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Dynamic Activity-Travel Assignment in Multi-State Supernetworks

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Abstract

The integration of activity-based modeling and dynamic traffic assignment for travel demand analysis has recently attracted ever-increasing attention. However, related studies have limitations either on the integration structure or the number of choice facets being captured. This paper proposes a formulation of dynamic activity-travel assignment (DATA) in the framework of multi-state supernetworks, in which any path through a personalized supernetwork represents a particular activity-travel pattern (ATP) at a high level of spatial and temporal detail. DATA is formulated as a discrete-time dynamic user equilibrium (DUE) problem, which is reformulated as an equivalent variational inequality (VI) problem. A generalized dynamic link disutility function is established with the accommodation of different characteristics of the links in the supernetworks. Flow constraints and non-uniqueness of equilibria are also investigated. In the proposed formulation, the choice of departure time, route, mode, activity sequence, activity and parking location are all unified into one time-dependent ATP choice. As a result, the interdependences among all these choice facets can be readily captured. A solution algorithm based on the route-swapping mechanism is adopted to find the user equilibrium. A numerical example with simulated scenarios is provided to demonstrate the advantages of the proposed approach.

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Keywords: dynamic activity-travel assignment; multi-state supernetwork; activity-travel link/path disutility

1. Introduction

It has been widely recognized in transportation research that travel is the demand derived from conducting activities at the destinations. Many issues in transportation planning and traffic management require prediction of

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travel demand for various social and economic activities as input. Thus, instead of focusing only on trips and transport networks, travel demand analysis should also examine why, where and when people engage in activities, and how activity engagement is related to the spatial and institutional organization of an urban area (Huang and Lam 2005; Rasouli and Timmermans, 2014). Because the activity-based modeling (ABM) paradigm of travel demand analysis better complies with this condition, ABM has become the dominant approach to travel demand forecasting in academic research (Axhausen and Gärling, 1992; Kitamura et al., 1996; McNally, 2000; Shiftan and Ben-Akiva, 2011; Pinjari and Bhat, 2011). Over the past decades, a great number of activity-based models have been proposed to address specific choice facets of travel behavior, such as mode choice, route choice and location choice, etc., (e.g., Bos, 2004; Prato, 2009; Horni et al., 2009; Arentze and Molin, 2013). More importantly, comprehensive activity-based travel demand forecasting systems have been developed to avoid weaknesses of conventional trip-based (4-step) models (e.g., Bowman and Ben-Akiva, 2001; TASHA, Miller and Roodra, 2003; ALBATROSS, Arentze and Timmermans, 2004a; CEMDAP, Bhat et al., 2004; MATSIM, Balmer et al., 2006). However, these systems need external traffic assignment models to converge to a state that no traveler wants to change his/her routes unilaterally nor change his/her activity-travel schedule. Recently, Lin et al., (2008) and Auld and Mohammadian (2009) have suggested feedback mechanisms between an activity-based model and a traffic assignment model. At a series of time intervals, the time-dependent activity-travel demand is fed into a traffic flow model. The predicted travel times are then returned to the activity-based model, which will reschedule activities. This process is repeated until a state of equilibrium is reached. Although this integration structure has improved the classic combination of these models, a fundamental limitation of such coupling is that behavioral principles underlying the activity-based model of travel demand are not necessarily consistent with assumptions underlying the assignment algorithms.

The shift of analysis from trips to activities has also been witnessed in a few traffic assignment models that combined multiple choice facets of implementing activities. These models offer a more realistic depiction of dynamic travel choice behavior and more compatible solutions than the traditional dynamic traffic assignment (DTA) models. Lam and Yin (2001) were the first to present a conceptual activity-based and time-dependent traffic assignment model. In their model, activity location choice is presented as a multinomial logit model and route choice is described as a dynamic user equilibrium (DUE) condition. Abdelghany and Mahmassani (2003) developed a stochastic DUE model to capture departure time, activity sequence and path choice. Lam and Huang (2002, 2003) proposed a combined activity/travel choice model for capacity-constrained networks, in which choice of route and departure time is modeled simultaneously. Zhang et al. (2005) established an equilibrium model considering path choice and congestion state based on the bottleneck model; however, the dynamic link travel time was simplified. As to the representation of travel behavior, these studies have only looked at specific combinations of choice facets but with less focus on behavioral realism. Overall, ABM and DTA are loosely coupled in the literature: in particular, (*1*) assignment models mostly focus on traffic and largely ignore or simplify activity program implementation; (*2*) the level of choice detail in time and/or space is low; (*3*) time window constraints at activity locations are often ignored in DTA; and (*4*) activity durations are generally assigned rather than treated as a choice.

In recent years, supernetwork representations have sparked interests in modeling multimodal travel choice problems in an integrated framework (e.g., Nagurney et al., 2002, 2003; Carlier et al., 2003). Although there is no essential difference between a supernetwork and a normal traffic network, supernetworks are capable of representing the transition and interactions between multiple modes. Different choices are turned to indifferent path choice through the constructed supernetwork (Nagurney et al., 2003). Therefore, supernetwork representations offer a natural basis for activity-travel assignment, which has the potential to solve the first two limitations aforementioned by default. Meanwhile, in the temporal dimension, time window constraints and activity duration also can be modeled by treating time as a continuum along the full ATPs. This feature allows addressing the latter two limitations in a consistent manner. However, integrated time-dependent activity-travel assignment models based on supernetworks are infrequent in the literature. Ramadurai and Ukkusuri (2010, 2011) proposed a unified framework termed *activity-travel networks* to model activity location, activity duration, and route choices simultaneously. In their model, dynamic traffic flow is captured by a cell-based transmission model, and an efficient algorithm for DUE assignment is proposed. Ouyang et al. (2011) proposed a model for solving the daily activity-travel pattern (ATP) scheduling problem by constructing an expanded time-space network. Fu and Lam (2014) purposed an activity-based network equilibrium model under uncertainties for scheduling daily activity-travel patterns in multi-modal transit networks. Nevertheless, most of these studies ignored transfer behaviors between