

# Enhanced traffic information dissemination to facilitate toll road utilization: a nested logit model of a stated preference survey in Texas

Guohui Zhang · Zhong Wang · Khali R. Persad · C. Michael Walton

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**Abstract** This paper investigates the effects of the provision of traffic information on toll road usage based on a stated preference survey conducted in central Texas. Although many researchers have studied congestion pricing and traffic information dissemination extensively, most of them focused on the effects that these instruments individually produce on transportation system performance. Few studies have been conducted to elaborate on the impacts of traffic information dissemination on toll road utilization. In this study, 716 individuals completed a survey to measure representative 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. The results revealed that the travelers using dynamic message sign systems as their primary mode of receiving traffic information are more likely to choose toll roads. The potential toll road users also indicated their desire to obtain traffic information via internet. Information regarding accident locations, road hazard warnings,

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G. Zhang (✉)  
Department of Civil Engineering, MSC01 1070, 1, University of New Mexico,  
Albuquerque, NM 87131-0001, USA  
e-mail: guohui@unm.edu

Z. Wang  
Dalian University of Technology, No. 2 Linggong Road, Ganjingzi District,  
Dalian City 116024, Liaoning Province, China  
e-mail: zwang@dlut.edu.cn

K. R. Persad  
Center for Transportation Research, University of Texas at Austin, 1616 Guadalupe,  
Austin, TX 78705, USA  
e-mail: kpersad@mail.utexas.edu

C. M. Walton  
Department of Civil, Architectural and Environmental Engineering, The University of Texas at Austin,  
1 University Station C1761, Austin, TX 78712-0278, USA  
e-mail: cmwalton@mail.utexas.edu

and congested roads is frequently sought by travelers. Furthermore, high-quality congested road information dissemination can significantly enhance travelers' preferences of toll road usage. Specifically the study found that travelers anticipated an average travel time saving of about 11.3 min from better information; this is about 30 % of travelers' average one-way commuting time. The mean value of the time savings was found to be about \$11.82 per hour, close to 1/2 of the average Austin wage rate. The model specifications and result analyses provide in-depth insights in interpreting travelers' behavioral tendencies of toll road utilization in support of traffic information. The results are also helpful to shape and develop future transportation toll system and transportation policy.

**Keywords** Toll roads · Traffic information dissemination · Survey study · Nested Logit model

## Introduction

Dramatically increasing travel demands and insufficient traffic facility supplies have induced severe traffic congestion. According to the 2009 Annual Urban Mobility Report (Shrank and Lomax 2010), the annual average delay per capita was 38 h for 439 surveyed urban areas, a 171 % increase from 1982. The total travel delay of 4.2 billion vehicle hours generated 2.9 billion gallons of excess fuel consumption and \$87.2 billion in excess costs due to congestion. Meanwhile, the costs to the aging transportation system maintenance are increasing and transportation infrastructure deterioration further strains transportation system operations due to financial shortages. Congestion pricing has been proposed as an effective means of mitigating traffic congestion and generating additional revenue to overcome the gap between limited funding supports and needed transportation infrastructure improvements. A suitable toll is able to balance traffic flow allocation over the network, more efficiently utilize existing infrastructure, and generate toll revenues for roadway construction and maintenance. For example, the Texas Department of Transportation (TxDOT) used toll financing to construct the Texas State Highway (SH) 130 toll road as an alternative to Interstate Highway (IH) 35 for congestion mitigation in central Texas in 2007. Using traditional financing from states and federal gas taxes, construction would have been delayed to around 2020 (Walton et al. 2006). Based on the Federal Highway Administration (FHWA) values for roadway lengths, about 5,000 U.S. miles (9 % of U.S. highway mileage) are tolled (Podgorski and Kockelman 2006). A number of states have implemented tolling projects, including the high occupancy toll (HOT) and express toll lane systems in California (SR-91, I-15, and I-580), Texas (I-10 and US-290), Minnesota (I-394 and I-35), Utah (I-15), Colorado (I-25), Washington (SR-167), and Florida (I-95) since 1994. As demonstrated in these tolling projects, tolling will play an important role in future transportation system developments. Under such a background, many researchers investigated public attitudes toward tolling and tolling policy developments through survey studies (Podgorski and Kockelman 2006; Dill and Wiensten 2007).

