A Review of Activity-Based Travel Demand Modeling

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ABSTRACT

Activity-based models belong to the third generation of travel demand models, which have received extensive interest in the past three decades. Activity-based modeling of travel demand treats travel as being derived from the demand for activity participation. This paper presents an overview of recent and on-going contributions made by "activity-based approaches" to forecast travel behavior. First, a brief history of two travel demand approaches is introduced. Then, four modeling methods in activity travel analysis are reviewed. On top of that, essential applications of this approach for addressing contemporary policy and planning issues are provided. Finally, some of the directions are highlighted for future development of activity-based analysis.

INTRODUCTION

Travel demand models are used for forecasting the response to transportation demand of changes both in the attributes of the transportation system and the people using transportation system. More specifically, travel demand models are used to predict travel characteristics and usage of transport services under alternative socio-economic scenarios and land-use configurations (Bhat et al, 2003). Since 1970s, transportation planning turned the focus from regional planning (associated with evaluating long-term investment-based capital improvement strategies), to policy planning, where the importance of individuals' reactions is essential. More behavior-oriented activity-based models had replaced the traditional statistic-oriented trip-based models.

The primary objective of this paper is to identify recent advances in activity-based travel demand modeling. The review is intended to include representative recent works in the field of activity based travel demand modeling, so that the type and extent of the advances can be made.

The remainder of the paper is organized as follows. Section 2 describes a brief history of trip based travel demand models and activity-based travel demand models; Section 3 provides an overview of recent advances in the modeling methods of activity-based travel models; Section 4 provides some essential applications of travel demand modeling, Section 5 concludes the paper by identifying important future research topics in the area of activity-based travel demand modeling.

TWO TRAVEL DEMAND APPROACHES

Trip Based Travel Demand Models

Trip based travel demand models was originally developed in the late 1950's, which used individual trips as the unit of analysis and consisted of four sequential steps: trip generation, trip distribution, mode choice (these three steps are also usually referred as 'travel demand') and assignment (also referred as 'travel supply'). There were mainly two types of trip based travel demand models: aggregate trip based models and disaggregate trip based models.

Although the derived nature of transport was understood and accepted, it was not reflected in the four-stage models (both trip based aggregate and disaggregate demand models). The limitations of the trip based models can be summarized as follows: (1) They ignored the fact that the demand for travel is derived from the demand for activity participation; (2) They focused on individual trips (or tours), ignoring the spatial and temporal relationship between all trips and activities completed by an individual; (3) They failed to include constraints defined by Hagerstand (Hagerstand, 1970) in their structure; (4) They saw an individual as a decision-maker isolated from the household context.

Activity Based Travel Demand Modeling

The activity-based travel demand analysis viewed travel as a derived demand from the need to pursue activity distributed in space (Axhausen and Garling, 1992). This approach was founded on the seminal work undertaken previously by the sociologist and planner, F. Stuart Chapin Jr., at the University of North Carolina at Chapel Hill (Chapin, 1974), and by the geographer Torsten Hagerstand at Lund University in Sweden (Hagerstrand, 1970). Hagerstrand postulated that individuals' activities were limited by a number of personal and social constraints. In his famous time-geography theory, he also postulated that individuals live in a time-space prism in which we can only function in different locations at different points by experiencing the time and cost of travel and by considering the above listed constrains (coupling constraints, authority constraints). Therefore, the theory assumed that travelling to certain destinations, at certain times of day and by certain travel modes resulted from the demand activity participation.

Focusing on opportunities and choices, Chapin's theory postulated that the activity demand was motivated by basic human desires, such as the desires for survival, social encounters and ego gratification, which had later on been modified by some more factors including commitments, capabilities and health.

Activity-based travel research had received much attention and seen considerable progress since these early studies (Kitamura, 1988; Pas, 1996; Jovicic, 2001; Bhat, 2003). Generally, activity based paradigm included five important features: (1) Travel was derived from activity participation; (2) Activity based approach focused on sequences of patterns of activities; (3) Individual's activity were both planned and executed in the household (family) context; (4) Activities were spread throughout a 24-hour period in a continuous manner, rather than simple categorization of 'peak' and 'off peak' events; (5) Travel and location choices were limited in time and space, and by personal constraints.

MODELING METHODS IN ACTIVITY-BASED TRAVEL MODELS

In this section, we discuss various methods used in activity-based travel analysis, including discrete choice models, hazard duration models, structural equation models, and computational process models.

