Accommodating Intra-Household Interactions in Activity-Based Model Systems: How Much Does it Matter from a Forecasting and Policy Sensitivity Standpoint?

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1. OBJECTIVES, MOTIVATION, AND INNOVATION

At a fundamental level, the emphasis of the activity-based approach is on activity participation and scheduling over a specified time period (usually a weekday in the U.S.), with travel being viewed as a derivative of out-of-home activity participation and scheduling decisions. While the detailed structures of activity-based models (ABMs) vary substantially, it is typical for operational ABMs to model "mandatory" activity decisions such as out-of-home work-related decisions (employed or not, duration of work, location of work, and timing of work) and education-related decisions (student or not, duration of study, location of study, and timing of study) as precursors to the generation of out-of-home non-work activity participations and the overall activity-travel schedules of individuals (including the scheduling of work and non-work episodes). Within the context of the generation of out-of-home non-work activity participation, while early activity-based travel studies and operational models ignored the interactions between individuals within a household, more recent studies and models have emphasized the need to explicitly consider such interactions and model joint activity participations within a household. This is motivated by several considerations. First, individuals within a household usually do not make their activity engagement decisions in isolation. Rather, an individual's activity participation decisions are likely to be dependent on other members of the household because of the possible sharing of household maintenance responsibilities, joint activity participation in discretionary activities, and pick-up/drop-off of household members with restricted mobility. For instance, a husband's and wife's activity schedules are necessarily linked because of the spatial and temporal overlap when they both watch a movie or an opera at a theatre. Second, there is a certain level of rigidity in joint activity participations (since such participations necessitate the synchronization of the schedules of multiple individuals in time and space), because of which the responsiveness to transportation control measures such as pricing schemes may be less than what would be predicted if each individual were considered in isolation (Vovsha and Bradley, 2006, Timmermans and Zhang, 2009). Third, the activity-travel attributes of joint activity participations are systematically different from individual activity participations, even beyond the issue of rigidity in schedule. For instance, descriptive studies indicate that, in general, joint discretionary activity episode participations entail longer travel distances and longer participation durations relative to individual episode participations (Srinivasan and Bhat, 2006 and Vovsha *et al.*, 2003). Moreover, when a joint activity episode participation entails joint travel of some or all members participating jointly in the activity episode, the travel is more likely to be undertaken using larger and more spacious vehicles such as sports utility vehicles and vans, impacting the vehicle composition by type in the region, a key determinant of vehicular emissions (Konduri *et al.*, 2011).

The emphasis on joint intra-household activity decisions has led to (or perhaps also been motivated by) another key substantive issue that has been receiving attention only more recently in the activity-based travel modeling literature. This pertains to the explicit modeling of children's activity decisions, and the inclusion of both adults' and children's activity-travel patterns within the travel demand modeling framework (this is as opposed to the focus until recently in the literature only on adults' activity-travel patterns; see Kapur and Bhat, 2007 and Bowman and Bradley, 2008). After all, as Reisner (2003) indicates, parents spend considerable time and resources transporting children to and from after-school activities, while other studies have found that parents, especially mothers, make frequent stops on the commute to work and to, or from, non-work activities due to the need to escort children to activities (see Paleti *et al.*, 2010 and Kato and Matsumoto, 2009 for extended discussions on this topic). The participation of children in activities, therefore, necessarily constrains adults' activity-travel patterns in important ways and may make an adult unresponsive to policy changes that attempt to modify travel mode, time of travel, or destination of travel. For instance, a parent driving a child to school during the morning peak is unlikely to shift away from the morning peak because of a congestion pricing strategy, even if the parent has a flexible work schedule. Similarly, in the case of a parent dropping a child off at soccer practice, it is the child's activity episode and its location that determines the temporal and spatial dimensions of the trip. In this context, Stefan and Hunt (2006) indicate that children as young as six years of age start developing their own independent activity participation needs that are then fulfilled by the logistical planning of their parents. Finally, the presence of children in the household can also increase joint activity participation in such activities as shopping, going to the park, walking together, and other social-recreational activities. Overall, modeling children's activity engagement (and the interactions between these engagements and those of adults) within activity-based travel model systems is an important pre-requisite for accurate travel forecasting in response to shifts in population demographics and land-use/transportation policies.