Previous studies analyzed public acceptance and willingness to pay a toll for travel time savings, and investigated different toll collection modes and policies to increase public supports for tolling, however, they did not emphasize the impacts of traffic information dissemination on toll road utilization. Can timely, accurate, and complete traffic information effectively enhance toll facility utilization? Previous studies showed that traffic growth on the tolled Melbourne City link in Australia has been partially attributed to aggressive provision of information about traffic conditions on competing routes (Lay and

Daley 2002). Currently, advanced traveler information systems (ATIS) are available to provide travelers with information about traffic conditions over the network on both pre-trip and en-route stages and assist travelers in selecting routes, travel modes, and departure times. The previous literature focused on the impacts of ATIS on traveler responses (Mahmassani and Jou 2000), and few of them investigated traffic information dissemination in favor of toll road utilization.

To address this gap, this paper therefore concentrates on toll road utilization enhancement supported by advanced traffic information dissemination. A stated preference survey was conducted in central Texas, and a nested Logit model was developed to identify significant attributes of traffic information dissemination, travelers' typical commuting patterns, and demographic characteristics, and analyze their impacts on toll road utilization.

The next section presents the prominent studies regarding congestion pricing and traffic information dissemination. In Sections “[Survey Design and Administration](#)” and “[Data Description and Analysis](#)”, the survey design and administration as well as data descriptions and analyses are introduced. The details of the nested logit model specification and estimation are presented in Section “[Nested Logit Model Specification and Estimation](#)”. Data analysis and result discussion are provided in Section “[Discussion of Results](#)”. The conclusions are given in “[Conclusion](#)” Section.

## Literature review

### Congestion pricing studies

As an effective means of reducing traffic congestion and raising revenues, congestion pricing has been proposed and studied for several decades since Pigou (1920) and Knight (1924) initially explored congestion pricing theory. In the 1960s, the research interest in congestion pricing was resurrected by the work of Walters (1961) and Vickrey (1969). Vickrey (1969) developed a dynamic vehicle congestion model to derive socially optimal tolls featured with flexible departure and arrival time. Since then, substantial research has been conducted by transportation economists and scientists. The well-known first-best or marginal-cost pricing theory has attracted much research attention. Based on this theory, the optimal toll should be equal to the difference between the marginal social cost and the marginal private cost to drive a user equilibrium (UE) flow pattern toward the system optimum (SO) by solving a socially optimal traffic equilibrium problem (Yang and Huang 2004). However, the first-best pricing theory has limited practical value despite its sound theoretical basis. The second-best pricing schemes have been proposed as a practical solution to determining tolls considering physical and economic constraints (Yang and Huang 2005; Lawphongpanich et al. 2006). Meng et al. (2005) proposed the iterative toll adjustment mechanisms based on the single and network-wide link flows without demand information. Arnott et al. (1993) compared four distinct pricing strategies and concluded that considerable benefits can be achieved under congestion pricing. In practice, congestion pricing strategies have been implemented worldwide such as Hong Kong, Singapore, Toronto, Stockholm and, London (Olszewski and Xie 2005).

### Public attitudes towards congestion pricing

More traffic congestion pricing systems will conceivably be developed for efficient congestion mitigation and revenue generation. Many previous studies were conducted to

investigate the public attitudes towards congestion pricing. Jaensirisak et al. (2005) conducted a stated preference study in Leeds and London in the UK and found that congestion pricing was acceptable to road users who perceived pollution and congestion as a very serious problem and considered the current situation unacceptable. Dill and Wiensten (2007) conducted phone surveys to examine public opinions regarding funding and tolling. They found fairly strong support for some tolling modes—particularly HOT lane systems. Schuitema and Steg (2008) investigated revenue usage in the acceptability of pricing policies, and argued that pricing is perceived to be more acceptable if revenues are allocated to transportation systems instead of to general public funds. Small (1983) and Evans (1992) studied the pricing equity impacts and argued that congestion pricing would be regressive without revenue redistribution. Kottenhoff and Freij (2009) studied the relationship between public transportation and congestion pricing through travel surveys in Stockholm. Winslott-Hiselius et al. (2009) analyzed public attitudes toward the Stockholm congestion pricing system by using survey data and found that about 50 % of the participants had positive attitudes toward the system. Pacific Rim Resources (2001) conducted a telephone survey and found 40 % of respondents will utilize HOT lanes for timing savings in the Puget Sound area in Washington State. Odeck and Bråthen (2002) examined travelers' attitudes toward the Oslo toll roads, and found that travelers' attitudes became more and more positive as they received substantial benefits through better infrastructure. Based on a telephone survey, Smith concluded that 91 % of respondents supported the I-15 toll road project in San Diego (FHWA 2002). Kockelman and Kalmanje (2005) conducted a study on credit-based congestion pricing policy through a survey and found 25 % of respondents were supportive of this strategy. Podgorski and Kockelman (2006) investigated the public perceptions of toll roads and argued that HOT lanes may have higher levels of support (52 % of respondents) compared with other toll facilities based on a telephone survey in Texas.