Discrete Choice Models

Discrete choice models have been used to model complex travel behavior by the activity-based approach since 1980s, although it was originally developed and applied in the context of trip based framework.

Ben-Akiva and Bowman (1995) developed a model in which they considered the daily activity-travel pattern as a set of tours. Each tour was assumed to have a primary activity and destination, in which the primary activity refered to the major motivation for the tour. In addition, tours were sub-divided into primary and secondary tours. Thus, the daily activity-travel pattern was characterized by the primary activity, primary tour type, and the number and purpose of secondary tours. The tour models, which were conditioned on the choice of daily pattern, included the choice of time of the day (one of four discrete time periods), destination (discrete traffic analysis zones), and mode. Although this model could be used by an MPO with the ability of estimating a nested-Logit model, it was quite limited in the context of spatial and temporal resolution.

On top of that, Bowman (1998) developed the Portland model in his Ph.D. thesis. In this model, the trade-offs among patterns that include at-home and on-tour activities, multiple tours and trip chaining could be captured. There were basically three types of results derived from the application of Portland model: (1) The basic output of the model was an activity pattern for each individual in the population. The individual patterns could also be visualized in GIS. (2) Predicting activity patterns for each individual in the population allowed a flexible aggregation of results for policy analysis. In other words, the results could be aggregated according to any socio-economic classification in which reliable variables were available at the individual level. (3) The individual activity patterns could be aggregated on the zonal level, which produced origin-destination trip matrices. The trip matrices were split by mode, trip purpose, time-of-day and income classes, and they could be assigned on the road and public transport networks.

Bhat (1997) developed a joint model of work mode choice and number of non-work stops during the work commute. Mode choice was modeled using a disordered choice model and number of stops was modeled using an ordered response formulation. Using the data from the 1990 Boston Area Survey, the results demonstrated the importance of accommodating the inter-relationship between mode choice to work and number of non-work activity stops in the work commute. The results also showed that commuters who made non-work stops on the work commute were unlikely to be drawn away from the drive alone mode.

Hazard Duration Models

Hazard-based duration models have been applied to travel demand modeling since 1980's. The general idea of a hazard-based duration model was that it tried to model the conditional probability of "failure" at time t, given that failure had not occurred prior to this time. Therefore, for example, one might try to model the probability that a worker finds a job at time t, given that she/he is unemployed up to this time.

The most pertinent application of the hazard-based duration in activity-based travel demand modeling is in connection with modeling the activities and home-stay duration (Mannering, *et al*, 1992; Ettema, *et al*, 1995). Another use of hazard-based duration models is modeling the time until the next particular activity occurs. For example, the time between shopping activities could be modeled with the appropriate data.

Mannering *et al* (1992) applied hazard-based duration models to model the length of time a traveler spent at home before making another trip. In particular, this work dealt with the amount of time a commuter spent at home after work and before leaving home to take part in another out-of-home activity.

Ettema *et al* (1995) used a "competing risk" hazard model to deal with both activity duration and activity choice. The results showed that spatial-temporal constraints such as time of day, opening hours and travel time, played an important role in activity scheduling. Activity duration and type were also found to be dependent on the history of the activity-travel pattern and the traveler's priorities. The author concluded that the estimated model performed satisfactorily,and hold promise for describing activity scheduling as a continuous decision-making process, although further development was needed to deal with some important technical issues.

Bhat (1996) extended the methodology of hazard-based duration models by developing a hazard-based duration model of shopping activity duration on the way to home from work.

Structural Equation Models

Structural equation models applied in travel demanded modeling were first conducted by Golob (Golob and Meurs 1987; Golob, 2003). Recently, more and more researchers started to apply this methodology to include activity-based travel demand modeling.

Golob and McNally (1995) developed a joint model of the out-of-home activity participation and the travel of couples in a household. Golob (2000) developed a trip generation model to forecast three sets of endogenous variables: (1) activity participation (2) travel time, and (3) trip generation as a function of household characteristics and accessibility indices. The results showed that, the basic model, which had 10 endogenous time use and trip generation variables and 13 exogenous variables, fit well, and all postulated relationships were upheld. Test showed that the basic model, which divided activities into work and non-work, could be extended to a three-way breakdown of subsistence, discretionary and obligatory activities. This model could also capture the effects of in-home work on trip chaining and activity participation.

