A Retrospective and Prospective Survey of Time-Use Research

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Abstract

The central basis of the activity-based approach to travel demand modeling is that individuals' activity-travel patterns are a result of their time-use decisions within a continuous time domain. This paper reviews earlier theoretical and empirical research in the time-use area, emphasizing the need to examine activities in the context or setting in which they occur. The review indicates the substantial progress made in the past five years and identifies some possible reasons for this sudden spurt and rejuvenation in the field. The paper concludes that the field of time-use and its relevance to activity-travel modeling has gone substantially past the "tip of the iceberg", though it certainly still has a good part of the "iceberg" to uncover. Important future areas of research are identified and discussed.

Keywords: Time use research, activity-based travel modeling, activity episode analysis, time allocation, hazard-based duration model, activity scheduling

1. Introduction

Activity-based travel analysis has received much attention and seen considerable progress in the past decade. It has enabled us to comprehend and appreciate the complexity and variability in the activities that an individual undertakes during any given period.

Very broadly, activity-based travel analysis attempts to better understand the behavioral basis for individual decisions regarding participation in activities in certain places at given times. This behavioral basis includes all the factors that influence the how, where and why of performed activities. Among these factors are the needs, preferences, prejudices, and habits of individuals' (and households), the cultural/social norms of the community, and the travel service characteristics of the surrounding environment.

In the evolution of approaches to travel demand analysis, there has been a distinct paradigm shift in the past couple of decades from trip-based methods to activity-based methods. Trip-based methods focus on analyzing trip-related decisions without considering the time-use context in which activity participation and travel decisions are made. The consequence is that trip-based methods lose sight of the broader picture within which travel decisions are made (for a detailed review of the shortcomings of the trip-based method, the reader is referred to Kitamura, 1988, Jones *et al*., 1990, Axhausen and Garling, 1992, and Kurani and Kitamura, 1996). The activity-based approach (see Recker, 1995 or Kitamura and Fujii, 1996) views travel as a derived demand; derived from the need to pursue activities distributed in space. This approach adopts a holistic framework that recognizes the complex interactions in activity and travel behavior. It focuses on sequences or patterns of activity behavior, with the whole day or longer periods of time as the unit of analysis.

A fundamental difference between the trip-based approach and the activity-based approach is the way time is conceptualized and represented in the two approaches (Pas, 1996, Pas and Harvey, 1997). In the trip-based approach, time is reduced to being simply a "cost" of making a trip. The activity-based approach, on the other hand, treats time as an all-encompassing continuous entity within which individuals make activity/travel participation decisions (see Kurani and Lee-Gosselin, 1996). Thus, the central basis of the activity-based approach is that individuals' activity-travel patterns are a result of their time-use decisions. Individuals have 24 hours in a day (or multiples of 24 hours for longer periods of time) and decide how to use that time among activities and travel (and with whom) subject to their schedule, socio-demographic, locational, and other contextual constraints.

This paper presents a retrospective review of time-use studies and a prospective agenda for time-use research. The retrospective review is organized under two categories: a) Activity time allocation studies, and b) Activity episode analysis.

Activity time allocation studies classify activities into one of several target types and then examine the allocation of time to these activity types based on household/individual characteristics. These studies generally ignore the context in which activities are performed; that is, for the most part, they do not consider the time of day (or day of the week) of activity performance, the sequence in which activities occur in the continuous temporal domain, the duration of each activity participation, the location of activity participation, and the company (alone, with spouse, with children, *etc.*) in which activity participation occurs. To highlight the activity context (or activity setting, as Harvey, 1982 refers to it), we will follow Chapin and Hightower (1966) and use the term "activity episode" to refer to a discrete activity participation.
The term "activity" refers to a collection of episodes of the same type or purpose over some time unit (say a day or a week).

Studies reviewed under the category of activity episode analysis emphasize activity episodes and their associated spatial, temporal, sequencing, and company contexts of participation.

2. Review of activity time allocation studies

The study of allocating time to different activities has received attention in the fields of psychology, anthropology, sociology, urban planning, geography, time-use analysis, and economics. We review theoretical developments in the field of activity time allocation in section 2.1 and empirical developments in section 2.2.