In the current paper, we use an intra-household interactions framework developed by Bhat et al. (2012) and embedded within the larger activity-based modeling structure for the Southern California region (labeled as Simulator of Activities, Greenhouse emissions, Energy, Networks, and Travel or SimAGENT) to examine two related questions: (1) How much improvement (if any) is obtained in terms of travel forecasting through the introduction of intra-household interactions?, and (2) How much difference is there in terms of policy sensitivity results between applying a model with and without household interactions? Conceptually, based on the interaction considerations discussed earlier, we would expect to see differences both in forecasting ability as well as in policy sensitivity. But are these differences substantial or small? The intent here is to quantify the differences to be able to make initial conclusions regarding the importance of accommodating household interactions.

2. METHODOLOGY

2.1. How SimAGENT considers intra-household interactions

There are several possible ways to model intra-household interactions in activity engagement decisions, including rule-based approaches (see Arentze and Timmermans, 2004 and Miller and Roorda, 2003) and econometric approaches. Most of the earlier studies have used the latter econometric approach to model intra-household interactions. These studies may themselves be grouped into three categories. The first category of studies uses structural equations modeling (SEM) to estimate models of individual and joint activity participation durations for household members over a daily period or a weekly period (see, for example, Chung *et al.*, 2004, and Mosa *et al.*, 2009)). Although SEM is a powerful technique often used in the social sciences to uncover complex relationships among several variables, it gets computationally intensive and intractable as the dimensionality of the problem increases. Moreover, model identification also becomes a critical issue as the number of dependent variables increases (Werner and Engel, 2009).

The second category of studies uses a discrete choice framework or a discrete-continuous framework to model individual and joint activity participations. For instance, Bradley and

Vovsha (2005) use a three-way aggregate activity purpose type classification to represent the daily activity pattern (DAP) for each individual in the household (participation in work/school activity with possible participation in one or more non-work activities during the day, participation only in non-work/school activities during the day, and stay-at-home over the entire course of the day) and then develop a traditional discrete choice model by developing composite alternatives each of which represent a specific combination of the DAPs across individuals. The problem with this approach, of course, is that there is an explosion in the number of composite alternatives as soon as one attempts to use a more disaggregate activity purpose type classification to represent the DAP, as acknowledged by Vovsha and Bradley.

The third category of studies models intra-household interactions using a time allocation framework (Zhang and Fujiwara, 2006, Kato and Matsumoto, 2009). In the class of such time allocation models, the Multiple Discrete Continuous Extreme Value (MDCEV) model developed by Bhat, 2008 is a simple and parsimonious way to accommodate intra-household interactions. It also is based on the notion that individuals determine the activity purposes to participate in, make decisions regarding with whom to participate in activities, and allocate time to different "activity purpose-with whom" combinations based on satiation and variety seeking behavior. Given these appealing behavioral characteristics of the MDCEV model, several recent studies have used the structure and its variants in the context of activity time use modeling (Habib and Miller, 2008, Xia *et al*., 2009, Paleti *et al.*, 2010). However, these earlier applications of the MDCEV model have been individual-level models of time-use among multiple activity purposes, sometimes with aggregate representations of the "with whom" context of activity participations. They are fundamentally not household-level models of activity pattern generation. At the same time, the use of the MDCEV framework for household-level activity generation lends itself nicely to incorporation within a larger activity-based model system, and does not have the explosion problem that characterizes traditional discrete choice methods.

In the SimAGENT model system, we use the MDCEV model to analyze the joint and individual activity participation decisions of all household members in out-of-home (OH) activities on weekdays (see Bhat, 2012 for details of the MDCEV model structure). SimAGENT includes many components that act together to generate activity-travel patterns, network flows by vehicle type, and travel-related greenhouse gas (GHG) emissions. Specifically, SimAGENT includes a population synthesizer, an accessibility generator, a land-use/demographic micro-simulator, an activity-travel pattern generator and scheduler, a traffic assignment modeler, and an emissions and fuel consumption predictor. A complete overview of the SimAGENT system is provided in Goulias *et al*. (2012). The household level activity pattern generator module of this paper is embedded within the activity-travel pattern generator and scheduler component of SimAGENT. This component of SimAGENT simulates activity-travel patterns of all individuals in the region for a 24 hour period along the continuous time axis. The component includes an (a) activity generation step in which work and school activity participation and timing decisions of all individuals in the household are created, children's travel needs to school are predicted, an allocation of school escort responsibilities to parents takes place, and household-level activity patterns in non-work activity participation decisions are modeled; and an (b) activity scheduling step that produces the sequence of activities, with the departure and arrival times, the participating individuals, activity durations, mode(s) used and accompanying individuals during the travel to each activity, the vehicle type used in the travel, and the location of each activity.