Lu and Pas (1999) developed and interpreted a structural equation model relating socio-demographics, activity participation and travel behavior, in which a complex set of interrelationships among the variables of interest were estimated simultaneously. This research reached the following conclusions. First, significant relationships among socio-demographics, activity participation and travel behavior could be simultaneously captured by the estimated model. Most of the estimated direct effects correspond with the historical findings. Second, travel behavior could be explained better by including activity participation in the model. Third, relationships between in-home and out-of-home activity participation did exist and could be estimated and interpreted. Finally, by examining the direct, indirect and total effects in the model system, we could better capture and understand the relationships among socio-demographics, activity participation and travel behavior, thereby demonstrate the usefulness of structural equation models in modeling the complicated relationships among socio-demographics, activity participation and travel behavior.

Kuppam and Penyala (2001) presented three separate models estimated using WLS applied to data for Washington DC. These models focused on relationships among (1) activity duration and trip generation, (2) duration of in-home and out-of-home activities, and (3) activity frequency and trip chain generation.

Rule Based Simulation Models

Simulation activity based models constructed activity schedules by considering Hagerstrand's constraints explicitly in their structure in a continuous time. There were two main groups of these models, i.e. activity schedule building models and switching models (Jovicic, 2001). The difference between the two approaches was that the building models constructed an activity schedule from scratch while the switching models altered the predefined schedule as a result of proposed changes (e.g., policy changes or infrastructure changes).

A number of rule based simulation models have been developed since 1980s. CARLA (Jones, et al., 1983) and STARCHILD (Recker et al. 1986) are the two early examples. In these models, the set of activities to be performed was generally taken as given. The SAMS model, developed by Kitamura in 1996, was an integrated simulation model and land-use, socio-demographics, vehicle transactions, activity-travel behavior, network performance and air quality. The AMOS model, which was at the heart of the SAMS model, was an example of Rule Based Simulation Model that had been applied to a real-world policy analysis situation. The development and application of the AMOS model in the Washington, DC area was designed to demonstrate how an activity-based travel demand model could be used to forecast commuters' short-term responses to the type of TCM measures. Other representative simulation models include SCHEDULER (Garling et al, 1994), SMASH (Ettema et al 1995), and PCATS (Kitamura, 1996).

APPLICATIONS OF ACTIVITY-BASED TRAVEL MODELS

Activity-based travel models have been applied to model many different phenomena. In this section, we mainly focus on the phenomena not mentioned in the methodologies section above.

In-Home and Out-of-Home Activity Substitution

Understanding the tradeoffs and relationships of In-Home and Out-of-Home Activity is important. Because the in home/out-of-home participation has an impact on the generation of trips. A number of works have examined this issue.

Based on random utility maximization, Kitamura et al. (1996) formulated a discrete-continuous model of time allocation of the two discretionary activities. They concluded that individuals who worked on a given day tended not to engage in discretionary out-of-home activities. Yet, those who work more hours per week tended to spend more discretionary time out-of-home. Individuals who spent more time commuting spend more time on in-home discretionary activities. In addition, the factors of child caring, size of the family strongly affected the in-home/out-of-home allocation, while income and number of vehicles and flexible work hours did not significantly influence the tradeoffs between in-home and out-of-home activities.

Using the data from Portland portion of the 1994/1995 Oregon-Southwest Washington Household Activity Survey, Lawson (1996), in her dissertation, modeled the decision to undertake an activity in-home or out-of-home and explicated the factors that contributed to the decisions. The explanatory factors in this model include household composition, work characteristics, age composition and lifestyle status.

Interpersonal Dependencies

Interpersonal dependencies have been recognized since the early work at TSU Oxford. Though modeling these dependencies is particularly difficult, some researchers have tackled the task.

Srinvivasan and Reddy (2005) examined maintenance activity allocation and participation of household members. They specifically modeled whether an activity is pursued alone or jointly with another household member, and the specific person in the household who pursued the activity. Their analysis suggested that household life-cycle variables such as household role, gender, income, auto availability, working status, and presence/absence of children played a major role in determining joint and solo activity participation in maintenance activity.