2.1. Theoretical developments

Theoretical studies of activity time allocation may be sub-divided into three classes. The first category of theories, which we label as motivational theories, have their origins in anthropology and psychology. Theories in this first category emphasize the fundamental motivational process underlying activity time allocation. The second category of theories, which we label as sociological and planning theories, have their origins in sociology and urban planning. This category of theories provides more immediate insights into the process governing time allocation behavior. The final category of studies, labeled economic theories, have their roots in micro-economics. Generally, economic theories have an explicit mathematical formulation, though they may not incorporate some of the more subtle determinants of time allocation behavior identified by motivational and non-economic theories.

2.1.1. Motivational theories

There are numerous theories of the process that motivates human activity time allocation behavior. The theories differ considerably in their views of the motivational basis of behavior but agree on the notion that behavior is dictated by felt needs -- whether innate or nurtured.

The earliest theory of human nature originates from the Greek philosophers - Aristotle and Plato. They believed that people have a "free will" and that intellect and reason governed human activity behavior. Rene Descartes (late seventeenth century) put forth a dualistic approach to behavior in which he theorized that animals and humans were intrinsically different in the process governing their activity behavior. This dualistic theory was challenged by Darwin's (1856) theory of survival of the fittest. He argued that the basic force motivating all animals (humans included) is survival and any difference in behavior between lower animals and humans can be attributed more to the ability of adjusting to the contextual environment rather than a qualitative difference in the process determining their activity behavior. The next important theory was the psychoanalytic approach of Freud (1915). His theory demonstrated how the need to survive could motivate activity behavior, though humans may perceive other motives as dictating their behavior. Freud's view that humans are motivated by blind, pleasure seeking, animal instincts was modified by new theories. Amongst them are Jung's theory (1938), Hull's drive theory (1943), and more recently, the humanistic approach.

The humanistic approach extends earlier theories to include motivation to grow and mature. Rogers's (1959) theory was founded on "self-concept". He believed that we are motivated to develop a positive image (perceiving our personality positively) and that we act to fulfill needs of growth to realize our inherent potential (he calls this self-actualization). Maslow (1970) expanded the humanistic approach to clarify the conditions necessary to express human need for self-actualization.

He distinguished deficiency motivation from growth motivation and stressed that any deficiencies (physical or psychological) need to be taken care of before an attempt can be made toward the direction of growth.

Closer to the field of activity analysis, Fried et al. (1977) proposed a micro-theory of adaptational change affecting individual activity time allocation behavior. Their micro-theory presents a set of propositions about the adaptation process that reduces the imbalance between current or expected needs and resource opportunities and constraints. in this structure, the main influence on behavior is environmental opportunities which are modified by psychological, social, and economic influences to determine the spatial distribution of human activities and travel. The theory emphasizes the dynamic process of behavioral adaptation arising from an effort to bring environmental opportunities into finer balance with current and anticipated needs.

2.1.2. Sociological and planning theories

This second class of theories has more directly focused on time allocation relative to the anthropological and psychological theories discussed earlier. Sociological studies have centered on "resource theory" and the effect of attitudes regarding sex-role behavior on time allocation of individuals living together. Most resource theorists relate "contributions toward resources" (which is the source of power) in terms of individual socio-economic attributes (such as income, education, job status etc.). However, the issue of resources has been interpreted in a much broader sense by Heer (1963). He suggests that it is not just the value to one partner of the other's resources that determines power, but how much those resources are worth relative to those available outside the current co-existing living arrangement. Geerken and Gove (1983) laid the foundation for an integrated socio-economic theory of "imperfect" utility maximization (implying that time allocation may not be the best of allocations and that under certain circumstances, a household may face only an array of bad choices). Geerken and Gove directed their attention on time spent on household work by individuals living together as a function of time spent at work. While recognizing and contributing toward the need for an integrated approach, they did not explicitly formulate or structure the time allocation process.

