORK

INTRODUCTION

Bhat and Singh (Ref 23) have recently developed a comprehensive continuous-time representation framework for the daily activity-travel pattern of workers, and identified an overall analysis strategy comprising several different model components that together predict the complete daily pattern of workers. The analysis framework is based on a descriptive examination of worker patterns from several metropolitan areas in the nation. A similar effort has been conducted by Bhat and Misra (Ref 24) for non-workers. The appropriateness of these two frameworks is examined in this chapter. We first describe the frameworks and then compare them, discussing their commonalities and differences. We conclude the chapter with an outline of potential methods for integrating and extending the two frameworks.

MODEL FOR WORKERS

The Comprehensive Activity-Travel Generation for Workers (CATGW) model system developed by Bhat and Singh (Ref 23) considers household and individual socio-demographics as exogenous determinants of workday activity-travel pattern behavior. The activity-travel environment is also considered as an exogenous input. The activity-travel environment comprises both the transportation system (i.e., the network configuration of roads and the transit system) and the land-use environment (the location of opportunities for activity participation). Conditional on socio-demographics and the activity-travel environment, individuals make medium-term decisions (in combination with other individuals in their household) regarding their employment (whether to be employed, hours of work, start time at work in the morning and end time of work in the evening, location of work place, etc.), residence (type of residence, location, etc.), and car ownership. These medium-term decisions are also considered as being exogenous to the determination of the daily activity-travel pattern (the medium-term activity-travel decisions may be modeled separately prior to the modeling of the daily activity-travel pattern, see Ref 25). Furthermore, it is assumed that all individuals are at home at 3 a.m., which is considered as the start of the day.

CATGW represents a worker's workday activity-travel pattern based on the regularity and "fixity" of the work activity, and the fixity of the home location. In concept, this approach is the same as the one proposed by Damm (Ref 26) in its use of the work activity as the "peg" to represent the activity-travel pattern. However, the representation developed in CATGW is more extensive and complete than the one by Damm, who focuses only on two dimensions of activity participation: activity participation choice and activity duration. CATGW also extends Hamed and Mannering's work (Ref 27) to accommodate mode choice and number of stops decisions in the activity-travel pattern and generalizes their post-work activity involvement to include the entire day.

Figure 3.1 provides an overview of the workday activity-travel representation. The daily pattern is characterized by four different (sub-)patterns: a) Before morning commute pattern, which represents the activity-travel undertaken before leaving home to work in the morning; b) Work commute pattern, which represents the activity-travel pursued during the morning and evening commutes; c) Midday pattern, which includes all activity and travel undertaken from work during the midday break; and d) Post home-arrival pattern, which comprises the activity and travel behavior of individuals after arriving home at the end of the evening commute. The morning and evening commutes are grouped into a single work commute pattern since the travel mode for both these commutes will, in general, be the same. Within each of the before work, midday and post home-arrival patterns, there might be several tours. A tour is a circuit that begins at home and ends at home for the before work and post home-arrival patterns and is a circuit that begins at work and ends at work for the midday pattern. Further, each tour within the before work, midday and post home-arrival patterns may comprise several activity stops. Similarly, the morning commute and evening commute components of the work commute pattern may also comprise several activity stops.