Kato *et al* (2009) investigated the joint resource allocation of households using a utility-maximizing model. The joint time allocation model was formulated, from which a nonlinear Tobit model was derived. The empirical analysis revealed that the greater the number of children in a household is, the higher the significance of the husband and wife's joint out-of-home leisure activity is ; the more the non-working days of the husbands had, the lower the significance of the their individual out-of-home leisure activities is .

Kang *et al* (2011) examined the impacts of criteria at different levels of flexibility (i.e., restrictive vs. flexible) on the identification of joint activities and our understanding of household time allocation pattern. Using data from the first wave of the Toronto Travel-Activity Panel Survey, the results derived from both the descriptive analysis and structural equation modeling provided evidence of disparity.

In particular, the use of flexible criteria improved model fit and provided more insights into household time allocation patterns. These findings suggested that new activity-travel surveys should collect information on involved persons. However, in the absence of such companion information, transportation modelers should use more flexible criteria instead of restrictive criteria to identify joint activities.

Daily Activity-Travel Patterns

Besides the work of Ben-Akiva and Bowman (Bowman, *et al*, 1995, 1998), a number of other researchers also made some contributions to the modeling of daily activity-travel patterns.

Wen (1998) developed an operational econometric model system for generating complex daily activity patterns. This model dealt with not only stop and tour generation and the assignment of stops to tours, but also the location for each stop and the mode for each tour. Meanwhile, he also incorporated interpersonal dependencies in the model system.

Vaughn et al (1997) replicated the distribution of activity travel patterns at the census block group level and recognized the interdependencies and linkages existed within households. The daily activity-travel pattern was generated by a two-stage procedure: generating the skeletal pattern based on socio-demographics and then simulating the pattern details on observed probability distribution.

Lee et al (2007) applied simultaneous doubly-censored Tobit modes to model time use behavior within the context of household activity participation. Using the entire sample and a sub-sample of worker households from Tuscon’s Household Travel Survey, two sets of models were developed to better understand the phenomena of trip chaining behavior among five types of households. Durations of out-of-home subsistence, maintenance, and discretionary activities within trip chains were examined. The results showed that intra-household interactions with the household types and their structure and household attributes were associated with trip chaining behavior.

Integration of Activity-Based Modeling and Dynamic Traffic Assignment

Most of the research efforts in activity-based approaches (the demand side) and dynamic traffic assignment techniques (the supply side) have been undertaken relatively independently. To maximize benefits from these advanced methodologies, Lin *et al* (2008) developed a conceptual framework and explored practical integration issues for combining the two streams of research. Technical, computational and practical issues involved in this demand-supply integration were discussed. They explored specific technical details related to the integration by employing CEMDAP for activity-based modeling and VISTA for the dynamic traffic assignment modeling. They also studied solution convergence properties of the integrated system, specifically examining different criteria for convergence, different methods of accommodating time of day and the influence of step size on the convergence. Further, they applied the integrated system to sample networks selected from the Dallas Fort Worth network. They examined different criterion for convergence, different means of partitioning the day and influence of step size on the convergence. As a result, it was evident that trip table convergence criterion, multiple time interval portioning and varying step size yield faster and more stable convergence results.

DISCUSSION & CONCLUSIONS

Overviewing the recent and on-going work of activity-based travel demand modeling, we can see that a wide variety of methodologies are being developed and employed in modeling many aspects of activity-travel behavior. Although substantial progress has been made in this field, there is still a long way to go in understanding how households and individuals make choices that drive their activity and travel patterns. The following two directions are considered to be important.

Time-Space Interaction in Activity Behavior

Most of the early research in the activity analysis area focused on the dependence in spatial choice among activities using either discrete choice models or semi-Markov processes, which had ignored the temporal aspects of activity process. More recently, some researchers emphasized timing and duration of activities but did not examine spatial issues. Little work has been done to develop an integrated modeling approach combining both temporal and spatial aspects.

Analysis Unit

In most of previous research on activity-based travel models, the analysis unit was the weekday, which did not allow the examination of the interaction in activity participation between weekends and workdays. In order to measure the variation in activity-travel patterns across different days of the week, the analysis unit should be expanded to at least one week, which will offer research opportunities for the development of data techniques that can collect time-use data over a week without being prohibitively unaffordable or appearing excessively intrusive to respondents.

There is no doubt that much more important theoretical and methodological advances will be made in the field of activity-based travel demand modeling.

Meanwhile, activity paradigm will be more widely applied in practices of travel demand modeling.

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