In the urban planning literature, Chapin (1974) postulated a framework in which constraints imposed by society (he classifies these constraints as preconditioning and pre-disposing) interact with inherent motivations, to result in the propensity of activity participation. Reichmann (1976) classified activities into a) Subsistence activities or work-related business services which are essential to provide the financial requirements for pursuing maintenance and leisure activities, b) Maintenance activities or purchase and consumption of goods to satisfy household and personal physiological & biological needs (hunger, thirst etc.) and cultural/consumption needs (needs for an individual or a household to establish its place in society), and c) Leisure activities or social, recreational and other discretionary pursuits motivated by cultural and psychological needs (needs for social interaction, achievement and self-actualization). This classification or similar ones have been adopted in almost all empirical time allocation research. For example, Aas (1982) uses a four-way classification of activities rather than a three-way classification. Aas's classification includes a) contracted (paid) work time, b) committed (unpaid) work time, c) necessary (personal care) time, and d) free time.

2.1.3. Economic theories

The economic approach to time allocation is based on the assumption that individuals (and the households of which they are a part) will always try to do their best to function as well as possible. Each person in the household allocates time as well as money income to various activities - receiving income from time expended in the market place and receiving utility from spending this income on the consumption of goods and services (Gramm 1975, Gronau 1973, Becker 1981;1965, Mincer 1962;1963). Individuals "produce" non-market activities using "inputs" - their time and market goods and services. An individual's choice of work time and time in other non-market activities depends on market wages and prices of the "inputs" used to produce non-market activities. In particular, non-market time and consumer goods used in "production" of each non-market activity is chosen so as to maximize utility subject to constraints imposed by wages, prices of consumption goods, and time (Juster, 1990). Building on Becker's economic theory, Kitamura (1984), Kitamura *et al*. (1996), Kraan (1997), and Bhat and Misra (1998) have used a resource allocation formulation to determine individual participation in an activity and duration of participation. Townsend (1987), on the other hand, presented a formal integrated theory of time allocation <u>among individuals</u> at the household level. Many recent reviews (for example, see Kraan, 1996 and Pas and Harvey, 1997) have discussed the economic formulations of time allocation and we refer the interested reader to these studies.

2.2. Empirical studies of activity time allocation

The earliest empirical studies of time allocation were conducted in the time-use field to descriptively examine the time-use patterns of individuals and compare these patterns across several countries (see, for example, Szalai, 1972, Andorka *et al.*, 1983, Harvey and Grönmo, 1986, and Harvey *et al*., 1984). Some other studies in the time-use field have examined changes in time-use patterns within the same country across time (Lingsom and Ellingsaeter, 1983, Juster, 1985).

Empirical studies in urban planning have focused on analyzing time-use patterns of different population segments (the segments are defined based on such variables as sex, marital status, employment status, income, presence of children, and ethnic race). Chapin (1974) studied time allocation of households to twelve different activity types on weekdays and weekends using a Washington, D.C. Standard Metropolitan Statistical Area (SMSA) sample. He first studied the mean time duration that households allocated to different activities without any sample segmentation. He found that "main job" and "homemaking" comprise a major portion of weekday activity (besides sleep which as a basic human physiological process remains fairly constant). However, he observed that discretionary activities assume more importance toward the weekend. Chapin then segmented the sample to study the effects of stage in lifecycle, race and status on household time allocation on weekdays.

In the transportation literature, Jones *et al.* (1983) studied the effect of lifecycle on activity time allocation based on a two-stage survey in Banbury, Oxfordshire. They found a very strong influence of lifecycle stage on the activity time allocations of adults in the household. Kostyniuk and Kitamura (1986) performed a similar analysis from two metropolitan areas in the U.S. and confirmed the importance of lifecycle stage in household activity time allocation.

In contrast to the transportation studies mentioned above which examine <u>household</u> time allocation, Kitamura *et al*. (1996), Kraan (1996), Bhat and Misra (1998), and Lawson (1996) have focused on <u>individual</u> time allocation with specific emphasis on the trade-offs and relationship between in-home and out-of-home activities. Kitamura *et al* (1996) studied individual activity participation in, and time allocation to, in-home and out-of-home discretionary activities. Their results indicate the strong negative effect of being employed and having a long work commute on out-of-home discretionary activity time. Older individuals and individuals in households with many people also have a lower tendency to allocate time to out-of-home discretionary activities. Kraan (1996) modeled total weekly time allocated by individuals to in-home, out-of-home, and travel for discretionary activities and also for all activity types considered together using a Dutch National Travel Survey data. Bhat and Misra (1998) extended Kraan's empirical model to include the allocation of discretionary time between weekdays and weekends (in addition to between in-home and out-of-home). Lawson (1996) is conducting similar research on in-home and out-of-home time allocation decisions and interactions.

