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Modeling duration choice in space–time multi-state supernetworks for individual activity-travel scheduling

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ABSTRACT

Multi-state supernetworks have been advanced recently for modeling individual activity-travel scheduling decisions. The main advantage is that multi-dimensional choice facets are modeled simultaneously within an integral framework, supporting systematic assessments of a large spectrum of policies and emerging modalities. However, duration choice of activities and home-stay has not been incorporated in this formalism yet. This study models duration choice in the state-of-the-art multi-state supernetworks. An activity link with flexible duration is transformed into a time-expanded bipartite network; a home location is transformed into multiple time-expanded locations. Along with these extensions, multi-state supernetworks can also be coherently expanded in space–time. The derived properties are that any path through a space–time supernetwork still represents a consistent activity-travel pattern, duration choice are explicitly associated with activity timing, duration and chain, and home-based tours are generated endogenously. A forward recursive formulation is proposed to find the optimal patterns with the optimal worst-case run-time complexity. Consequently, the trade-off between travel and time allocation to activities and home-stay can be systematically captured.

1. Introduction

It has been widely recognized that observed activity-travel patterns (*ATPs*) are the results of an underlying scheduling process that involves the planning and execution of activities in time and space. Activity-travel scheduling has become the core of many activity-based travel demand models. Given the high choice dimensionalities and demand–supply complexities in the scheduling process, a one-fits-all scheduling approach cannot be found in the literature. Various scheduling models have been proposed from different perspectives (e.g., Recker, 1995; Lam and Yin, 2001; Bowman and Ben-Akiva, 2001; Balmer et al., 2006; Li et al., 2010; Arentze et al., 2010; Kang et al., 2013; Auld et al., 2016). The multi-state supernetwork approach has been advanced recently for individual activity-travel scheduling based on an integrated and detailed representation of the land-use transport system. Introduced by Arentze and Timmermans (2004) and substantially improved by Liao et al. (2013), a multi-state supernetwork is constructed as an individual's choice space of activity sequences, locations, routes, modes and parking locations for implementing a daily activity program (*AP*). (Unless stated otherwise, *activity* alone refers to out-of-home activity). By predicting individuals' daily *ATPs*, the outcomes offer great potential for systematic assessments of a large range of policy interventions and emerging modalities (e.g., virtual mobility (Kenyon, 2010), shared bike scheme (Lathia et al., 2012), electric vehicles (He et al., 2015), park and ride (Chen et al., 2015)).

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However, duration choice of activities and home-stay has not been fully captured in the current state-of-the-art multi-state supernetwork models. First, activity duration only depends on the static characteristics of and arrival times at the activity locations. In other words, activity durations are fixed if arrival times are given. This is a non-issue for certain fixed activities, but it may be problematic for discretionary activities such as *leisure* and *shopping*. Second, the choice of home-return and home-stay duration in-between two activities has not been addressed when there are two or more activities in the *AP*s. As evidenced by empirical studies, travel and time allocation to home-stay and activities are interrelated under a constrained time frame. Thus, insufficient treatments of duration choice in the scheduling models would lead to inaccurate and less relevant *ATP*s along the temporal dimension.

Few fundamental scheduling approaches are capable of simultaneously modeling duration choice of activities and home-stay in the multi-modal multi-activity trip chains. Ettema et al. (2007) concluded that three factors, i.e., activity chain, timing and duration, should be taken into account to obtain an adequate sensitivity to policy scenarios when modeling activity participation. Despite the recognition, these factors have often been modeled separately. Even when timing and duration have been modeled jointly, duration choice is decided using an external model and then fed into an activity-travel scheduler. In such a way, duration choice is not linked to mode and route choice, resulting in weak linkage between travel and activity duration. Likewise, choice of home-stay duration tends to be ignored or given lower priority. In sequential models that build *ATP*s by blocks, start time and activity duration (or end time) are usually decided first, and the remainder continuous timeslot is automatically reserved for home-stay. In simultaneous models, activity duration choice has recently been considered by allowing random duration variations in MATSim (Feil et al., 2010) and as decision variables in the family of HAPP model (Yuan, 2014; Chow and Nurumbetova, 2015; Chow and Djavadian, 2015); at the aggregate level, several activity-based traffic assignment models (Li et al., 2010; Ramadurai and Ukkusuri, 2010; Fu and Lam, 2014) have also included activity duration choice, but the *ATPs* have been limited to either car or transit networks. In these models, multi-modal travel and home-stay duration choice are basically omitted due to the lack of an overall representation of *ATP*s. In addition, computation complexity is not addressed in such models.

The purpose of this study, therefore, is to incorporate duration choice of activities and home-stay in multi-state supernetworks for individual activity-travel scheduling. To that effect, an activity link with flexible duration is transformed into a time-expanded bipartite network to represent activity duration choice. To represent home-stay choice, it can be considered as an optional activity (a new concept in *ATP*s); or in an implicit format, a home location is transformed into multiple time-expanded locations. With these extensions, multi-state supernetworks can be coherently expanded in space–time. Any path through a space–time supernetwork still represents a consistent *ATP* and the (dis)utility of duration choice can be explicitly defined in terms of activity chain, timing and duration. Two further advantages can be derived. First, home-based tours are generated endogenously since the choice of home-return and home-stay are included. Second, space–time supernetworks support a more efficient routing algorithm with reduced run-time complexity than the label correcting algorithm proposed in Liao et al. (2013). Hence, the contribution of the current study is not limited to incorporating duration choice in multi-state supernetworks but also enhancing the behavioral realism and applicability of the approach. To highlight the contributions of the current study, Table 1 gives a short summary of recent simultaneous models on activity-travel scheduling.

The remainder of this paper is organized as follows. The next section introduces the concept of multi-state supernetworks and discusses the previous treatments of duration choice. Section 3 discusses the suggested extensions of duration choice at activity links and home locations, and proposes recursive formulations for finding the optimal *ATP*s. Section 4 illustrates the proposed extensions and discusses the applicability of the model. Finally, the paper is completed with conclusions and plans of future work.

Table 1
Comparative summary of simultaneous models.

References	Activity duration	Home-stay duration	Multi-modal trip chain[a]	Objective	Method	Run-time complexity
Li et al. (2010), Ramadurai and Ukkusuri (2010), and Fu and Lam (2014)	Y	Y[b]	N	User equilibrium (UE)	Heuristics-based	N[c]
MATSim: Feil et al. (2010)	Y	N	Y[d]	Micro-simulation based UE	Evolutionary algorithm	N
HAPP: Yuan (2014) and Chow and Nurumbetova (2015)	Y	N	N	Household utility maximization	Mixed integer programming	N
HAPP: Chow and Djavadian (2015)	Y	N	Y	UE	Heuristics-based	N[c]
Liao et al. (2013)	N[e]	N	Y	Individual utility maximization	Label correcting	Y
Current study	Y	Y	Y	Individual utility maximization	Dynamic programming	Y

Y and N: with and without the referred element respectively.
[a] Trip chains of private vehicle and public transport.
[b] Possible when "staying at home" is an explicit activity.
[c] Convergence analysis instead.
[d] Need to link other components of MATSim.
[e] Referring to activity duration profiles.