Transportation Research Part C 60 (2015) 339–359

Contents lists available at ScienceDirect

Transportation Research Part C

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

Bayesian network-based formulation and analysis for toll road utilization supported by traffic information provision

Cong Chen [a], Guohui Zhang [a,*], Hua Wang [b], Jinfu Yang [c], Peter J. Jin [d], C. Michael Walton [e]

[a] Department of Civil Engineering, University of New Mexico, Albuquerque, NM 87131, USA
[b] School of Transportation Science and Engineering, Harbin Institute of Technology, Harbin 150090, China
[c] School of Electronic Information and Control Engineering, Beijing University of Technology, Beijing 100124, China
[d] Department of Civil and Environmental Engineering, Rutgers University, New Brunswick, NJ 08901, USA
[e] Department of Civil, Architectural, and Environmental Engineering, The University of Texas at Austin, Austin, TX 78712, USA

ARTICLE INFO

Article history:
Received 29 April 2015
Received in revised form 24 August 2015
Accepted 14 September 2015
Available online 2 October 2015

Keywords:
Toll road
Traffic information provision
Nested logit model
Bayesian network

ABSTRACT

Congestion pricing has been proposed and investigated as an effective means of optimizing traffic assignment, alleviating congestion, and enhancing traffic operation efficiencies. Meanwhile, advanced traffic information dissemination systems, such as Advanced Traveler Information System (ATIS), have been developed and deployed to provide real-time, accurate, and complete network-wide traffic information to facilitate travelers' trip plans and routing selections. Recent advances in ATIS technologies, especially telecommunication technology, allow dynamic, personalized, and multimodal traffic information to be disseminated and impact travelers' choices of departure times, alternative routes, and travel modes in the context of congestion pricing. However, few studies were conducted to determine the impact of traffic information dissemination on toll road utilizations. In this study, the effects of the provisions of traffic information on toll road usage are investigated and analyzed based on a stated preference survey conducted in Texas. A Bayesian Network (BN)-based approach is developed to discover travelers' opinions and preferences for toll road utilization supported by network-wide traffic information provisions. The probabilistic interdependencies among various attributes, including routing choice, departure time, traffic information dissemination mode, content, coverage, commuter demographic information, and travel patterns, are identified and their impacts on toll road usage are quantified. The results indicate that the BN model performs reasonably well in travelers' preference classifications for toll road utilization and knowledge extraction. The BN Most Probable Explanation (MPE) measurement, probability inference and variable influence analysis results illustrate travelers using highway advisory radio and internet as their primary mode of receiving traffic information are more likely to comply with routing recommendations and use toll roads. Traffic information regarding congested roads, road hazard warnings, and accident locations is of great interest to travelers, who tend to acquire such information and use toll roads more frequently. Travel time formation for home-based trips can considerably enhance travelers' preferences for toll road usage. Female travelers tend to seek traffic information and utilize toll roads more frequently. As expected, the information provided at both pre-trip and en-route stages can positively influence travelers' preferences for toll road usage. The proposed methodology and research findings advance our previous study and provide insight into travelers' behavioral tendencies concerning toll road utilization in support of traffic information dissemination.

* Corresponding author.
E-mail address: guohui@unm.edu (G. Zhang).