Golob and McNally (1995) developed a structural equations model to analyze interactions in time allocated to out-of-home activities and travel in three categories (work, maintenance, and discretionary) between male and female heads in a household. They also studied the effect of socio-demographic characteristics on time allocations. Thus, while their study examines individual time allocation like those of Kitamura *et al*. (1996), Kraan (1996), and Bhat and Misra (1998), it also explicitly accounts for inter-individual interaction effects within a household. Other research efforts to capture inter-individual interaction effects have been undertaken by Koppelman and Townsend (1987), van Wissen (1989), Stopher and Vadirevu (1995), and Lu and Pas (1997). The results from these studies provide extensive insights on interactions in time allocations among individuals in a household as well as among various activity/travel categories for each individual.

3. Activity episode analysis

In this section, we review studies which have examined activity episodes and their associated spatial, temporal, sequencing, and company contexts of participation. Activity episode analysis is closer in spirit to activity-based travel analysis than is activity time allocation since it emphasizes the context (the why, when, where, with whom, duration, and sequence) of activity participation.

The discussion of activity episode analysis is sub-divided into two sections. The next section reviews conceptual developments, while the subsequent section presents empirical studies.

3.1. Conceptual origins

The first explicit discussion of activity participation in the context of space, time, and participation in other activities appears to have been proposed by Hagerstrand (1970). Hagerstrand identified the spatial and temporal constraints under which individuals participate in activity episodes using the now well-known space-time "prism". In addition to such space-time constraints (which Hagerstrand referred to as authority constraints), Hagerstrand also identified capability constraints and coupling constraints. Capability constraints refer to constraints imposed by biological needs (such as eating and sleeping) and/or resources (income, availability of cars, *etc.*) to undertake activities. Coupling constraints define where, when, and the duration of planned activities that are to pursued with other individuals.

Cullen and Godson (1975) extended Hagerstrand's notion of constraints to accommodate varying degrees of rigidity (or flexibility) of the constraints. Their hypothesis (which they supported with empirical observations) was that temporal constraints are more rigid than spatial constraints and that temporal constraints weaken at later times of the day as more rigid subsistence activities give way to flexible discretionary evening activities. Cullen and Phelps (1975) and Heideman (1981) included the consideration of individuals' perception of their action-space and their mental capabilities to absorb information regarding their action-space in determining activity episode patterns.

A comparison of theoretical research on activity time allocation (section 2.1) and on activity episode analysis (this section) points to the large body of literature on the former topic compared to the latter. Further, theories of time allocation are more formalized than are the relatively "loose" concepts of activity episode analysis. Clearly, the development of a comprehensive theory of activity episode analysis should be an important area of future research, as we elaborate further in section 4.

3.2. Empirical studies of activity episode analysis

The studies reviewed here analyze activity episode participation and its temporal characteristics, along with one or more other contextual attributes of the participation (location, sequence, type, *etc.*). To keep the review focused and also because of the time-use emphasis of the current paper, we do not consider studies that do not treat time as a continuous domain for activity participation.

The studies are organized in two categories. The first category of studies focuses on a single activity episode. The second category examines activity episode patterns (that is, multiple activity episodes and their sequencing).

3.2.1. Single activity episode analysis

Mannering and his colleagues (Mannering *et al*., 1992, Kim *et al*., 1993) have examined activity episode duration (specifically, home-stay duration) between successive participations in out-of-home activity episodes using a Cox proportional hazard model to analyze duration. Their results suggest that older people, individuals in households with fewer members, unemployed individuals, and lower income individuals tend to have longer home-stay episode duration. The context in which the home-stay duration episode occurs is considered by using the travel time and the type of activity preceding the home-stay episode as explanatory variables. The effect of these contextual variables are found to be important determinants of home-stay duration.

Neimeier and Morita (1996) analyze the duration of out-of-home activity episodes associated with maintenance-related shopping, personal business, and free time activities for workers, also using a Cox proportional hazard model. Their work distinguishes between four types of patterns within which an activity episode may be pursued: work-activity-work, home-activity-home, home-activity-work, and work-activity-home. Their empirical results suggest that men and women spend approximately the same amount of time for personal business and free time activity episodes. However, women appear to be much more likely to have a larger maintenance-related shopping activity episode duration than men, and this effect is particularly noticeable if the activity episode is pursued during the return home from work.