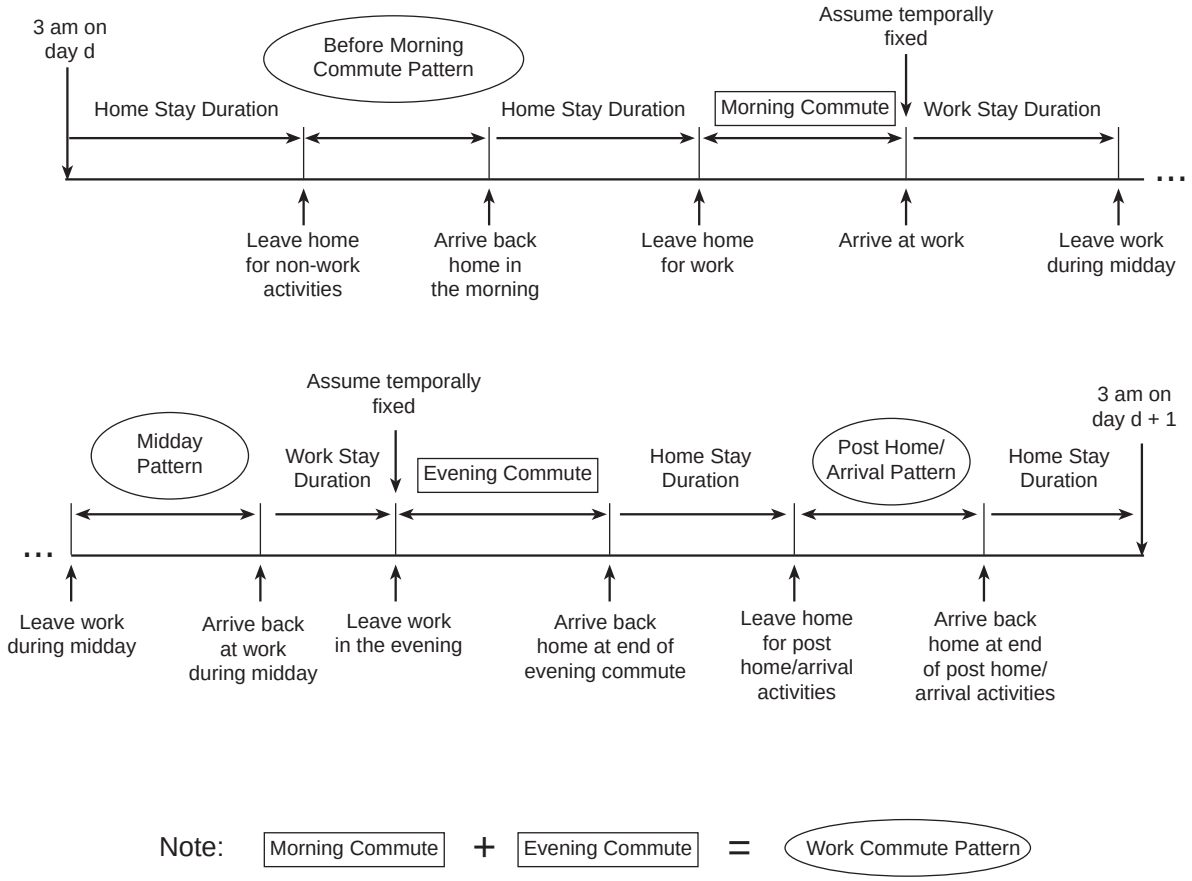

Figure 3.1. Diagrammatic representation of a worker's daily activity travel pattern

The characterization of the complete workday activity-travel pattern is accomplished by identifying a number of different attributes within the representation discussed above. These attributes may be classified based on the level of representation they are associated with; that is, whether they are associated with a pattern, a tour, or a stop. Pattern-level attributes include the number of tours for the before work, midday and post-home arrival patterns, and the home-stay duration before the morning commute for the work commute pattern. Tour-level attributes include travel mode, number of stops, home-stay duration before each tour in the before work and post home-arrival patterns, work-stay duration before each tour in the midday pattern, and sequence of tour in the pattern. Stop-level attributes include activity type, travel time to stop from previous stop, location of stop, activity duration, and sequence of stop in the tour.

The analysis of the workday activity-travel pattern of individuals entails the modeling of each of the attributes identified in the activity-travel representation. Due to the large number of attributes and the large number of possible choice alternatives for each attribute, the joint modeling of all the attributes is infeasible. The development of an analytic framework is needed to model the representation that is feasible to implement from a practical standpoint. This is achieved by descriptively examining the activity-travel pattern of workers using empirical data to inform the process of developing an operational analytic framework. Two data sets have been used for this purpose: the 1991 Boston Region Household Activity Survey and the 1990 Bay Area Household Travel Survey. The observations made from the descriptive analysis suggest the framework shown in Figure 3.2 for analysis of pattern-and tour-level attributes, and the framework shown in Figure 3.3 for analysis of stop-level attributes in each tour for each period.

