Analysis of Temporal Dependencies in the Occurrence of Life Events Using Dynamic Bayesian Networks

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1. Introduction

Previous research in the behavioral sciences has emphasized the importance of the interdependency of different life course events and recognized that residential relocation, employment relocation and travel mobility change are not independent from each other. Neglecting people's decisions on various interrelated life choice from the long-term perspective may lead to inaccurate travel demand forecasts. The interaction between different long-term decisions should be investigated using an integrated framework (Ommeren and Nijkamp, 1999; Waddell, et. al., 2007). Existing studies on the modeling of multi-dimensional choices found that the different aspects are interrelated in the sense that one choice dimension is not exogenous to the other, but endogenous to the system as a whole (Lerman, 1976; Salon, 2009; Pinjari, et al., 2011; Paleti, et al., 2012; Guo, et al., 2018).

However, examining the state of the art, studies are mainly based on cross-sectional analysis, neglecting the temporal dynamics of decision-making over the life course (Oakil, 2013). This may be attributed to the difficulty of collecting panel data. As a consequence, these models can only capture a snapshot of behavior at a particular point of time. In reality, however, the interdependency between the multi-dimensional mobility decisions is dynamic in nature. The effect of a certain event or decision does not necessarily lead to an immediate change of another event, e.g. changing job may not be a concurrent response to buying/renting a house. In additional, people may face the limitations in time and money budget for long-term decisions, which typically results into the trade-off between the investment on dwelling or cars (Ettema, et al., 2007, (a, b); Oakil et al., 2014). The temporal dependency between the long-term decisions indicates that different events do not necessarily happen at the same time slice. Prior mobility change can strongly affect present mobility choices (Box-Steffensmeier and Jones, 2004).

In addition, a certain long-term decision can be dependent not only on their past experiences or life events, but also the extent of individuals' anticipation. The anticipation of future events may trigger the change of current decisions or behavior adaptation in earlier time (Oakil, 2013; Zhang et al., 2014; Tran, 2015). For instance, the birth of a child may have a lead effect on car acquisition, indicating that buying an (extra) car can take place before the actual occurrence of an event (Oakil, et al., 2014b). Likewise, people might consider residential relocation one or two years before getting married. The actual change induced by the lead effects can closely connect with the extent of certainty of individuals' judgement that a certain future event will happen. From a dynamic perspective, therefore, including the lead effect to analyze the long-term decision is of high importance.

A recently emerging body of studies on the dynamics of mobility decisions suggests that a life course approach which examines individuals' life trajectories may be needed (Lanzendorf, 2003; Scheiner, 2007; Schafer et al., 2012; Beige and Axhause, 2012; Zhang, et al., 2014). Indeed, life trajectories may provide a rich conceptual framework for a better understanding of the interdependency among multi-dimensional decisions (Scheiner, 2006; Oakil, et al., 2011). However, the studies based on dynamic models, especially the analyses of temporal associations are limited. Most studies considered only the lagged responses, but ignored the anticipation and lead effects (Beige and Axhausen, 2008; Verhoeven, et. al., 2007). Moreover, recent studies examine the temporal effects in a rather static way in the sense that the inherent interdependency structure within each time horizon may be jeopardized, leading to biased conclusions.

Therefore, the objective of this study is two-folded. First, this study looks into the interdependence concerned with long-term household events, residential choice, work choice and car ownership change. Second, as an extension to the time-dependent models, this study further examines the dynamics in mobility decisions under the effects of historical and future life events by proposing a dynamic modeling framework. The analysis will further explore the concurrent, lagged and lead effects based on an integrated dynamic model.

2. Methodology

The aim of this study is to uncover the interdependency of long-term mobility decisions under the influences of various events of life trajectories. The key events considered include household mobility change, residential mobility change, job change and car ownership change. More specifically, household structure trajectory includes baby birth and getting married; residential and work change includes location change; and the change of car ownerships include purchasing and/or replacing a car. Furthermore, the influences of commuting time and sociodemographic characteristics on various decisions are also taken into consideration.

In case of the temporal dependencies between the multiple domains, it is assumed that current household events or decision influence not only the mobility events of the current year, but also those in the next 1-2 years and previous 1-2 years. In another word, the decision made on the current time slice is assumed to be influenced by historical events, current events and future expected events. In this way, the proposed framework comprehensively examines the concurrent, lagged and lead effects among various time-dependent events and states, which reflects the effects in the same year, previous years and next years, respectively.

