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The effects of social networks on choice set dynamics: Results of numerical simulations using an agent-based approach

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A B S T R A C T

Activity-based analysis has slowly shifted gear from the analysis of daily activity patterns to the analysis and modeling of dynamic activity-travel patterns. In this paper, we address one type of dynamics: the formation and adaptation of location choice sets under influence of dyad relationships within social networks. It extends the dynamic model developed in earlier work, which simulates habitual behavior versus exploitation and exploration as a function of discrepancies between dynamic, context-dependent aspiration levels and expected outcomes. Principles of social comparison and knowledge transfer are used in modeling the impact of social networks through information exchange, adaptations of spatial choice sets and formation of common aspiration levels. We demonstrate model properties using numerical simulation with a case study of shopping activities.

1. Introduction

Now that comprehensive, operational activity-based models of transport demand have become available and are moving to practice (Timmermans et al., 2002), the academic research community has started to address a new challenge: how to develop dynamic activity-based models of transport demand. In this paper, we address one type of dynamics: the formation and adaptation of location choice sets. Current activity-based models typically assume that choice sets remain invariant over time (Swait and Ben-Akiva, 1987; Thill and Horowitz, 1997; Swait, 2001), but obviously this is a rather restrictive assumption. In fact, choice sets may change over time because travelers become familiar with new alternatives or may no longer be interested in alternatives they know because they no longer meet the travelers' expectations or because they have become dominated by other alternatives in the choice set.

Knowledge about new alternatives that travelers may decide to explore may be the result of different sources. During implementation of activity-travel patterns, travelers may observe alternatives that they have not tried before (Arentze and Timmermans, 2005). Dynamics in choice sets then may come about as the outcome of exploring such new alternatives, resulting from direct visual encounters emanating from activity-travel behavior. Travelers may also try new choice alternatives due to exposure to advertising, depending on their risk attitude and how well existing alternatives satisfy their needs. Finally, they may decide to explore new alternatives because members of their social network told them about their experiences (Paez and Scott, 2007). The latter is the topic of this paper.

As suggested above, we focus on the *process* underlying the formation of choice sets. This phenomenon is difficult to model. Ideally, one would desire panel or time-series data. Such data however requires significant resources and therefore are not

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readily available. Moreover, respondent burden involved is high and therefore the reliability and validity of such data may be problematic. Even if such data can be collected, the behavioral interpretation of such data would be limited as these empirical models describe statistical associations rather than elaborate behavioral concepts and mechanisms. Rather than building empirical econometric models, in this paper we therefore describe a model that is more in line with state-of-the-art multi-agent modeling. Individuals are represented as agents. Agents are independent decisions makers with their view of the world and their behavioral principles and mechanisms. Consistent with this new modeling tradition, the first step in the development of the model is to demonstrate the working of the model; the patterns that emerge and the face validity of the model. In this context, it should be noted that in econometric modeling the working of the model is a priori known and results immediately from the choice of the mathematical equations. In agent-based modeling, in contrast, aggregate patterns emerge from the accumulated decisions of individual agents. Before collecting any data, it is critical therefore, to first examine the model using numerical simulations. This approach which is quite common in agent-based modeling (see e.g. Rindfüeser and Klügl, 2005; Rosetti and Liu, 2005) is also followed in this paper.

The purpose of this paper is to incorporate social influence processes in a formal model on dynamic choice set composition. The framework is developed in the context of the Forecasting Evolutionary Activity-Travel of Households and their Environmental RepercussionS (FEATHERS) project (Janssens et al., 2007), which focuses on developing a dynamic activity-based micro-simulation using an extension and elaboration of the Aurora model of activity (re-)scheduling behavior (Joh et al., 2006). It will integrate and elaborate different types of dynamics and learning discussed in Arentze and Timmermans (2003), and explores some new concepts where relevant. The framework underlying the multi-agent system predicts habitual behavior versus exploitation and exploration as a function of discrepancies between dynamic, context-dependent aspiration levels and context-dependent expected outcomes. Principles of exploration effort and strength of memory traces, which play a role in switching between different modes of choice behavior, and influence of cognition on learning and choice behavior, taking uncertainty generated endogenously into account, are described in more detail in another paper (Han et al., 2008).

The intended contribution of the present study is to extend this basic framework to take into account and explore the potential influence of social networks. In addition to cognitive learning, it is assumed that properties of dyad relationships within social networks will influence dynamics of norms regarding what qualifies as a satisfactory outcome as well as information acquisition on availability and attributes of choice alternatives. A person's position in his/her social networks and desire to belong to the network and comply with its set of attitudes and behavioral patterns will thus influence the tendency of exploring any new choice options (McPherson et al., 2001). Based then on experiences, social comparison and possibly other factors, the newly searched and explored alternatives may become part of a travelers choice set, creating the dynamics of interest. Different from focusing on computational efficiency using random information exchange in social learning as described by Marchal and Nagel (2005), in this paper, we will model the impact of the social network considering all these behavioral aspects including information exchange, mutual adaptation of individuals' choice sets and formation of common aspiration levels. It should be stated from the outset that the actual multi-agent system is more elaborate than can be discussed in this paper due to limited space. This paper focuses on the role of social interactions between agents in spatial travel behavior.

In the remainder of this paper, we will first briefly introduce the main components of the proposed framework that consists of functions describing how cognitive learning, exploration effort and memory traces influence choice set composition over time. It is extended with a heuristic method to model social interaction that influences the formation and adaptation of choice sets. Next, based on this formal framework, the face validity of an agent-based system will be tested and demonstrated using an illustrative case study of shopping activity, focusing on the effects of social networks on location choice set formation and dynamics. Finally, a conclusion and discussion of avenues for future research will complete the paper.

2. The model of choice set dynamics within an uncertain environment

The model considers a traveler making a location choice for a given activity at some moment in time. We assume that individuals make decisions based on the believed attributes of choice alternatives, as they generally have imperfect and incomplete information about the choice alternatives in their environment. Let X denote the set of attributes that describes location choice alternatives for a particular activity, including a subset of temporally static attributes (X^s) such as parking space and a subset of dynamic attributes (X^d) such as crowdedness.

We assume that for each dynamic attribute, X_j^d, the individual uses some classification, denoted as $X_j^d = \{x_{j1}, x_{j2}, \ldots, x_{jN}\}$, where $x_{j1} - x_{jN}$ represent possible states of X_j^d, and specifies his/her beliefs regarding location i based on his/her current knowledge as a probability distribution across X_j^d denoted as $P_i^t\left(X_j^d\right)$, which sums up to 1 (t is an index of time moment). The degree of uncertainty is given by the degree of uniformity of $P_i^t\left(X_j^d\right)$. The state probabilities are conditional upon certain contextual variables, therefore we extend the probabilities $P_i^t\left(X_j^d\right)$ to $P_i^t(X_j|c)$, where c stands for a particular condition set (i.e., a state configuration of one or more condition variables) of a universal set of relevant condition states. For example, crowdedness of a shopping location will depend on day-of-the-week and time-of-the-day. The expected utility of a choice alternative for some context setting c and given a set of beliefs about the attributes of the location (including travel time) is then equal to: