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Modeling the dynamic effect of information on drivers' choice behavior in the context of an Advanced Traveler Information System☆

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A R T I C L E I N F O

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A B S T R A C T

In this paper, we present a modeling approach, based on Fuzzy Data Fusion, to reproduce drivers' dynamic choice behavior under an Advanced Traveler Information System (ATIS). The proposed model uses the Possibility Theory to model Uncertainty embedded in human perception of information. We have introduced a time-dependent Possibility Distribution of Information to model the users' changing perception of travel time also based on current network conditions. Drivers' choice models are often developed and calibrated by using Stated Preference (SP) surveys, amongst others. In this work, we present an experiment to set up an SP-tool based on a driving simulator developed at the Polytechnic University of Bari. The results obtained by the proposed model are analyzed and compared with the driver dynamic behavior observed in the experiment.

1. Introduction

A key issue in evaluating the performance of an Advanced Traveler Information System (ATIS) is understanding the impact of the information supplied on the travelers' behavior. The analysis of driver decision-making in a context of real-time information and of changing traffic conditions requires dynamic models of drivers' behavior. This analysis is a crucial task, to simulate phenomena correctly, such as compliance with information, route choices in the presence of information, etc. Different conceptual models of drivers' behavior under information provision have been proposed in the literature. These models are based on the idea that each driver updates his/her knowledge of costs of alternatives using provided information. Then, the driver compares the updated costs of alternatives and chooses, among them, the best one from his/her point of view. Since both knowledge of alternatives and the information provided to users are rarely perfect, uncertainty affects every person's decision; therefore, handling uncertainty is an important issue for these models. We can arrange approaches followed by different scientists to face this problem into two main groups, according to how they modeled the uncertainty. Methods in the first group use randomness to represent uncertainty; for a comprehensive review see Ben-Elia and Avineri (2015). For this kind of model, unavailability of full numerical data could limit their reliability; in fact, these models are unable to handle non-numerical values of parameters. On the contrary, models included in the second group can model uncertainty in verbal, incomplete or imprecise data using the concepts of Fuzzy Logic. In fact, the fundamental concepts of Fuzzy Set Theory like linguistic variables, approximate reasoning, and computing with words introduced by Zadeh enable more understanding of uncertainty, imprecision, and linguistically articulated observations. These concepts support "the brain's crucial ability to manipulate perceptions of distance, size, weight, color, speed, time, direction, force, number, truth,

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likelihood, and other characteristics of physical and mental objects. A fundamental difference between perceptions and measurements is that, in general, measurements are crisp whereas perceptions are "fuzzy" (Zadeh, 1978). Teodorović and Kikuchi (1990) first proposed a route choice model based on Fuzzy Set Theory.

In this paper, we have examined drivers' dynamic compliance with information in detail, using Uncertainty-based Information Theory. In particular, we made the hypothesis that drivers' compliance with information services is a function of Uncertainty and can change over time. Therefore, we set up a relation between Uncertainty and compliance level, and obtained a new, original model. The model is based on a Fuzzy Fusion of the drivers' previous experience and of the perceived information, expressed by a time-dependent Possibility distribution. Dell'Orco and Marinelli (2009) first introduced a static version of the model. Afterward, Di Pace et al. (2011) used that version of the model to evaluate drivers' risk perception in an ATIS context. Recently, the model has also been used to represent drivers' choice behavior when data come from different information sources (Marinelli et al., 2015). In this work, we have introduced a new dynamic formulation of the model and better parameter description and evaluation.

Moreover, to validate the proposed model, we have carried out a Stated Preference (SP) experiment at the Technical University of Bari (Italy), using a PC-based driving simulator. The road network employed in the experiment reproduces a real one existing in the city of Bari. The respondents recruited for the experiment were travelers more or less familiar with the network. To evaluate the dynamic effect of information, the road network proposed to respondents simulates different arrival times with two different randomly generated messages. In this way, we were able to reproduce different congestion levels and travel times, according to their statistical distribution in the real world.

