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Network-oriented Household Activity Pattern Problem for System Optimization

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Abstract

The recently emerging trend of self-driving vehicles and information sharing technologies, made available by private technology vendors, starts creating a revolutionary paradigm shift in the coming years for traveler mobility applications. By considering a deterministic traveler decision making framework at the household level in congested transportation networks, this paper aims to address the challenges of how to optimally schedule individuals' daily travel patterns under the complex activity constraints and interactions. We reformulate two special cases of household activity pattern problem (HAPP) through a high-dimensional network construct, and offer a systematic comparison with the classical mathematical programming models proposed by Recker (1995). Furthermore, we consider the tight road capacity constraint as another special case of HAPP to model complex interactions between multiple household activity scheduling decisions, and this attempt offers another household-based framework for linking activity-based model (ABM) and dynamic traffic assignment (DTA) tools. Through embedding temporal and spatial relations among household members, vehicles and mandatory/optional activities in an integrated space-time-state network, we develop two 0-1 integer linear programming models that can seamlessly incorporate constraints for a number of key decisions related to vehicle selection, activity performing and ridesharing patterns under congested networks. The well-structured network models can be directly solved by standard optimization solvers, and further converted to a set of time-dependent state-dependent least cost path-finding problems through Lagrangian relaxation, which permit the use of computationally efficient algorithms on large-scale high-fidelity transportation networks.

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Keywords: Household Activity Pattern Problem; Space-time-state network; Activity-based modeling; Dynamic traffic assignment

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1. Introduction

The activity-based modeling approach has been widely studied in the area of transportation planning and operations to better capture various facets of travel behavior and decision making. How to recognize complex resource constraints, multi-agent interactions, and consistency through trip chains of different individuals is an important concern for accurate activity-based modelling and analysis at the household level. Different modeling paradigms have been developed, including deterministic optimization-based models by Recker (1995), and probabilistic micro-simulation-based utility maximization models by Bhat et al. (2004), Pendyala et al. (2005), Pribyl and Goulias (2005), Miller and Roorda (2003), and Arentze and Timmermans (2004).

Currently, the emerging mobile apps with multi-modal traveler information and personal activity schedules enable travelers to intelligently schedule their activities and share their trip requests. In addition, transportation network companies such as Uber and Lyft and the forthcoming autonomous vehicle system would allow and encourage a fully optimized planning process for mapping household activities and travel requests (to be met by personal or shared vehicles). In this paper, we focus on the household activity pattern problem (HAPP) that is first systematically formulated by Recker (1995), which aims to find the optimal path of household members for completing their prescribed activities based on the available number of vehicles, scheduled activity participation, and ride-sharing options within a long period as the unit of analysis.

Typically, based on a conventional mixed integer linear programming model for the pickup and delivery problem with time windows (PDPTW), many typical cases in HAPP, e.g., five cases in a classical paper by Recker (1995), require a very large number of linear and integer constraints to capture the complex rules in real-world household-level activity scheduling progress. Recently, several algorithms had been proposed to address more realistic side constraints and large-sized examples, to name a few, Chow and Recker (2012) and Kang and Recker (2013). In addition, Liao et al. (2013) presented a new set of super-network models for various person-level activity scheduling problems, where the multi-dimensional network construct contains travel links, state transition links and activity transaction links. To formulate HAPP as a mathematically rigorous model, how to fully consider complex coupling constraints among three layers, namely household members, vehicles and mandatory/optional activities, is extremely challenging, especially for large-scale multi-modal transportation network with flexible ride-sharing and household member activity-coordination options.

To consider the traffic congestion and feedback loops associated with complex trip interactions, there are a wide range of studies aiming to combine ABM and DTA to better capture the interplay between human activity-travel decisions and underlying congested networks with tight road capacity constraints. For example, Lin et al. (2008) proposed a conceptual framework and explored the model integration of activity-based model (CEMDAP) and dynamic traffic assignment model (VISTA). Pendyala et al. (2012) further integrated activity-travel demand models (OpenAMOS), DTA tools with the long-term land use modeling layer (UrbanSim). Based on mathematical programs of HAPP, Kang et al. (2013) studied the network design problem considering the interaction between the household-level activity pattern and infrastructure changes. Chow and Djavadian (2015) proposed a new market equilibrium model to capture the interaction of traveler activity schedules in a capacitated system with a macroscopic flow restriction on a link or node facility. In a recent study by Fu et al. (2016), the intra-household interactions are considered through Markov decision processes and the road congestion effect is reflected by the static travel time function. To further study the impacts of dynamic traffic management strategies and real-time traveler information provision, Pendyala et al. (2017) proposed a tightly integrated modeling framework for representing activity-travel demand and traffic dynamics in an on-line environment.

This paper first aims to cast HAPP problems as number of time-dependent and state-dependent path searching problems, which have a class of computationally efficient algorithms available in discretized space-time network and high-dimensional space-time-state networks. To capture the impacts of traffic congestion on activity generation and scheduling, this paper also reformulates two special cases of HAPPs as system-optimal multi-household activity scheduling subject to the tight road capacity constraints. The key is how to prebuild a set of embedded finite state machines (FSM) in a network to precisely represent and translate side constraints from the traditional models, which could eliminate activity time window and vehicle selection constraints in the resulting optimization model.