Bhat (1996) develops a hazard-based model of shopping activity episodes during the evening commute. His model uses a non-parametric baseline hazard and also accommodates unobserved heterogeneity in durations using a non-parametric distribution. The baseline parameters are explicitly estimated unlike in the Cox approach used in the studies discussed earlier. Thus, Bhat's study provides insights into the dynamics of duration. The covariates used in the model to explain the duration of shopping activity episodes include the individuals's work schedule characteristics, the work duration characteristics of the individual's spouse, travel mode to work, and socio-demographic attributes.

In contrast to the studies reviewed above that use a hazard model to analyze episode durations, Hamed and Mannering (1993) and Bhat (1998) use a discrete-continuous framework to analyze activity episode type, episode duration, and travel time duration to the activity episode. Duration is modeled using a linear regression structure. Both these studies focus on post-work activity episodes.

3.2.2. Activity episode patterns

In this section, we review studies which examine activity episode patterns (*i.e.*, multiple activity episodes and their sequence) within a continuous time domain. We distinguish between two types of studies here. The first category focuses on activity episode scheduling. The studies in this first category consider the generation of activity episodes and their temporal and other attributes as exogenous inputs. The second category of studies models both activity episode generation and scheduling.

3.2.2.1. Activity episode scheduling

The structure of activity episode scheduling models generally takes the form of a computerized production system. A production system comprises a set of rules (or condition-action pairs) which attempt to capture the decision-making process of individuals. Originally developed in the psychology field (see Newell and Simon, 1972), production systems are compatible with a behavioral decision-making architecture in which spatial and aspatial information is perceived, appraised, and acted on within a limited-information human processing framework. Gärling *et al*. (1994) discuss production systems in detail.

Among the earliest activity episode scheduling models was CARLA, developed by the Oxford University Transport Studies Unit (Clarke 1986). This model uses the list of activities to be scheduled, and their durations, to produce all feasible activity patterns (alternative permutations of activity sequences). The influence of interactions within the family on scheduling behavior is implemented by insisting that those activities that take place jointly in the observed activity diary should also be capable of taking place jointly in the modeled patterns. The model has been applied to investigate the consequence of implementing reduced bus services in the Netherlands (van Knipperberg and Clarke 1984).

STARCHILD, another scheduling model, was developed by Recker et al. (1986a, 1986b). This model requires the directory of activities along with their duration, location and time window as input. It extends the generation process (that is, generation of alternative patterns) embodied in CARLA to include an actual pattern choice model. Distinct non-inferior patterns are generated by combinatorics and a logit choice model is used to establish pattern choice. The STARCHILD model has been applied to three policy areas: variable work hours, changes in network travel speed, and changes to individual travel time budgets (Recker and McNally 1986). More recently, Recker (1995) has extended the STARCHILD approach to include a mathematical programming formulation for the choice of a household activity-travel pattern from several possible patterns. The household activity pattern problem (HAPP) is formulated as a variant of the pick-up and delivery problem with time-windows. The objective of HAPP is to generate the choice of the household activity pattern as an optimization of the household's utility function across several possible patterns, while accommodating inter-related space-time paths of several household members with given activity agendas. McNally (1997) develops a GIS-based micro-simulation model that syntheses population activity-travel patterns from individual activity-travel patterns generated by HAPP.

Another activity scheduling model is SCHEDULER (Garling *et al.*, 1989). The conceptualization of this model is based on psychological principles of social interaction among household members. The computational model assumes that at the start of any time period, an individual has a long term calendar (an agenda of activity episodes with duration, appointment details and preference). A small set of episodes with high priority are selected from this long term "calendar" and stored in a short term calendar as the subset of episodes to be executed in the short-run. This activity subset is sequenced, and activity locations determined based on a "distance-minimizing" heuristic procedure. Detailed scheduling (temporal dimension of participation, mode choice etc.) follows and includes checks for temporal conflicts in activities. SMASH (Ettema *et al.*, 1993) is a development of the SCHEDULER framework in which heuristic scheduling rules are specified and tested.