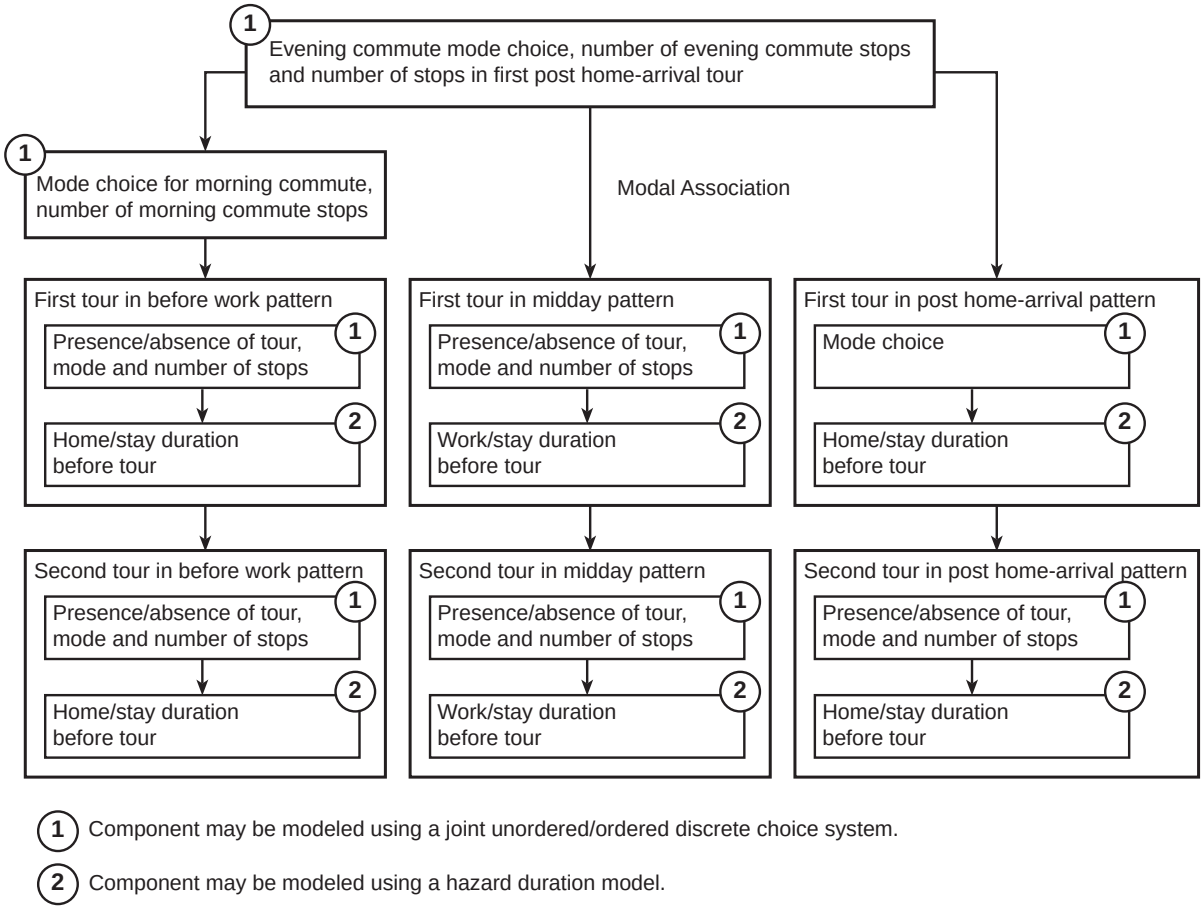

Figure 3.2. Analysis framework for patter- and tour-level attributes.

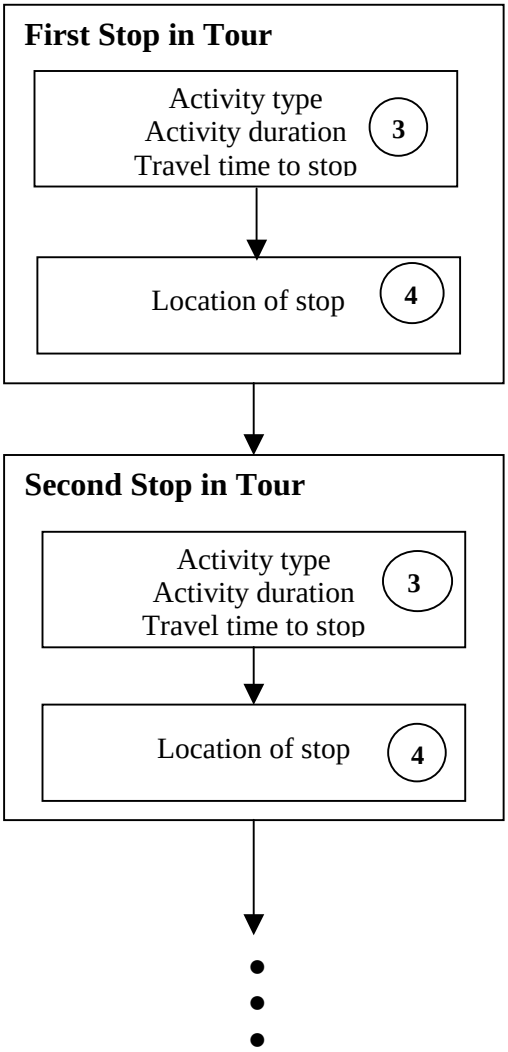

Figure 3.3. Analysis framework for stop-level attributes of workers.