http://dx.doi.org/10.1016/j.trc.2015.09.005
0968-090X/

1. Introduction

In the past three decades, annual Vehicle Miles Traveled (VMT) increased by 96%, while national road mileage increased by only 4% in the U.S. (Bureau of Transportation Statistics, 2013). Dramatically increasing travel demands and insufficient traffic facility supplies have induced severe traffic congestion. Traffic congestion costs billions of dollars every year due to lost time, wasted energy, excess air pollution, and lost productivity. In 2011, traffic congestion resulted in 5.5 billion hours of travel delays and 2.9 billion gallons of extra fuel consumptions resulting in a total cost of $121 billion dollars (Schrank et al., 2012). Congestion pricing has been developed as an effective means of addressing increasing congestion problems and transportation funding shortfalls. With the increasing popularity of toll road projects, de Palma and Lindsey (2011) summarized major methodologies and techniques for roadway congestion pricing, regarding their advantages, disadvantages and application limitations. Numerous studies have been conducted to better understand various toll road operations and explore different toll schemes to optimize transportation network serviceability (Gardner et al., 2010; Hamdouch et al., 2007; Lawphongpanich and Yin, 2012, 2010; Lee et al., 2008; Lou et al., 2011; Meng and Liu, 2012; Meng et al., 2005; Wie, 2007; Wu et al., 2011; Xu et al., 2011; Yang et al., 2010; Yin et al., 2004; Zangui et al., 2013; Zhang et al., 2014b). For instance, Hamdouch et al. (2007) proposed user equilibrium and system optimization models to establish a toll charging framework for multi-modal transportation networks. Lawphongpanich and Yin (2012) developed nonlinear pricing models based on piecewise linear functions to optimize toll scheme where tolling payment is not linearly proportional to travel distances. Lou et al. (2011) presented a self-training method based on loop detector data for dynamic tolling on High-Occupancy/Toll (HOT) lanes. Zangui et al. (2015) proposed corresponding methods and solutions to address the location issues of vehicle identification sensor to better implement path-differential tolling schemes. However, most transportation networks are associated with traffic operation uncertainty regarding travel demand and behavior. Therefore, peer studies have focused on addressing these uncertainty issues for toll implementation and operation optimization (Boyles et al., 2010; Gardner et al., 2010; Han and Yang, 2009; Yang et al., 2010). As can be expected, many important issues, such as public acceptance and preference, economic equity, and environmental justice, are closely associated with various toll road projects. Significant studies have been conducted to address these issues for proper tolling policy development through various survey studies (Dill and Wiensten, 2007; Hamilton and Eliasson, 2013; Holguín-Veras and Preziosi, 2011; Holguín-Veras and Wang, 2011; Jaensirisak et al., 2005; Jou et al., 2013, 2011; Ogden, 2001; Wu et al., 2012). For instance, Wu et al. (2012) developed a congestion pricing modeling framework considering the affordability of different income groups as well as tradable credit schemes. Jou et al. (2011) discovered that road users' impression change on ETC system due to the information acquired from media broadcast and people communications significantly contributed to their inclinations. Holguín-Veras and Wang (2011) applied discrete choice analysis to investigating the contributing factors on freight carrier drivers' propensity on using electronic toll collection system.

On the other hand, traffic information provision plays a critical role in facilitating travelers to select routes, travel modes, and departure times. Advanced Traveler Information Systems (ATIS) are widely deployed to provide travelers with accurate, complete, and timely information about traffic conditions over roadway networks. Considerable contemporary literature has been focusing on the importance of traffic information provision, including ATIS, on traffic operations. Emmerink et al. (1995) concluded that real-time traffic information dissemination was critical for non-current congestion mitigation. Mehndiratta et al. (2000) found that 22% of travelers changed their routes entirely and 34% changed partially when given en-route travel information. Yin and Yang (2003) proposed a multiple behavior network equilibrium model to identify equilibrium market penetration and compliance rate for ATIS. Yang and Recker (2005) proposed a simulation procedure to examine the information dissemination patterns in self-organized traffic information system for autonomous vehicle communications. Ettema and Timmermans (2006) discussed the costs resulting from travel time uncertainty and the benefits from the provision of traffic information based on a departure time choice model. Chorus et al. (2007) developed a multimodal travel simulator with an embedded traffic information provision component. Tseng et al. (2013) discovered that the provision of real-time traffic information led to larger variance on travel times than traditional traveler perceptions. Jou and Chen (2013) found that traffic information for non-recurring conditions was the most needed among freeway drivers, and their needs on alternative routes were positively related to those on main freeways. Based on agent-based modeling, Ma et al. (2015) devised a traffic information provision system providing personalized traffic information to road users with various demands.

Although previous studies have investigated congestion pricing and traffic information dissemination extensively, most of them concentrated on the effects that these instruments produce on transportation system operations (Enrique Fernández et al., 2009). Some researchers analyzed the joint application of congestion pricing and traffic information dissemination against recurrent and non-recurrent congestion (de Palma and Lindsey, 1998; Verhoef et al., 1996; Zhang and Verhoef, 2006). However, few studies were conducted to determine the impacts of traffic information dissemination on toll road utilization simultaneously (refer to (Zhang et al., 2014a) for a complete literature review). Our previous study (Zhang et al., 2014a) investigated public opinions and preferences for toll road usage in support of various traffic information dissemination classified by different modes, contents, and timeliness categories. A nested logit model was developed and estimated to identify the significant attributes of traffic information dissemination, traveler commuting patterns, routing behavior, and demographic characteristics and analyze their impacts on toll road utilization. However, due to the model specification