An adaption simulation model system labeled AMOS (for Activity-MObility Simulator) was developed by Kitamura *et al.* (1996) to examine the short-term responses to Transportation Control Measures (TCMs). The model takes an observed daily activity-travel pattern of an individual (baseline pattern) and generates an adaption choice for the individual (for example, do nothing, change mode, change departure time, *etc.*). The adaptation choice is determined in a response option generator calibrated by Neural Network methods using stated responses of commuters to a variety of TCMs. An activity-travel pattern modifier examines the baseline pattern and the generated response option, and changes the pattern if the response option (primarily a mode or departure time change) implies an infeasible or impractical baseline pattern. The change in the baseline pattern may involve re-sequencing the activity episodes in a different way than earlier and/or changes in destination and modes for certain activities. The set of activity episodes and their activity durations are not changed from the baseline pattern. AMOS has been applied in the Washington, D.C. area to assess the potential short-term responses of commuters to the TCM measures being considered in the region.

3.2.2.2. Activity episode generation and scheduling

Two approaches have been proposed recently to model activity episode generation and scheduling within the context of a continuous time domain. The first is the Prism-Constrained Activity-Travel Simulator proposed by Kitamura and Fujii, 1996 and the other is the Comprehensive Activity-Travel Generation for Workers (CATGW) model system proposed by Bhat and Singh (1998).

PCATS is based on dividing the day (or any other unit of time) into "open" periods and "blocked" periods. "Open" periods represent times of day when an individual has the option of traveling and engaging in "flexible" activities. "Blocked" periods represent times when an individual is committed to performing "fixed" activities. The determination of what constitutes a "fixed" activity or a "flexible" activity is based on certain assumptions and/or the indication of the survey respondent that certain activities are fixed in time and space. PCATS then attempts to "fill" the open periods based on a space-time prism of activities which can be accomplished within the open period. PCATS uses a sequential structure for generation of the activity episodes and associated attributes (activity type, activity duration, activity location, and mode choice) within the "open" period (thus, the unit of analysis in PCATS is the individual activity). While several different sequential structures can be used, PCATS sequences the models for each activity episode by type, location, travel mode to activity, and duration. The sequential structure makes the estimation process simple. While activity duration is determined at the end in PCATS, a distributional model of duration is estimated first for each activity episode type, and the likelihood of an episode of an activity type fitting within the time available from end of an earlier episode and the next "fixed" activity start time is used as an explanatory variable in determining the type of "flexible" activity episode that may be pursued during the "open" periods. PCATS has been applied in a small validation study in which aggregate (across all individuals) predicted values of certain activity-travel attributes (such as total travel time, in-home flexible activity duration, *etc.*) are compared to observed values.

The CATGW framework is based on the fixity of two temporal points in a worker's continuous daily time domain. The two fixed points correspond to the arrival time of an individual at work and the departure time of an individual from work. The day is divided into four different 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. Within each of the before work, midday and post home-arrival patterns, several tours may be undertaken. 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 episodes. Similarly, the morning commute and evening commute components of the work commute pattern may also comprise several activity episodes. The modeling representation for the entire daily activity-travel pattern is based on a descriptive analysis of actual survey data from two metropolitan areas in the U.S. The suite of models in the modeling representation can be used for generation of synthetic baseline patterns as well as to evaluate the effect of Transportation Control Measures (TCMs). The models have been applied to evaluate the potential effect of TCMs on stop-making and cold starts in the Boston Metropolitan area.

4. A prospective discussion of time-use research

The retrospective review of time-use studies indicates the substantial progress that has been made in recent years. There is no question that there is an increasing realization and awareness of the need to model travel as part of a holistic (and temporally continuous) activity-travel pattern. This has led to the adoption of relatively non-traditional (in the travel analysis field) methodologies such as duration analysis, limited-dependent variable models, structural equations models and computational process models (see Bhat, 1997 for an exhaustive methodological review). There have been several applications of these techniques to develop synthetic activity-travel patterns for forecasting and to assess the impact of Transportation Control Measures (TCMs) on traffic congestion and air quality. Thus, it is probably fair to state that time-use studies have gone past the usual cliche of promoting a better understanding of human activity-travel behavior to application for purposes of forecasting and policy analysis.