2.2. Assessing Forecasting Ability and Comparing Policy Sensitivity

The assessment of forecasting ability will not simply be based on comparing the predicted results from the SimAGENT model without household-level interactions (SimAGENT-1) and the SimAGENT model with household-level interactions (SimAGENT-2) to observed network link flows. Rather, the emphasis will be on examining forecasting performance along multiple activity-travel dimensions, such as total travel (total number of trips, total vehicle miles of travel, and vehicle hours of travel), travel by purpose (number of trips and vehicle miles of travel by purpose), mode shares by purpose, trip distance distribution by purpose and mode, activity chaining behavior, and time-of-day distribution by purpose. The “ground truth” for assessing forecasting ability will include (a) observed *trip making attributes* obtained from the Southern California Association of Governments (SCAG) 2003 Household travel survey data and the 2000 Census data, and (b) observed *travel and travel distribution attributes* from the 2003 Household travel survey data, the HPMS (Highway Performance Monitoring System) data, and link and cordonline counts by vehicle class and time of day. The fit measures employed for comparison of model attributes with the observed data will be the Absolute Percentage Error (APE) measure and the Root Squared Error (RSE) measure, defined as follows:

$$APE = \frac{|\,(\text{Observed Data} - \text{Predicted Data})\,|}{\text{Observed Data}} \times 100$$

$$RSE = \sqrt{(\text{Observed Data} - \text{Predicted Data})^2}$$

For the policy sensitivity tests, a wide range of land-use and transportation policy scenarios will be considered, and the predicted activity-travel changes from the two models (SimAGENT-1 and SimAGENT-2) will be examined with respect to the relative order of magnitude of changes (elasticity effects), the direction of shifts, and overall reasonableness. The policies will include scenarios such as increased auto operating costs and gasoline costs, cordon pricing and similar area pricing schemes, increase in parking charge in downtown areas, and improved transit service and transit accessibility

3. EXPECTED MAJOR RESULTS

State agencies across the U.S. are currently considering and implementing land-use and transportation control strategies to reduce traffic congestion, curb greenhouse gas (GHG) emissions, and decrease fossil-fuel dependence. In this regard, it is important to be able to assess the potential effectiveness of different policies, so that informed decisions can be made. Within this context, conceptual arguments would clearly favor the consideration of household-level interactions in activity-based travel models to capture the potential complex responses of households and individuals. However, there has been no research in the literature examining the performance of model systems with and without household-level interactions, a gap that this research attempts to fill.

A caveat is in order here. The results obtained from this study should not be generalized, since they are based on a specific modeling structure for household-level interactions and the activity-based modeling system as a whole. But the current paper should provide a first glimpse on the practical importance of considering intra-household interactions within activity-based modeling systems.

4. IMPLICATIONS FOR THE SCIENCE AND PRACTICE OF TRAVEL MODELING

The study contributes to the science of travel modeling by quantitatively examining the importance of considering household-level interactions. The analysis is undertaken in the context of the SimAGENT modeling framework that has formulated and estimated a household-level activity pattern generation model that at once predicts, for a typical weekday, the independent and joint activity participation decisions of all individuals (adults and children) in a household, for all types of households, for all combinations of individuals participating in joint activity participations, and for all disaggregate-level activity purposes. The model uses a host of household, individual, and residential neighborhood accessibility measures as inputs, and has been embedded within the larger activity-based modeling structure for the Southern California region.

The results from this study is not intended to provide any conclusive evidence in terms of whether or not household interactions should be considered in the practice of travel modeling. But we believe studies such as the one proposed here are needed to better understand the practical value of behaviorally and conceptually rich model specifications.

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