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A mathematical programming formulation of the household activity rescheduling problem

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Abstract

The so-called activity-based approach to analysis of human interaction with the social and physical environments dates back to the original time–space geography works of Hägerstrand and his colleagues at the Lund School. Despite their obvious theoretical attractiveness, activity-based approaches to understanding and predicting travel behavior have suffered from the absence of an analytical framework that unifies the complex interactions among the resource allocation decisions made by households in conducting their daily affairs outside the home, while preserving the utility-maximizing principles presumed to guide such decisions. In this paper, we develop a computationally tractable system, based on an extension and modification of some rather well-known network-based formulations in operations research, to model human dynamics in uncertain environments. The research builds on the mixed integer linear program formulation of the Household Activity Pattern Problem (HAPP) by embedding in the household activity schedule decision process a means of capturing uncertainty by introducing the dynamics of rescheduling.

Keywords: Activity scheduling; Activity rescheduling; Activity-based models; Travel behavior

1. Introduction

In introducing time–space geography as a paradigm for understanding human movement, the seminal work of Hägerstrand (1970) offered the potential to better integrate the spatial and temporal components of human interaction decisions that underpin the concepts of human movement within the built environment. His concept is a ‘‘constraint-based approach’’, given the defining role that spatial and temporal constraints in the formulation; space is typically expressed as a two-dimension plane, while time is depicted via a third, vertical axis. Within this three-dimensional space, so-called time–space prisms define the limits of what is accessible, or ‘‘reachable’’ in the urban environment. The line of previous research efforts loosely based on Hägerstrand's original concept focus on the following themes: analysis of activity demand, scheduling of activities, investigation of constraints on activity and travel choices, spatial–temporal dynamics of activity–travel decisions and

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how they relate to one's role in the household, and overall effect of household structure (e.g. lifestyle, lifecycle, role) on individual activity/travel.

Notable among activity-based models are those that follow the utility maximization (UM) framework originating from the economic theory of consumer choice, including the works of Becker (1965), Ghez and Becker (1975), Recker (1995), and Ben-Akiva and Bowman (1995), and those that treat the activity scheduling problem as a human problem solving process; examples of these latter so-called computational process models (CPM), include STARCHILD by Recker et al. (1986a,b), SCHEDULER by Gärling et al. (1989), and SMASH (Ettema et al., 1993). The UM approach is limited in that the decision process of the individuals (including the decision-making interaction among other household members) generally is overlooked and, while the CPM generally are capable of overcoming many of the limitations of the UM model, it is difficult to enumerate the elaborate decision rules that may play an important role in the schedule planning problem.

It is generally recognized that a travel/activity schedule formed before commencement of travel is tentative; instead of being a static system, the activity scheduling problem involves a dynamic process that incorporates the degree of uncertainty arising both from factors associated with the physical transportation network, as well as those relating to the agenda of activities either desired or needed to perform. At any moment in the day, there may be the need to reschedule those remaining, not-yet-completed, activities due to unexpected events that happen in real time, including: traffic congestion, the need for more time to accommodate a certain activity, illness, etc. The occurrence of uncertain events, as well as the uncertainty of the occurrence of such events, can affect the execution of the individual's preplanned schedule. This is in contrast to the basic assumptions of most of the existing activity-based models which are posed as a static problem, and designed to produce the optimal travel/activity decisions relative to the prescribed objective of completing its activity agenda at the outset of the day.

Observed activity schedules are the result of an unobserved decision "process" involving the planning and execution of activities over time within a household context (Doherty and Axhausen, 1999; Doherty, 2000). However, this process has been unspecified in the literature due to its complexity. To our knowledge, few efforts have been devoted to the adaptation of human behavior as it relates to the rescheduling of activities in response to uncertain events (Doherty and Axhausen, 1999 and Joh, 2004).

Doherty and Axhausen (1999) proposed to develop a unified modeling framework for the household activity–travel scheduling process in which the core element is the Weekly Scheduling Process model. The conceptual model developed proceeds in a sequential way. It begins by taking an individual's Household Agenda of activities, and establishes a set of Routine Activities and a skeleton schedule for the individual for the week via an optimization model, then feeding the resulting skeleton schedule to the Weekly Schedule Process model to replicate the dynamic process during activity execution over time. The Weekly Scheduling Process model is developed to simulate the dynamic process after preplanning, revision, impulsive, and opportunistic decisions made over the course of the week. The rescheduling decision is made based on activity priority and predefined decision rules. The "priority" in their study is derived simply to be the proportion of the activity duration to any feasible time windows on a schedule. The smaller the value is, the higher the priority should be. Throughout the simulation, decision rules are applied to make decisions. Despite its appeal, the proposed model has shortcomings. The "priority" variable is so simplified as to probably driving the model to arrive at a solution far from optimal. Moreover, a number of factors affecting rescheduling decisions are overlooked, including resistance to reschedule the preplanning, mental fatigue due to rescheduling.

The aforementioned SCHEDULER (Gärling et al., 1989), SMASH (Ettema et al., 1993), and ALBATROSS (Arentze and Timmermans, 2000) assume that household members sequentially make activity–travel decisions considering coordination and compromise among them. In general, the notion of activity priority acts as a primary determinant in the sequencing of activities. However, many assumptions (most of which are arbitrary) regarding the decision process and travel behavior have to be exogenously stipulated beforehand rather than endogenously incorporated in the simulation system.

Joh (2004) formulated an innovative model of short term activity rescheduling called AURORA (Agent for Utility-driven Rescheduling of Routinized Activities) in which the rescheduling problem is cast within the objective of maximizing the utility of (rescheduling) decisions, subject to situational and institutional constraints. Although the model is driven by utility-maximization principles, it states bounded rationally as a result of incomplete information and imperfect choice behavior, contrasting it with existing UM models, such