Lest we should be misunderstood, we are not suggesting that we have a complete understanding of how households and individuals make their time-use decisions. Far from that. However, in our view, the field of time-use and its relevance to activity-travel modeling has gone substantially past the "tip of the iceberg", though a good part of the "iceberg" remains to be explored.

In the next few sections, we discuss some of the directions in time-use research that we consider to be important in the context of activity-travel analysis.

4.1. Develop a comprehensive theory of time-use

Researchers from many different disciplines have contributed to the development of theories and concepts of time-use. Psychologists and anthropologists have emphasized intrinsic human tendencies that shape the way we live and make overall time-use decisions. While these motivational theories are not meant to explain detailed daily or weekly time-use behavior at an individual (or household) level, they have the potential to provide information on the broad activity-travel changes due to changes in the activity-travel environment. Theories originating in other fields, on the other hand, are more specific in their relevance to daily or weekly time-use behavior. Sociological theories explain the interaction and allocation of activities amongst individuals in a household. Theories and concepts in geography and urban planning focus on the space-time prism and the effect of constraints imposed by this prism on activity-travel behavior of individuals. Economic theories are more formalized and are based primarily on the concept of choice using an optimization principle.

An important direction for future time-use research is to integrate the plethora of extant and developing theories from various fields to develop a comprehensive theory that emphasizes all the relevant aspects of time-use behavior. This integrated effort needs to be much more than a detailed review of the various theories; it needs to juxtapose the theories, highlight consistencies among the theories, and resolve inconsistencies. We do not conceive such a comprehensive theory to be prescriptive; the intention is that it will provide a platform for researchers in different disciplines to work together in collaborative research. To this end, the comprehensive theory must itself be the result of a collaborative effort involving researchers from several fields. Of course, the level of integration desired among disciplines is a function of the purpose of the integration, and so it is important to be clear about the purpose of integration in the first place. Finally, the theory must address activity episode behavior, not just time allocation behavior among different activity types.

4.2. Accommodate inter-individual interactions in activity episode patterns

The analysis of activity episode patterns is clearly at the heart of the activity-based travel analysis approach. An activity episode has several contextual attributes associated with temporal and spatial characteristics. Examining activities independent of the context leads to a loss in detail in time-use research and a loss in relevance in travel demand analysis.

Several studies in the travel demand field, and more recently in the time-use field, have focused on the analysis of activity episode patterns (see Harvey, 1997 for a review). As indicated earlier, these studies have either focused on activity episode scheduling or have focused on both activity episode generation and scheduling. Activity episode scheduling models do not address the issue of how to generate the activity episode agenda. However, they do accommodate inter-individual interactions and coupling constraints within a household. On the other hand, activity episode generation and scheduling models, while being broader in their focus, use the individual as the behavioral unit of analysis. Thereby, they are unable to explicitly accommodate inter-individual interactions in activity-travel behavior. There is a need to formulate joint activity episode generation and scheduling models at a household level within a continuous time domain to capture interactions among individuals in a household. Wen and Koppelman (1998) have recently contributed in this direction by proposing a framework which models the choices of household activity (stop) generation, assignment of activities and cars to household members, tour generation and assignment of stops to tours (placement in the work tour or to before or after work tours) for each household member and links these decisions to mode choice for each tour and destination choice for each stop. Model estimation results (Wen, 1988) confirm the linkages among these component choices. Integration of such an effort which accommodates inter-individual interactions in activity generation and scheduling with other efforts that use a continuous time domain (such as those discussed in section 3.2.2.2) is likely to be a particularly fruitful area for further research.

4.3. Study the activity episode generation and scheduling process

As described earlier in the paper, there have been several previous modeling efforts to generate activity episode patterns. However, we still do not know much about the fundamental time-use decision mechanism underlying revealed activity episode patterns. Specifically, we lack a detailed understanding of a) how households and individuals acquire and assimilate information about their environment (both opportunities for activity participation and transport system attributes), b) how is information or perception used to determine time allocation to activities and travel; is time use behavior pre-planned, is it subject to dynamic adjustment, is it rather unplanned, or is there a mixture of these different processes, c) whether the attributes of activity episodes are determined jointly or sequentially, and d) how exactly are spatial-temporal and inter-individual constraints brought to bear on activity episode patterns and how do individuals (as part of their households) make decisions about in-home and out-of-home activity episode participations.