The proposed analysis framework is based on modeling the pattern/tour-level attributes first, and then modeling the stop-level attributes conditional on the pattern/tour-level attributes. The number of tours in the before work, midday and post home-arrival patterns, and the sequence of tours in these patterns, are implicitly modeled in Figure 3.2 by determining if an individual makes a first tour and then conditional on making the first tour, if the individual makes a second tour (in concept, the procedure can be extended to more than two tours in a pattern). Similarly, the sequence of stops in a tour is modeled implicitly in Figure 3.3 by determining the

characteristics of the first stop, then the second conditional on the first, the third conditional on the first two, and so on.

The modeling of the described framework entails the econometric modeling approach. The components labeled (1) in Figure 3.2 may be modeled using a joint unordered discrete choice and an ordered discrete choice model system. For example, Bhat and Singh (Ref 28) have recently modeled mode choice in the evening commute, the number of evening commute stops, and the number of stops in the post-home arrival tour jointly using such a methodology. The components labeled (2) may be modeled using hazard-based duration models (see Refs 27, 29 for use of such models to examine activity duration). The joint activity type choice, activity duration, and travel time duration model labeled (3) in Figure 3.3 may be modeled (separately for each of the periods) using a joint discrete/continuous econometric system (see Ref 30 for the estimation and application of such a joint model for the evening commute period). The joint modeling approach allows for spatial-temporal interactions in stop-making decisions. The location choice of the stop (labeled (4) in Figure 3.3) can be modeled subsequently using disaggregate spatial destination choice models (Ref 31) by identifying all possible destinations which can be reached by the travel mode assigned for the tour (of which the stop is a part) and within the travel time duration estimated earlier.

MODEL FOR NON-WORKERS

The Comprehensive Activity-Travel Generation for Non-Workers (CATGNW) developed by Bhat and Misra (Ref 24) takes as exogenous input the same set of variables as that used in CATGW. It also assumes 3 a.m. to be the start of the day and that all individuals are at home during the start of the day. In their framework, a non-worker's activity-travel pattern is considered as a set of out-of-home activity episodes (or "stops") of different types interspersed with in-home activity stays. The chain of stops between two in-home activity episodes is referred to as a tour.

A non-worker's daily activity-travel pattern is characterized again by attributes associated with the entire daily pattern, a tour in the day, and an episode. *Pattern-level attributes* include whether or not the individual makes any stops during the day, the number of stops of each activity type if the individual leaves home during the day, and the sequencing of all episodes

(both stops and in-home episodes). The only *tour-level attribute* is the travel mode for the tour. *Episode-level* attributes include the episode duration, travel time to episode from previous episode (except for the first home-stay episode), and the location of out-of-home episodes (i.e., stops).

Based on the attributes identified, the modeling of a non-worker's daily pattern is achieved by modeling the pattern-level attributes first, followed by the tour-level attribute of mode choice, and finally the episode-level attributes. This hierarchical approach is adopted because the decisions regarding pattern-level attributes are driven by the basic activity needs of the individual (and the household of which the individual is a part). Consequently, and consistent with the derived demand philosophy of the activity-based approach, the pattern-level decisions are considered at the highest level of the analysis hierarchy. On the other hand, decisions regarding the episode-level attributes tend to be driven primarily by scheduling convenience, short-term temporal constraints, and travel conditions. Consequently, these attributes are relegated to the lowest level of the analysis hierarchy. The tour-level attribute of travel mode choice is positioned at the intermediate level of the analysis hierarchy since it affects the attributes of all out-of-home episodes within the tour.