The paper is structured as follows. The next section presents a literature review. The modeling approach, based on the Possibility Theory and the Data Fusion, is described in Section 3. In Section 4, a numerical application is proposed to explain how the proposed model works. The SP experiment designed to acquire information about drivers' choice behavior through a driving simulator is described in Section 5. In Section 6, we report the results of the proposed model and the conclusions are in the last section.

2. Literature review

Drivers' travel choice behavior under information provision has been deeply investigated in the past. Recently, Ben-Elia and Avineri (2015) have proposed a review focusing on individual travel behavior as well as network studies involving collective responses. Different models can be set up, depending on the fact whether the study of choice behavior is static or dynamic. In fact, in the static case, pre-trip decisions are made based on transport mode, route and time departure. In this case, the decisions are influenced by drivers' experience and by pre-trip information. Instead, in the dynamic case, en-route decision switching is made using the perception of the current network conditions. In both cases, three factors are involved in routing decision (Adler and Blue, 1998): historical experience; current perception of the network conditions; and information given by an information system.

Horowitz (1984) modeled dynamic route choice by adaptive learning based on utility maximization. Arentze and Timmermans (2003) proposed a reinforcement learning-based approach for dynamic travel choice modeling. Lo et al. (2006) suggested a route choice model based on the concept of travel time budget. They postulated that travelers perceive the variability of route travel times based on experience and other different factors as a travel time budget, which every traveler wants to minimize. They formulated a multi-class mixed-equilibrium mathematical program to capture the route choice behavior of travelers with different risk aversions or requirements for punctual arrivals. To extend stochastic route choice models, Mirchandani and Soroush (1987) proposed a generalized traffic equilibrium problem on stochastic networks (GTESP) that incorporates in the path choice process both probabilistic travel times and variable perceptions. Siu and Lo (2006) formulated a stochastic equilibrium to address uncertainty in the actual travel time, due both to incomplete traffic information about link capacity degradations and to the perception of variations in the travel time budget. To address the effect of other parameters on drivers' route choice, Aashtiani and Iravani (1999) incorporated signalized and un-signalized delay to the deterministic traffic assignment. They proposed some delay functions based on the HCM manual and included these functions in the link delay function. Some experiments indicated that the learning and adaptive process of commuters' route choice might take a long time, partly because of feedback from the traffic system. Indeed, complex switching resulting from the provision of better information (Hu and Mahmassani, 1995; Mahmassani and Chang, 1986; Mahmassani and Liu, 1999) can lengthen the process. Gao (2012) studied the impacts of real-time information on drivers' routing choices in time-dependent networks where random incidents are the source of stochasticity. The author formulated a fixed–point problem of the user equilibrium solved through a method of successive average heuristics. Kucharski and Gentile (2016) proposed a probabilistic model to represent the process of spreading information to drivers via multiple information sources. They embedded the model in a macroscopic dynamic traffic assignment (DTA) of a simulation framework providing a dynamic forecast of informed drivers in road networks. Li et al. (2017) proposed an optimization model with different types of traveler knowledge in an Advanced Traveler Information System context. Some works proposed solutions based on Variable Speed Limit (VSL) systems to manage traffic flow (Abuamer et al., 2016; Demiral and Celikoglu, 2011; Li et al., 2015; Muller et al., 2016; Sadat and Celikoglu, 2017; Soriguera et al., 2017; Yang and Rakha, 2017).

Khattak et al. (1993) used multinomial logit models to analyze drivers' en route diversion and return choices. They identified that: information can indeed encourage drivers to divert from their regular routes; information on travel times should be supplied on many alternative routes; drivers are sensitive to the quality of the information: the more precise the information on the location of congested sections, the more likely drivers are to divert. The conceptual frameworks for analyzing the effects of traffic information on driver behavior should take explicit account of the process of information acquisition and use. The linkage between this process and observed driver behavior should also be considered (Ben-Akiva et al., 1991a, 1991b; Polak and Jones, 1993; Mahmassani and Jayakrishnan, 1991). Hato et al. (1999) proposed a route choice model that takes account of drivers' behavior in the acquisition and