The main challenge to studying these issues is that time-use diary data provide only revealed activity episode patterns. The generation and scheduling process that determines the revealed episode patterns can only be understood if additional data on the internal mechanism leading up to revealed episode patterns is collected. Such data might be obtained in experimental (but fairly realistic) settings using "think-aloud" protocols or by collecting information on intended episode patterns at several points in the day, comparing these patterns with actual revealed patterns, and asking respondents to identify reasons for updating/revising their patterns.

A question that arises quite naturally in the above context is how much of the process do we really need to understand for the purpose of travel demand forecasting and policy analysis. To address this question, it is important to compare predictions and policy forecasts from realistic, but complicated episode generation and scheduling models with those from less realistic, but simpler modeling methods. Developing guidelines indicating when (*i.e.*, in what kinds of forecasting and policy situations) a more realistic process model is warranted and when a simpler model will suffice is an important research area in and of itself.

4.4. Use of geographic information systems in time-use research

A modeling tool that has developed quite considerably in the past few years is Geographic Information Systems (GIS). A GIS facilitates the representation of spatial information in an intuitive manner and also allows storage and manipulation of vast amounts of spatial information. Thus, it is useful in modeling the spatial contexts of activity episode patterns and the interaction of temporal characteristics with spatial attributes. Fotheringham and Rogerson (1993) discuss the potential of integrating activity-travel analysis methods with GIS technology. A specific application of GIS technology to activity-travel analysis is the development of a measure of accessibility for use in the modeling of spatial-temporal attributes of multistop and multi-purpose travel (see Arentze *et al*., 1994a,b,c; Lee, 1996). Golledge *et al.* (1994) and Kwan (1994) have used a GIS to calibrate a production system model of activity scheduling behavior.

While existing GIS tools can be used for activity episode analysis, they have yet to receive much attention in time-use research. A possible reason is the predominant spatial orientation of GIS systems to date. Almost all GIS systems do not accommodate a temporal dimension. This is a limitation of GIS for time-use research. But developments to include a temporal as well as a spatial dimension are currently underway and such dynamic GIS systems will provide a valuable tool for time-use researchers to describe, present, and model activity episode patterns.

5. Summary and Conclusions

The activity-based travel paradigm is being increasingly accepted as the basis for travel demand analysis. A central component of this paradigm is the examination of individuals' activity episode pattern involvement within the context of spatial, temporal, family, social, and other environmental considerations; that is, the study of time-use in appropriate context.

This paper has reviewed earlier theoretical and empirical research in the areas of activity time allocation and activity episode analysis. The paper emphasizes the need to focus on activity episode analysis rather than activity time allocation.

The review indicates substantial progress in empirical activity episode analysis research in recent years. The accelerated progress in this field may be traced to at least four factors. First, Metropolitan Planning Organizations (MPOs) in the United States and elsewhere are moving away from traditional trip-based surveys to time-use surveys which provide the relevant data for development of activity episode models (see Lawton and Pas, 1997). Second, the tools available for data storage and processing have seen dramatic improvement over the past few years. Desktop and even notebook computers are able to store data of large sizes and are remarkably fast in the retrieval and processing of such data. This has facilitated the analysis of activity episode patterns as a whole rather than in a disjointed fashion. Third, the use of methods that recognize the continuous nature of time are becoming more common place in travel demand modeling. Examples of such methods include hazard-based duration analysis, limited-dependent variable models, and computational process models. These methods stand in contrast to traditional discrete choice models which have pervaded much of travel demand literature and which are unable to accommodate the continuous nature of time. Finally, the shift in emphasis from evaluating long-term investment-based strategies to understanding the impact of shorter term congestion management policies (such as alternate work schedules, telecommuting, and congestion-pricing) has led to the practical need for activity episode pattern models.

While we have made considerable progress in empirical models of activity episode analysis, there is still a substantial void in our knowledge about the fundamental time-use decision mechanism underlying activity episode patterns. Hopefully, as we collect more extensive time-use data and complement this with experimental data that provides information on the episode generation/scheduling process, this void will be filled. In turn, this will provide insights into refining our empirical episode generation and scheduling models.

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