The *Pattern-level attributes* are modeled using a system of three model components (Figure 3.4). The first model component, which takes the form of a bivariate binary-ordered response probit formulation, jointly models the decision to make at least one stop (versus staying at home for the entire day) and the decision of the number of stops if the individual leaves home during the day. The second model component, which uses a multinomial logit formulation for stop type, partitions the total number of stops (determined in the first model component) into number of stops by each out-of-home activity type. The final model component, which has a multinomial logit form with a pattern string as the unit of analysis, models the number of in-home episodes in an individual's activity-travel pattern along with the entire sequence of all episodes (in-home and out-of-home) in the individual's activity pattern, given the number of stops by type in the pattern.

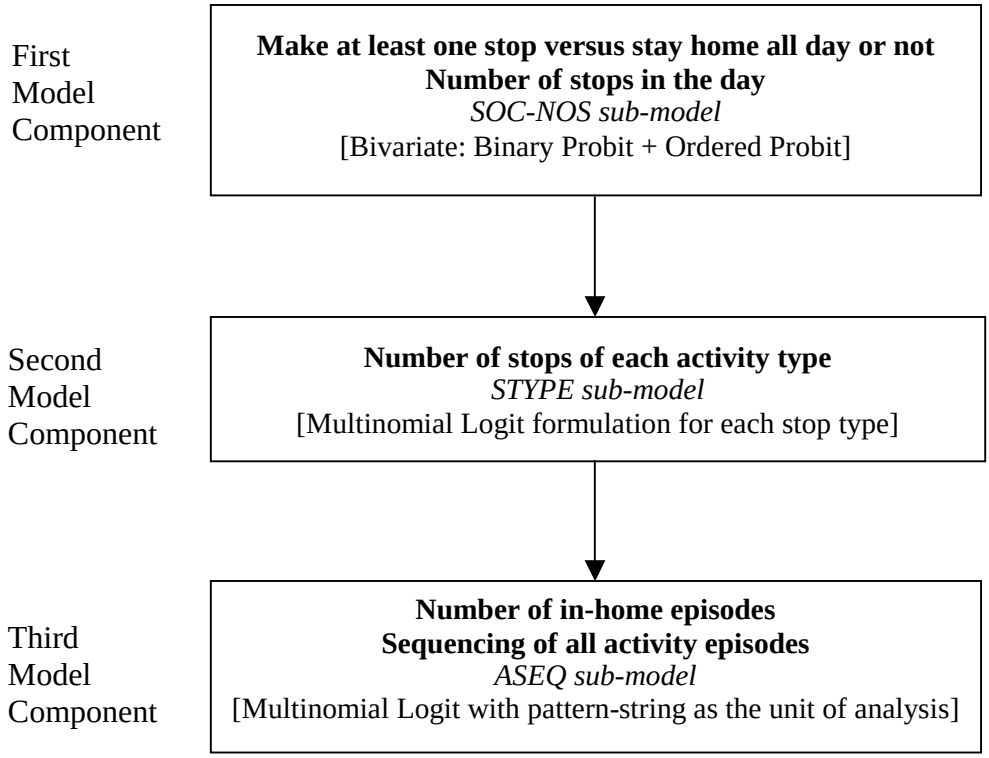

Figure 3.4. Analysis framework for pattern-level attributes for non-workers.

Figure 3.5 presents an overview of the four remaining model components used to analyze the tour- and episode-level attributes. The tour travel mode is modeled using a discrete choice formulation. Since the duration of the first home-stay episode is likely to be different from other subsequent home-stay episodes because of life-style and sleeping habits, the first home-stay duration is modeled prior to all other episode-level attributes using a hazard model. Next, the travel time to the episode from previous episode and activity duration of the episode for all episodes other than the first home-stay episode are modeled jointly. Finally, the spatial location of each out-of-home episode (stop) is modeled using a disaggregate spatial destination choice model.

