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A random utility based estimation framework for the household activity pattern problem

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ABSTRACT

This paper develops a random utility based estimation framework for the Household Activity Pattern Problem (HAPP). Based on the realization that outputs of complex activity-travel decisions form a continuous pattern in space-time dimension, the estimation framework is treated as a pattern selection problem. In particular, we define a variant of HAPP that has capabilities of forecasting activity selection and durations in addition to activity sequencing. The framework is comprised of three steps, (i) choice set generation, (ii) choice set individualization and (iii) model estimation. The estimation results show that utilities for work, shopping and disutilities for travel time, time outside home, and average tour delay are found to be significant in activity-travel decision making.

1. Introduction and literature review

In the field of transportation planning and engineering, the activity-based approach continues to generate interest in terms of model development and implementation Pinjari and Bhat (2011). Activity-based models focus on travelers' participation in *activities* that derive the need to *travel* and therefore account for a more realistic disaggregate view of travel behavior. Instead of focusing on modeling individual trips, activity-travel models focus on *why* such trips are derived, and more generally focus on modeling entire travel-activity patterns.

Broadly, there exist four types of approaches: (1) constraint-based, (2) econometric, (3) simulation process, and (4) mathematical programming. Constraint-based approaches use an activity program as an input, these models consider the feasibility of particular patterns with respect to a set of constraints, such as business hours for commercial or retail organizations. Implementations of this approach include PESAP (LENNTORP, 1979), CARLA (Jones et al., 1983), MASTIC (Dijst and Vidakovic, 1997; DIJST, 1995), and GISICAS (Kwan, 1997). Econometric approach views activity patterns as the outcome of utility maximizing decisions or choices, which serves as a theoretical foundation of econometric models of discrete choice. Due to its flexibility and behavioral foundations, it has been widely implemented. Notable models include the Comprehensive Econometric Micro-simulator for Daily Activity-travel Patterns (CEMDAP) (Bhat et al., 2004), and Florida Activity Mobility Simulator (FAMOS) (Pendyala et al., 2005). Simulation process approach conceptualizes activity scheduling as a process than can be modeled and simulated through computational methods, such as agent-based modeling and other stochastic process simulation approaches. Implementation of this approach includes Travel Activity Scheduler for Household Agents (TASHA) (Miller and Roorda, 2003), A Learning-Based Transportation Oriented Simulation System (ALBATROSS) (Arentze and Timmermans, 2004), the Forecasting Evolutionary Activity-Travel of Households and their Environmental RepercussionS (FEATHERS) (Bellemans et al., 2010), etc.

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The Household Activity Pattern Problem (HAPP) (Recker, 1995), is a mathematical programming approach to travel analysis under the activity-based framework. According to HAPP, activity travel patterns are the result of a household optimization with respect to a set of space-time and resource constraints, where the objective function represents travel (dis) utility. HAPP serves as a theoretical reasoning behind travel and activity decisions when faced with temporal and spatial constraints, in addition to resource constraints such as travel budget and tour length (Hägerstraand, 1970; Kwan, 1998). Mathematically, HAPP is an interpretation of personal- (household-) level daily travel posed as a variation of the well-known Pickup and Delivery Pattern Problem with Time Windows (PDPTW) formulation.

$$\text{(HAPP)}\min_{X,T} \text{Travel Disutility} \tag{1}$$

$$A\begin{bmatrix} X \\ \hline T \\ \hline Y \end{bmatrix} \leq B \tag{2}$$

Decision variable X explains spatial decisions, T represents temporal decisions of a traveler, and Y is the tour length variable. Specifically, $X_{u,w}^{k} = 1$ represents a traveler traveling from one activity location, u, to another, w, by vehicle k. T_u will take the time at which activity u begins, and Y_u will represent the tour length at the beginning of the start of activity u. Constraints, A, B in Eq. (2) are comprised of (a) spatial constraints and (b) temporal constraints. Spatial constraints state that mandatory activities need to be performed (or, selective activities can be performed) and traveler flow conservation. Temporal constraints state that these activities must be performed within given time windows by given activity durations while respecting travel times between locations. Additional constraints may limit the total tour length or travel budget. The objective function is represented as a weighted combination of multiple terms that are used to capture the key factors of determining travel disutilities. Previous literature typically uses travel disutilities (travel time, total extent of the day, tour length delay), and recent work by Chow and Nurumbetova (2015) added utility gain of activity participation in addition to travel disutilities.

