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# Bayesian networks for multimodal mode choice behavior modelling: a case study for the cross border workers of Luxembourg

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**Abstract**

Reducing car use and promoting public transport in the cross border area of Luxembourg has become a priority for sustainable development of the Greater region. In this study, we analyze daily mobility mode choice behavior of these cross border workers, in particular, focusing on their multimodal mode choices (e.g. park and ride mode choice) and on their trip chaining behavior. A rule-based approach based on Bayesian networks is proposed to capture the non-linear effects of related determinants/constraints on individuals' mode choice behavior. The result shows the propose Bayesian network has a competitive performance compared with classical discrete choice models with reasonable good corrected prediction rates.


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*Keywords:* mode choice; bayesian network; multimodal; Luxembourg; uncertainty

## 1. Introduction

Reducing car use and promoting public transport in the cross border area of Luxembourg has become a priority for sustainable development of the Greater region. According to STATEC (STATEC 2015), the number of cross border workers, i.e. individuals working in Luxembourg but living in Germany, France or Belgium, has increased to 161 300 in 2013. In spite of good impression of public transportation service, car is still the main transport mode for their daily commuting trips (Schmitz et al. 2012). Facing to increasing daily mobility demand and a high car-use dependency, better understanding travelers' mode choice behavior provides useful insight for the stakeholders to

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promote public transport and soft modes. Although the cross-border worker mobility survey of Luxembourg (Schmitz et al. 2012) has collected detailed daily travel-activity data, the issues in the causal structure and decision process of their mode choice behavior are still less studied. By distinguishing various multimodal combinations as alternatives (instead of grouping them by a main mode with longest travel time), this study aims to model complex mode choice behavior in relationship with relevant determinants and causal structure of their mode choice behavior.

Mode choice models are usually based on random utility theory, which assumes individuals aim at maximizing the utility of their choice. The utility of an alternative of choice is expressed as a function of its attributes. Unobserved preference of decision makers is modeled as an error term following some probability distributions. The error term can represents bounded/non-complete rational behavior. More flexible models have also been developed such as nested logit or probit models for modelling the correlations between choice alternatives (Bhat, 1997) and mixed logit models for incorporating preference heterogeneity (Greene and Hensher, 2003; Train 2009). In spite of the popularity of the discrete choice models, past studies have revealed the limits of utility-maximization framework (Ben-Akiva and Lerman, 1985; Train 2009) for modeling discrete choice behavior, resulting in recent developments in rule-based reasoning/modeling system for inferring travelers' choice behavior (Vause, 1997; Arentze and Timmermans, 2004, 2007; Janssens et al. 2004, 2006). The rational choice theory assumes individuals make their choice decisions based on the comparison of different alternatives in their choice set and select one with maximum utility. The theory assumes that a decision maker has complete information about his choice alternatives and has full cognitive capacity and time to compare the alternatives. These disadvantages lead to its model extensions based on bounded rationality of human decision making (Newell and Simon 1972, Rubinstein, 1998) and to the development of causal modeling of decision making under uncertainty (Sloman 2005). In this study, we focus on the latter one by applying Bayesian networks (BN, or Bayesian belief networks) for modeling mode choice behavior. We analyze their daily mobility mode choice behavior, in particular, focusing on the causal relationship by taking into account multimodal mode choice (e.g. park and ride mode choice) and trip chaining.

The organization of this paper is as follows. In Section 2, we review firstly main determinants of mode choice decision making and then present Bayesian network modeling approach for reasoning travelers' mode choice decision. Section 3 reports descriptive statistics of the survey data and discusses possible causal relationships between the determinants. Section 4 presents the proposed Bayesian networks for causal structure modeling of travelers' mode choice. Model calibration and validation are tested and compared with the traditional multinomial logit model. Finally the conclusion is drawn and future extensions are discussed.

## 2. Determinants of mode choice behavior and Bayesian network modeling approach

### *2.1. Determinants of mode choice behavior*

Modeling mode choice behavior needs to understand the relevant determinants and their causal relationships to explain travelers' decisions. Past studies show mode choice may be influenced by different factors (Ye et al. 2007; Krygsman et al. 2007; Carpentier and Gerber 2009; De Witte et al. 2013; Enaux and Gerber 2014; Ma et al. 2015):

- Journey characteristics: trip purpose, trip chaining, weather condition, departure time, travel time, travel distance, travel cost etc.
- Socio-demographic characteristics: driving license, car availability, season ticket ownership, presence of children, gender, age, household income, household composition, occupation etc.
- Spatial characteristics: population density of residential location, proximity to infrastructure and services, parking, frequency of public transport etc.
- Socio-psychological factors: habits, lifestyle, transport mode perception, past positive/negative experience etc.

In general, these factors are correlated, and their relationships are usually implicit and sometimes unobservable. To investigate the causal structure of choice outcomes, some causal structure modeling technique, e.g. structural equation modeling approach, has been applied to identify these complex relationships (Simma and Axhausen, 2001). The identified causal structures can be served as references for further adjustments to find better causal models based on the empirical data.