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# Network-oriented household activity pattern problem for system optimization

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A B S T R A C T

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.



## 1. Introduction

The activity-based modelling 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 modelling paradigms have been developed, including deterministic optimization-based models by Recker (1995), and probabilistic micro-simulation-based utility maximization mod-

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**Nomenclature**

| | |
|---|---|
| $N$ | set of nodes in the physical network, including necessary virtual nodes |
| $N_v$ | set of vehicle nodes for vehicle selection |
| $L$ | set of links in the physical network, including necessary virtual links |
| $P$ | set of household members |
| $P_m$ | set of household members who have mandatory activities |
| $P_n$ | set of household members who chooses one mandatory activity from multiple candidates |
| $P_q$ | set of household members who have discretionary activities |
| $V$ | set of available vehicles |
| $A$ | set of activities |
| $A_n(p)$ | set of household member $p$'s candidate activities for one kind of mandatory activity |
| $A_v$ | set of mandatory activities of vehicle $v$'s driver |
| $R$ | set of vertices in the space-time/space-time-state network |
| $E$ | set of edges/arcs in the space-time/space-time-state network |
| $W$ | set of cumulative vehicle activity-performing state |
| $E(p, a_m)$ | set of edges/arcs of household member $p$'s mandatory activity $a_m$ |
| $E(p, a_n)$ | set of edges/arcs of household member $p$'s candidate activity $a_n$ for one kind of mandatory activity |
| $E(p, a_q)$ | set of edges/arcs of household member $p$'s discretionary activity $a_q$ |
| $E(v, a_m)$ | set of edges/arcs of mandatory activity $a_m$ of vehicle $v$'s driver |
| $i,j$ | index of node set $N$ |
| $(i,j)$ | index of link set $L$ |
| $t, s$ | index of time intervals in the space-time-state network |
| $w, w'$ | index of state in the space-time-state network |
| $(i, t)$ | index of vertex in the space-time network |
| $(i,j, t, s)$ | index of edges/arcs in the space-time network |
| $(i, t, w)$ | index of vertex in the space-time-state network |
| $(i,j, t, s)$ | index of edges/arcs in the space-time-state network |
| $p$ | index of household member set $P$ |
| $a$ | index of activity set $A$ |
| $t(i,j)$ | travel time of link $(i,j)$ |
| $c^p_{i,j,t,s}$ | travel cost of arc $(i,j,t,s)$ of person $p$ in the space-time network |
| $c^v_{i,j,t,s,w,w'}$ | travel cost of arc $(i,j,t,s,w,w')$ of vehicle $v$ in the space-time-state network |
| $[a_k, b_k]$ | the time window of event $k$, such as, activity starting time window, activity ending time window |
| $TD(p)/TD(v)$ | earliest departure time of household member $p$/vehicle $v$ |
| $O(p)/O(v)$ | origin node of household member $p$/vehicle $v$ |
| $D(p)/D(v)$ | destination node of household member $p$/vehicle $v$ |
| $T$ | the time horizon in the space-time network/space-time-state network |
| $Cap_{i,j,t,s}$ | capacity of arc $(i,j,t,s)$ |
| $Cap_{i,j,t,s,w,w'}$ | capacity of arc $(i,j,t,s,w,w')$ |
| $x^p_{i,j,t,s}$ | binary variable, $= 1$, if household member $p$ visits the travelling/waiting arc $(i,j,t,s)$ in the space-time network; $= 0$ otherwise |
| $x^v_{i,j,t,s,w,w'}$ | binary variable, $= 1$, if vehicle $v$ visits the travelling/waiting arc $(i,j,t,s,w,w')$ in the space-time-state network; $= 0$ otherwise |

els 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-level 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, 2001), Recker et al. (2001), and Gan and Recker (2008), 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