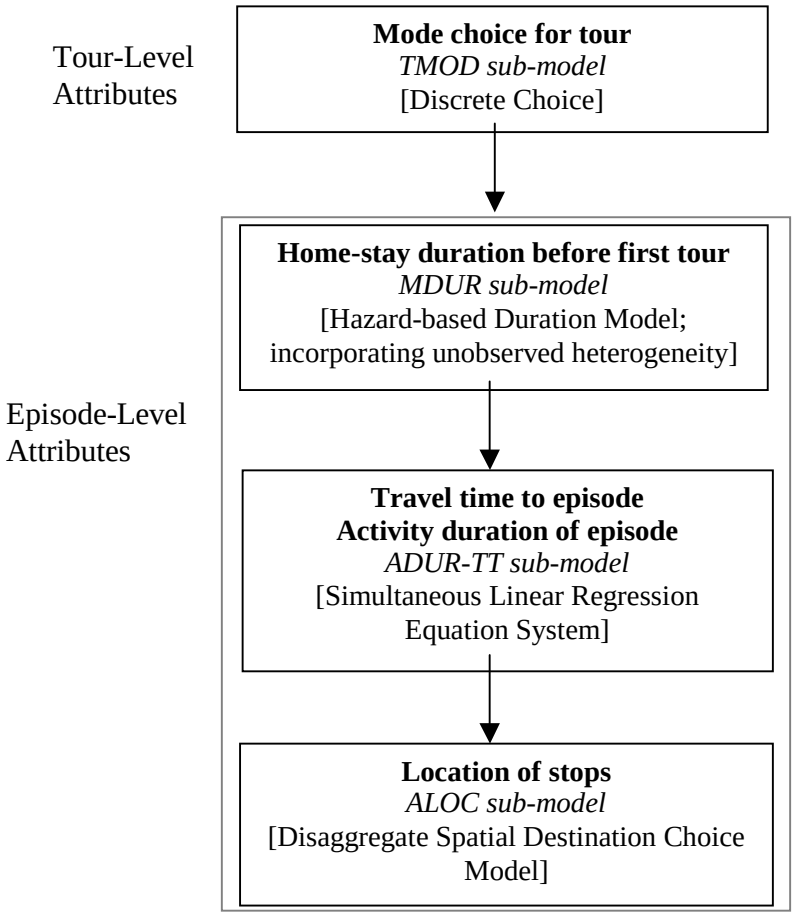

Figure 3.5. Analysis framework for tour-level and episode-level attributes for non-workers.

MODEL COMPARISON

Worker vs. Non-workers

The most fundamental difference between the frameworks for workers and for non-workers lies in the pattern level of the representation. CATGW takes advantage of the "regularity and fixity" of work activity and use the work activity as the "peg" to represent the activity-travel pattern of a worker. On the contrary, the non-workers are considered as not being constrained by temporal fixities and hence having rather flexible schedules. Thus, in CATGNW, the activity-travel pattern of a non-worker is not a priori divided into sub-patterns in their study. As a result, the modeling process allows for a more flexible arrangement of activity episodes.

The presence (absence) of fixities in the representation framework for workers (non-workers) results in the different ways in which activity-travel attributes are classified into the pattern, the tour and the episode levels. Attributes such as the stop activity type and stop sequencing are classified as stop level attributes for the workers, but as pattern-level attributes for the non-workers. A number of attributes defined for the workers are also absent in the framework for non-workers. In CATGNW, due to the absence of any fixity, a daily pattern is considered as several out-of-home activities interspersed with in-home activity stays. A tour is the result of stops chained between two in-home activity episodes. Therefore, the emphasis of analysis is on the stops. Even at the pattern level, the attributes are that of the stops, rather than of the tours. The tour characteristics are implicitly embedded in the stop characteristics. In the framework for non-workers, the distinction between the three levels is less clear. For instance, the home-stay duration before the morning commute is classified as a pattern-level attribute, yet the home-stay or work-stay durations for the other sub-patterns are considered as tour-level attributes. This seeming inconsistency is perhaps intended to highlight the dominating effect of the work commute pattern on the entire day pattern. It is also noted that the sequencing of tours of non-workers is considered as a tour-level attribute. However, as sequencing concerns multiple tours, which together construct a pattern, it is probably more of a pattern characteristic than a tour characteristic. Had the tour sequencing and all the home-stay or work-stay duration attributes been shifted to the pattern level, the classification schemes adopted by the two frameworks would exhibit more resemblance and symmetry.

In the modeling framework for non-workers, the classification scheme of activity-travel attributes is followed through the modeling process. A sequential approach is taken to model the pattern-level attributes first, followed by the tour-level and finally the stop-level attributes. Once the presence, frequency and sequencing of stops are determined, the tours and the overall pattern become apparent. The travel mode of each tour is then considered, followed by the determination of the temporal and spatial attributes of the stops. CATGW, on the other hand, does not address the attributes in the same sequence as they appear in the classification scheme. Instead, the system is designed in a more hierarchical approach and models the four sub-patterns separately. For a sub-pattern, conditional on the presence of a tour, the presence of the first tour is first determined, followed by the attributes of the tour itself and the attributes

of the stops within that tour. Conditional on the first tour, the presence of the next tour, and the characteristics associated with that tour and the comprising stops, are then modeled. Thus, the hierarchy of a pattern comprising of tours and a tour comprising of stops is more apparent in CATGW than in CATGNW.