Based on the conceptual framework which deals with temporal data, a Dynamic Bayesian network (DBN) is use to reveal the causal relationships among different life domains. A Dynamic Bayesian Network, (also called temporal Bayesian networks) is a Bayesian network (BN) which relates variables to each other over adjacent time slices. Bayesian networks which are a graphical model for probabilistic relationships among a set of variables have been applied in transportation field in recent decades (Arentze and Timmermans, 2005; Oakil, et al., 2011; Sun and Erath, 2015, Wang, et al., 2018). While BN model is a powerful tool for representing uncertainty, it is static in nature. In domains that evolve temporal dependencies, simply adding some timing nodes to specific life events cannot represent the real dynamic mechanism, thus failed to capture the time-dependent relationship in reality. When dealing with time series data, as a promising alternative of the static Bayesian network, dynamic Bayesian networks are more flexible to represent complex temporal stochastic processes (Dean and Kanazawa, 1989; Murphy, 2002). Therefore, the dynamic Bayesian Belief Network is used in our research to estimate potential causal relationships among these multiple long-term domains.

The final network structure is shown in Figure 1. Red dashed lines represent the 1 & 2 years of lead effects between household events and mobility events. Black bold lines represent the 1 year lagged effects between various events and states. Blue lines represent the 2 year lagged effects between household events and mobility events.

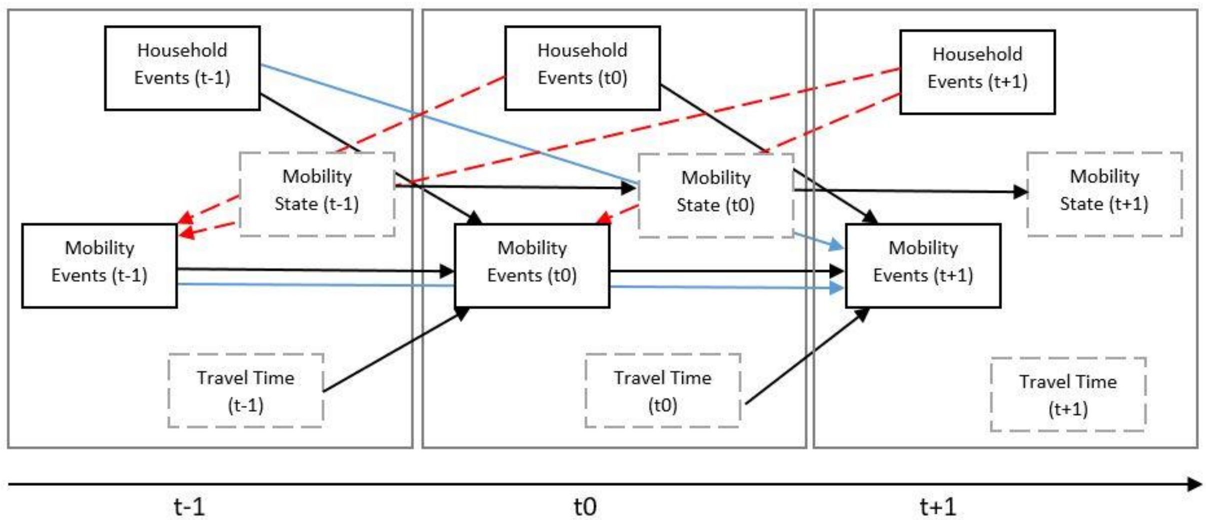

Figure 1 Conceptual framework of intra-slides mobility relationship

With the given network structure, the conditional probability tables was learned from the data using EM (Expectation Maximization) algorithm. In order to test the concurrent, lagged and lead effects between different mobility decisions and life events, data that were collected through a web-based retrospective survey in Shenyang, China, during the autumn of 2016, were used. Except the relevant socioeconomic data, respondents were asked to provide a wide range of longitudinal information of various life events. In particular, the data was collected regarding life events and states from four dimensions, including: 1) motilities in household structure biography (i.e., get married and birth of child); 2) residential history (i.e., the year move in, residential location in history); 3) employment history (i.e., the year to change job, job locations in history); and 4) historical car ownership biography and commuting time. In each domain, the information of mobility change for each individual were collected for the last five times. As a result, a total of 414 valid sample were obtained in Shenyang city, coving 5 urban areas and 4 surrounding areas.

3. Results

The model results have evidenced that household events, residential mobility, work mobility, car ownership, commuting time and household characteristics are directly and/or indirectly interdependent. Compared to the middle-aged group of people, younger generation are more likely to change their current mobility status. Regarding the causal dependency between household life events and various mobility decisions, our results revealed that life cycle events indeed trigger mobility change. Key life events such as getting married and child birth triggers the change of residence, work and car ownership, and concurrent effect is stronger than lagged and lead effects. Likewise, contemporaneous, lagged and lead effects of residential and work mobility change on car ownership mobility change are confirmed in this study.

In addition, the study suggests that commuting time influences individuals' decision on residences or worksites. Results based on the analysis of commuting time indicate that, the longer the commuting time, the higher probability people change residences, jobs and cars. However, compared with the effects of key life events, the influence of commuting time is relatively smaller. Moreover, our findings regarding location choice confirmed that people tend to locate within or close to their home location or worksites to achieve a job-housing balance. Current residence and work locations have clear impacts on individuals' future location choice. All these findings enrich the existing knowledge incorporating multiple scopes for behavioral mechanisms for policy making.