Computers, Environment and Urban Systems 51 (2015) 25–33

Contents lists available at ScienceDirect

Computers, Environment and Urban Systems

journal homepage: www.elsevier.com/locate/compenvurbsys

Simulating choice set formation processes in a model of endogenous dynamics of activity-travel behavior: The effect of awareness parameters

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ARTICLE INFO

Article history:
Received 26 May 2014
Received in revised form 11 December 2014
Accepted 8 January 2015

Keywords:
Endogenous dynamics
Activity-travel behavior
Stress
Choice set
Context-dependent
Awareness

ABSTRACT

Models of activity-travel behavior can be a useful tool in order to predict the direct or secondary effects of various spatial, transportation or land-use policies. Whereas existing activity-based models of travel demand focus on a static, typical day, dynamic models simulate behavioral response to endogenous or exogenous change, along various time horizons. The current study focuses on modelling endogenous dynamics of activity-travel behavior. Endogenous dynamics are triggered by stress, which is regarded as dissatisfaction with current habits. It is assumed that people try to alleviate stress by conducting short-term changes, within or beyond their current choice sets. If these attempts prove to be unsuccessful, they may also consider long-term changes, such as moving to a new residence, and buying a car. In this study, this self-improvement process, which can result in both short and long-term adaptations, is modeled. In the proposed framework, choice set formation and the key concepts of aspiration, activation, awareness and expected utility are integrated, while both rational and emotional mechanisms are taken into account. Numerical simulations are conducted in order to check the face validity of the model, as well as the impact of awareness parameters on choice set formation and on the overall system behavior.

1. Introduction

Models of activity-travel behavior can analyze and predict choice-making mechanisms of people and better predict the direct and side-effects of various urban and transportation policies (Jin & White, 2012). Now that operational, one-day activity-based models of travel demand have been developed, the next challenge is to create dynamic models, which should provide more sensitive and accurate predictions, regarding the effect of a larger scope of policies (Arentze & Timmermans, 2000; Manley, Cheng, Penn, & Emmonds, 2014). If the environment was static, one would suppose that a steady state could be established: activity-travel patterns would be stabilized and become habitual. In reality, the space–time environment is stochastic, while travelers may also be willing to try new choice alternatives, depending on their risk attitude and how satisficing the existing alternatives are. Finally, as the system is stochastic, by implementing choices, an individual may observe a discrepancy between actual experience and expectation, which may trigger negative or positive emotions that have an impact on evaluating various alternatives. Therefore, as it is described in Han et al. (2008), individuals' activity-travel behavior may change due to new information, actual travel observation and social contact, which may prompt the individual to switch from habitual behavior to consciously changing his/her activity-travel patterns.

Dynamic changes in the activity-travel patterns of an individual can occur either in a short or in a long-term perspective. Specifically, those changes that affect the context of available resources and imposed constraints within which an individual acts, are considered to be long-term changes. For instance, moving to another residential or work location, is considered to be a long-term change. On the other hand, the short-term changes, that an individual may conduct, can only take place within the context of long-term decisions and the availabilities or constraints that this context imposes (for instance, changing route or departure time are considered short-term changes) (Miller, 2005; Miller, Hunt, Abraham, & Salvini, 2004). Therefore, long-term changes directly affect the daily activity travel patterns (top-down chain of influence), while, on the other hand, day-to-day experiences feedback whether the current context of long-term decisions is satisficing enough, or whether a long-term change should be considered (bottom-up process of influence). Most of the existing studies on dynamics of activity-travel behavior focused either on a specific

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http://dx.doi.org/10.1016/j.compenvurbsys.2015.01.003
0198-9715/

time-horizon (dynamics occurring only on short or long-term level) (Beige & Axhausen, 2006; Klökner, 2004; Prillwitz & Lanzendorf, 2006; Salomon, 1983; Sarjeant, 1986; Vanhunsel, Janssens, & Wets, 2007; Xiong, Chen, & Zhang, 2015) or focused on the effect of a specific long-term change (e.g. purchase of a car) or of a specific policy on the daily, short-term practice (Prillwitz & Lanzendorf, 2007; Scheiner, 2006). In contrast, the main goal of this study is to develop a model linking short and long-term endogenous dynamics of activity-travel behavior, by focusing on the bottom-up process of influence. Endogenous dynamics are induced by stress, which is triggered when current habits are, for some reason, not satisfactory anymore (Brown & Moore, 1970; Evans, Wener, & Phillips, 2002; Habib, Elgar, & Miller, 2006; Han, Arentze, Timmermans, Janssens, & Wets, 2008; Miller, 2005; Rossi, 1955). Stress is taken into account in this model, both in short (dissatisfaction with current activity-travel habits) and long-term time horizon (dissatisfaction with current long-term decisions, e.g. current residential location, or current number of household cars).