The flexible structure of HAPP as a Mixed Integer Linear Programming (MILP) provides a good platform that is easily extended to meet a modeler's specific objectives while keeping the governing rules of travel and activity decisions within the constraints imposed by time-space geography intact. Rescheduling problem (Gan and Recker, 2008, 2013), destination choice (Kang and Recker, 2013), multi-day (Chow and Nurumbetova, 2015), multi-modal extensions (Chow and Djavadian, 2015), activity arrival and duration choice (Yuan, 2014), time-dependent scheduling (Yuan, 2014) have been proposed based on the original concept. In the application side, scenario-based assessment studies were conducted (Kang and Recker, 2014; Chow, 2014; Recker and Parimi, 1999).

This distinct structure of HAPP brings diversity for travel demand models that are mostly based on discrete choice or agent-based approaches. This helps bring explanations for certain transportation issues that arguably could not have been addressed by other types of travel demand models. For example, it is possible to simulate cases that we have no previously observed travel demand data of, utilizing the property of HAPP that it is built from the governing rules of travel and activity decisions within the constraints imposed by time-space geography. Despite the advantages and potential, HAPP model has not been widely used as a forecasting tool due to the difficulty in estimating the objective function. Forecast activity-travel decisions and activity-travel patterns cannot be generate personalized pattern with constraints alone. The objective function of HAPP needs personal input, specifically people's valuation of things that influence their fundamental activity participation and travel behavior.

One methodological challenge in implementing HAPP as a forecasting tool is parameter estimation required for the linear-in-parameters objective function given a conventional dataset of observed travel-activity decisions. These parameters reflect the weighting or value households endogenously place on the components of the objective function. Additionally, the constraints in the mathematical program also contain behavioral parameters that require estimation, such as household time and money budgets.

Growing interest in operationalizing the HAPP model has led to two parameter estimation procedures in the literature. In Recker et al. (2008), decisions from variables X, T, Y are treated as a set of strings and the parameters of HAPP are tuned by genetic algorithm to minimize Levenshtein distance of strings from observed pattern and strings generated by HAPP. Chow and Recker (2012) proposed an inverse optimization based method to estimate HAPP parameters based on the structure of the MILP.

In this paper, an estimation procedure based on random utility maximization (RUM) choice theory is developed to provide parameter estimates for the HAPP objective function. Specifically, a Path-size Logit model (PL) with its utility function the same as the objective function of HAPP is estimated based on the observed one day activity-travel patterns in found in conventional travel datasets. Contributions of this proposed approach can be summarized as the following. First, the model itself has behavior implication, as travelers are making decisions based on utility, based on a discrete choice model. Secondly, the estimation is stable and computationally efficient and allows for scaling of utility gain and travel disutility parameters. Thirdly, there are existing criterion to judge how the model fit is. Fourth, the proposed method eliminates potential issues that may arise in convergence and computational time as each data point does not need to be individually estimated. Lastly, the proposed framework is flexible that can further be refined and adjusted to specific problems.

Methodologically, this paper applies a discrete choice estimation procedure for an optimization problem. An analogous problem in transportation is route choice problems where the shortest path problem is approached as discrete choice models (Bekhor et al., 2006; Prato, 2009). To our knowledge, our paper is the first attempt of applying econometric estimation for the objective function used in a problem from the class of Vehicle Routing Problems (VRPs). Broadly, we present a methodological framework that enhances behavioral interpretation while keeping the constraint-based property found in optimization-based approaches.