The strategy of modeling the tours before the stops for workers probably attributes back to the introduction of fixity in a daily pattern. As a daily pattern is divided into sub-patterns, a temporal constraint is imposed onto each sub-pattern. The number of tours in a sub-pattern is mostly likely much smaller than the total number of tours if the entire day had been treated as one pattern. In fact, the study finds that the majority of workers make either no tours or one tour in the before work, midday and post home-arrival patterns. Consequently, the modeling framework assumes that there are no more than two tours in each of these three patterns.

The subdivision of a worker's activity-travel pattern is originally intended to reflect the fixities observed in a worker's daily activities. However, one sub-pattern is not independent of the other. The need to capture stop-making across different time periods of the day results in a less clear modeling hierarchy than CATGNW. For instance, the first step in the modeling process is to jointly model the evening commute mode choice, the number of evening commute stops and the number of stops in first post-home arrival tour.

Against Other Operational Daily Activity-Travel Models

The proposed frameworks for workers and non-workers share the same underlying objective of developing a comprehensive framework that takes into account both the generation and the scheduling of activities. Both studies adopt a three-level representation structure to characterize an individual's daily activity pattern. The three levels, comprising of the pattern level, the tour level and the stop level, together for the unit of analysis. Their attributes that are identified and modeled in the systems encompass all the choice dimensions listed in Table 2.3. These attributes are modeled either individually or jointly using econometric modeling techniques, implying the use of principle of utility maximization as the fundamental decision mechanism. The modeling approach provides forecasting capability and potential for policy analysis.

Both systems consider time as an all-encompassing continuous entity in analysis and location choice as zone based. Both systems capture inter-stop dependency at the tour level. They do not consider joint activities or other inter-personal dependency. No explicit distinction is made between fixed and flexible activities. However, the framework for workers uses work activity as a means of introducing fixity into a daily pattern. It also takes into account space-time interaction by modeling the activity location of stops using the travel time duration to determine feasible destinations.

Data Requirements

Both model systems consider the same range of exogenous variables. The variables include household and individual social-demographics, the transportation and the land-use environment, and individual's medium-term decisions regarding employment, residence and car ownership. These exogenous variables suggest that the application of these two model systems requires the types of data typically involved in operational activity-travel models. These include land-use and network data, household activity diaries, and other sources of socioeconomic data.

CHAPTER 4. DIRECTIONS FOR FURTHER DEVELOPMENT

The number of assumptions researchers introduce into a model may require a trade-off between the model's flexibility and its reasonableness. In the proposed framework for workers discussed in Chapter 3, the assumption about fixity and the consequent constraints imposed on the model have been derived from empirical analysis. The representation framework and, consequently, the model structure are developed based on the statistical relationships found in the observed data. The question of transferability arises when the model system is applied to different geographical context. Hence, further empirical analysis involving Texas data is required to evaluate the appropriateness of the current model structure for workers. Similarly, it is not necessarily true that non-workers do not exhibit any regularity, as is assumed in the proposed framework. For instance, within a household with young dependents, the homemaker usually has to organize his or her activities around the times to pick up or to drop off the children. Analysis of data for non-workers is required to examine if the introduction of such fixity into the model will be beneficial.

The example about the dependency between young kids and adults also raises the question of how a student's activity-travel patterns can be modeled. Intuitively, students are constrained by the school activities in a similar way as workers are restricted by their work activities. Yet, the life styles of students, especially for those in colleges, are likely to be more active than that of the workers. Accordingly, the activity-travel pattern of a student is less "fixed" than that of a worker.

The common ground between the two frameworks makes it possible to combine the two frameworks into one. As pointed out in the previous chapter, a major limitation to both frameworks is the inability to capture the effect of inter-personal interactions on activity behavior within a household. This limitation is also found in most of the operational activity-travel models reviewed in Chapter 2. Interactions among individuals include joint participation in certain activities, "serve-passenger" and "escort" activities, and allocation of autos and activities among individuals (especially in multi-adult, one-car households). Such interactions can lead to constraints that may be very important in individual activity/travel responses to changes in the transportation or land-use environment. Accommodating

inter-individual interactions in activity patterns is therefore an important area for further development of the proposed frameworks.

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