Moreover, both rational and emotional responses are taken into account. Based on reinforcement learning and forgetting mechanisms (Arentze & Timmermans, 2003) the model can predict which options an individual is aware of, at every time step and under various context-conditions. The current paper focuses on the effect of these awareness responses on the choice set formation and, also, on the overall dynamics of activity-travel behavior. Specifically, the influence of the awareness parameters of the model is illustrated with some numerical simulation results. In this way, it can be traced how this dynamic model responds, when the value of each of those parameters varies and some interesting results can be collected regarding the effect of awareness responses on dynamic activity-travel behavior of people. Finally, important inferences can be drawn regarding the appropriate value of these parameters in a basic case simulation run of the model.

The starting point of this study is Han et al.'s work (Han, Arentze, Timmermans, Janssens, & Wets, 2009; Han et al., 2008) on choice set formation. Their work focuses on shopping location choice sets. In the current study, this work is extended by taking into account (i) all activity types that an individual may conduct, (ii) not only location, but a larger set of activity attributes and (iii) the evolution of long-term dynamics.

First, the conceptual framework of the model is described. Some simulation results follow, in order to illustrate the properties of the model and the effect of awareness parameters. Finally, conclusions and future work are discussed.

2. The model

A detailed description of the model structure can be found in Psarra, Liao, Arentze, and Timmermans (2014). In this section, a short description of the basic concepts is going to follow, so that the numerical simulation results that are presented in this paper become more comprehensive and clear. The model structure is based on assumptions of the authors, regarding the decision making mechanism of people. These assumptions are based on satisficing theory of Simon (1957), while bounded rationality is also taken into account. As the emergent behavior of the system is not a priori known, the simulation results allow to derive conclusions regarding the model behavior and the effect that various awareness responses have on it.

2.1. Universal choice set and activity profiles

The universal choice set of an individual is given by a list of N feasible activity profiles. An activity profile includes information regarding activity type, location, start-time, origin location, transport mode, etc. Indicatively, two activity profiles, belonging to the universal choice set of an individual can be:

- A_1: Shopping, city center, start time: 10:00, starting from home, bike
- A_2: Shopping, supermarket, start time: 17:30, starting from work, walking

A universal choice set contains all these possible combinations of activity attributes, within the current context of long-term decisions of an individual. However, an individual is aware of only a subset of all these activity profiles, when making a choice. This is the choice set of that individual at time t. A choice set is dynamic, as new activity profiles can be explored, while others may be forgotten.

2.2. Cognitive and emotional values of activity profiles

Making a decision means selecting and implementing an activity profile. To calculate the expected utility of an activity profile, its activity attributes and the resulting outcomes (e.g. travel time, travel cost, etc.) are taken into account. The expected utility of an activity profile i_k of activity type k is:

$$EU_{i_k}^{t} = EU_{i_k}^{static} + EU_{i_k}^{dynamic,t} \tag{1}$$

$$EU_{i_k}^{static} = \sum_{j}\sum_{n}\beta_{jn}^{static}\log(x_{jn})I_{i_k j}(x_{jn}) \tag{2}$$

$$EU_{i_k}^{dynamic,t} = \sum_{j}\sum_{n}\beta_{jn}\log(x_{jn})P_{i_k j}^{t}(x_{jn}|c_t) \tag{3}$$

where $EU_{i_k}^{static}$ is the expected partial utility of an activity profile i_k for static attributes j under state n, $X_j^{static} = \{x_{j1}, x_{j2}, \ldots, x_{jN}\}$ are the static attributes, β_{jn}^{static} is the individual's preference regarding state n of attribute j and $I_{i_k j}(x_{jn})$ equals to 1 if state n of the attribute j is included in the activity profile i_k, otherwise equals to 0. $EU_{i_k}^{dynamic,t}$ is the expected partial utility of activity profile i_k, for dynamic attributes under states x_{jn} in context c_t and time t, $X_j^{dynamic}$ are the dynamic attributes, β_{jn} is the individual's preference regarding dynamic attribute j with state n, $P_{i_k j}^{t}(x_{jn}|c_t)$ is the conditional, time-varying probability distribution across states of dynamic attribute $X_j^{dynamic}$ at time t. Finally, c stands for context-condition variables (e.g. weekday/weekend, rush/non-rush hour). The log transformation is used in the utility functions, for the reason that the marginal utilities decrease when continuous values (such as travel time) increase (thus, a linear function could not be assumed).

When implementing an activity profile, the actual state of each attribute is experienced. The experienced utility of an activity profile i_k at time t equals:

$$AUT_{i_k}^{t} = \sum_{j}\sum_{n}\beta_{jn}\log(x_{jn})I^{t}(x_{jn}) + \varepsilon_{i_k}^{t} \tag{4}$$

where: $I^t(x_{jn})$ equals to 1, if state n of the attribute j was experienced at time t, otherwise equals to 0. The experienced surprise is denoted as $\varepsilon_{i_k}^{t}$.

If the expected and the experienced utility deviate, negative or positive emotions of this experience emerge. The emotional value of an experience event of an activity profile i_k at time t is:

$$R_{i_k}^{t} = AUT_{i_k}^{t} - EU_{i_k}^{t} \tag{5}$$

If an activity profile was experienced several times, the emotional values of the experiences will be accumulated in a positive or negative overall affective value, linked to that activity profile. The emotional value of an activity profile i_k at time t, under context c, is: