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Agent-based en-route diversion: Dynamic behavioral responses and network performance represented by Macroscopic Fundamental Diagrams

Chenfeng Xiong [a], Xiqun Chen [b], Xiang He [c], Xi Lin [d], Lei Zhang [a,*]

[a] Department of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742, United States
[b] College of Civil Engineering and Architecture, Zhejiang University, Hangzhou 310058, PR China
[c] International Aviation Division, Institute of Air Transport, China Academy of Civil Aviation Science and Technology, PR China
[d] Department of Civil Engineering, Tsinghua University, Beijing 100084, PR China

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ABSTRACT

This paper focuses on modeling agents' en-route diversion behavior under information provision. The behavior model is estimated based on naïve Bayes rules and re-calibrated using a Bayesian approach. Stated-preference driving simulator data is employed for model estimation. Bluetooth-based field data is employed for re-calibration. Then the behavior model is integrated with a simulation-based dynamic traffic assignment model. A traffic incident scenario along with variable message signs (VMS) is designed and analyzed under the context of a real-world large-scale transportation network to demonstrate the integrated model and the impact of drivers' dynamic en-route diversion behavior on network performance. Macroscopic Fundamental Diagram (MFD) is employed as a measurement to represent traffic dynamics. This research has quantitatively evaluated the impact of information provision and en-route diversion in a VMS case study. It proposes and demonstrates an original, complete, behaviorally sound, and cost-effective modeling framework for potential analyses and evaluations related to Advanced Traffic Information System (ATIS) and real-time operational applications.

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1. Introduction

En-route diversion is a significant travel behavior that occurs frequently in every-day travel. Recurrent congestion, non-recurrent incidents, work zones, etc. are likely to trigger drivers to change route. Drivers usually make this decision based on their own spatial/temporal knowledge. They identify alternative route(s), extract and compare the likely travel conditions on both the downstream links and the alternative route(s) using their knowledge and subjective beliefs formed from prior experiences. More recently, information provision alters this situation a great deal. With technical improvement, Advanced Traffic Information System (ATIS), smart-phone applications, and GPS devices with en-route information become readily available in daily travels. Drivers can easily acquire pre-trip and/or en-route information when any diversion decisions are to be made. For instance, when traffic incidents take place in the downstream roadway segments, variable message

* Corresponding author at: 1173 Glenn Martin Hall, Department of Civil and Environmental Engineering, University of Maryland, College Park, MD 20742, United States. Tel.: +1 (301)405 2881.

E-mail address: lei@umd.edu (L. Zhang).

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signs (VMS) can convey real-time traffic information and encourage diversion. This arouses new research questions that need to be better addressed:

- to what extent do travelers comply to en-route information?
- how do we effectively evaluate information provision schemes and measure the network performance changes?

The authors are thus motivated to develop a useful analysis tool to accurately model en-route diversion, predict behavioral responses, and quantify the impact on transportation network. With enhanced computational power and the exploration of new paradigms, transportation modelers' ambition to go "microscopic" and "dynamic" has never been greater. This paper proposes a comprehensive analysis tool which integrates a calibrated agent-based en-route diversion model and a simulation-based dynamic traffic assignment (DTA) model. In order to answer the aforementioned first research question, this paper focuses on microsimulating agent behavior and gauging the model parameters based on calibration and solid empirical evidence. In order to answer the second research question, the behavior model is dynamically linked with a simulation-based DTA model. This integration is completely agent-based and produces time–space trajectories for each simulated agent. Moreover, it estimates time-dependent network conditions for quantifying the network performance. In order to demonstrate the applicability of the proposed model, a case study using a subset network for Washington/Baltimore region is presented in this paper.

The remainder of the paper is organized as follows. Section 2 presents a literature review on behavior modeling and network performance measures. The integrated modeling framework of the agent-based model and operational applications is proposed in Section 3. Section 4 introduces the behavior model and calibration method. The network model and various performance measures are presented in Section 5. The integration and results are interpreted in Section 6. Conclusions and discussions on future research directions are offered at the end of the paper.

2. Literature review

2.1. Behavior modeling

Drivers' en-route diversion behavior has been traditionally modeled by the econometric theory of random utility maximization. In 1990s, a great deal of research efforts have been spent on this line of research. Bivariate and multinomial probit models have been used to model joint pre-trip departure time and en-route diversion behavior in response to real-time information (Khattak et al., 1995; Mahmassani and Liu, 1999). Logit models were also developed to capture the effect of information provision when drivers were en-route (Abdel-Aty et al., 1997). Stated preference and revealed preference data were typically applied to estimate these types of models. More recently, mixed logit, which can incorporate more heterogeneous taste variations, has been broadly employed in modeling diversion behavior (Gan and Ye, 2014; Ben-Elia and Shiftan, 2010). Gao et al. (2010) developed non-linear utility functions based on cumulative prospect theory (CPT) to consider the flexibility towards risk when real-time traffic information is provided. In these recent advances, information on travel time and travel time reliability on the original route and the diverting route plays a crucial role in influencing drivers behavior. Ben-Elia et al. (2013) then analyzed how different information accuracy would influence behavior.

One obvious limitation for random utility maximization models is the assumed perfect rationality. In these models, it is assumed that drivers know the probabilistic distribution of link travel time and can make a rational decision (under risk in some cases). This limitation is especially evident when modeling en-route diversion behavior, as the en-route diversion is a decision triggered by impulsion and governed by uncertainty. Rather than acquiring the real-time information, processing the information, comparing the original route with the diverting route, and reaching a decision, drivers' knowledge is more likely to be biased and their en-route diversion is more likely to be governed by certain heuristics or rules (Paz and Peeta, 2009; Pahlavani and Delavar, 2014). Rule-based computational process models were explored by researchers to look at various behaviors including activity-scheduling (Ettema et al., 2005) and mode choice (Janssens et al., 2006). Bayes' Rule is believed to be among the most prominent behavioral rules to represent decision-making under uncertainty (El-Gamal and Grether, 1995). In the field of travel behavior modeling, Bayes' Rule has been employed to update model parameters (e.g. Janssens et al., 2006; Amador et al., 2005; Xiong et al., 2015a). Travelers' day-to-day perception evolution has been modeled using Bayes updating (e.g. Jha et al., 1998; Xiong and Zhang, 2013b). And there are studies using Bayes' Rule to infer drivers' behavior and innate emotional status (e.g. Malta et al., 2011). The application of rule-based approach in en-route diversion modeling is coarse except one research to model and recalibrate the if-then diversion rules based on fuzzy logics and weight factors (Paz and Peeta, 2009). The behavioral foundation and flexibility of the Bayesian method can be quite substantial for modeling en-route diversion before any pertinent new theories are devised to accommodate those apparent violations of perfect rationality.

From a practical point of view, another limitation of the existing behavior models is that they are often not well-calibrated due to data limitation and other issues. The inherent bias of the stated preference data and driving simulator data have long been argued as a major deficiency of the models (Bonsall and Parry, 1991). The simulation experiment may reinforce the subject's perception of the simulator as artificial. In practice, drivers' route knowledge and en-route diversion propensity differ on a case-specific basis. For instance, in some cases, drivers may have strong preference to stay on the

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