#### Traffic information dissemination studies

Many studies have been conducted to investigate the impacts of traffic information dissemination on transportation system operations (Jou et al. 2005). Yim et al. (1997) reported that 75 % of commuters surveyed in the San Francisco Bay area listen to traffic information on radio, and 50 % of them change their travel behavior accordingly. A survey in the Seattle area (Mehndiratta et al. 2000) found that among the en-route travel information users, 34 % partially change their routes while 22 % change their routes completely. In addition to mitigating recurrent congestions, the provision of real-time traffic information can also significantly improve traffic operations for non-recurrent congestion (Levinson 2003). Travelers are generally appreciative of accurate, timely, and complete traffic information and their common responses to traffic information about congestion include changing departure time or routes (Srinivasan and Krishnamurthy 2004). With the aid of ATIS, travelers can make better use of traffic information to mitigate congestion and benefit from an optimized traffic system; travel time savings range from 7 to 20 % (Levinson 2003). Many issues such as information quality and costs, drivers' compliance rates, and market penetration rates were examined by the researchers (Yin and Yang 2003).

As discussed above, although many researchers have studied congestion pricing and traffic information dissemination extensively, most of them focused on the effects that these instruments individually produce on transportation system performance (Enrique Fernández et al. 2009). Some researchers analyzed the joint application of congestion

pricing and traffic information dissemination against recurrent and non-recurrent congestion (Zhang and Verhoef 2006). However, few studies examined the impacts of information dissemination on toll road usage. Recent advances in ATIS technologies (telecommunication technology in particular) allow dissemination of dynamic, personalized, and multimodal traffic information and impact travelers' choices of departure times, alternative routes, and travel modes in the context of congestion pricing.

### **Survey design and administration**

The stated preference survey was designed to illuminate the impacts of traffic information dissemination on toll road utilization by the researchers at the Center for Transportation Research (CTR) at The University of Texas at Austin (UT-Austin). UT-Austin's Office of Survey Research administered the survey. A wide range of data were collected to comprehensively analyze public attitudes about using toll roads when given traffic information, including travelers' preferences for traffic information, attitudes toward toll roads, routing behavior, demographic characteristics, and travel patterns. The survey questionnaire was administered and distributed online through an online survey provider. The Austin Chamber of Commerce helped distribute the survey by including an article about it in the chamber's electronic newsletter, which is widely circulated among employers in the Austin area. Subsequently, a number of other agencies in the Austin area, including CTR, the City of Austin, and Capital Metro (Austin's regional public transportation provider), provided a link to the survey on their Web pages. IP addresses of survey-participating computers were recorded so that duplicated entries could be screened. The survey consisted of 28 questions in 4 sections. The first section collected travelers' commuting patterns and travel characteristics. The second section examined travelers' preferences for traffic information usage, and the third section sought travelers' opinions about toll settings and values of time (VOT). The last section collected general information on demographic characteristics. To relieve respondents' burden, the questionnaire was relatively uncomplicated and on average the surveys took approximately 10–12 min to complete. The data collection lasted for 7 months; 734 responses were obtained.

### **Data description and analysis**

#### Data collection and description

Due to non-completion of demographic data, only 716 responses were used for analysis. Special care was taken to analyze the respondents' demographic data and recognize their diversity for equity considerations. The respondents are distributed over most of the greater Austin metropolitan area in 13 counties identified by their five-digit zip code inputs. Further analysis indicates that the number of surveyed respondents in each sub-area is generally proportional to its population. Sixty percent of the survey respondents were women, 3.4 % were from lowest income group, and 51.9 % were between the ages of 20 and 45. Based on a comparison with Austin's 2006 region-wide travel survey (Podgorski and Kockelman 2006), the sample reasonably represents the population distribution in the greater Austin area. Variable descriptions along with their means are given in Table 1.

**Table 1** Trip characteristics and demographic variables

Type	Variable	Description	Mean
Trip	The number of commuting days per week during peak hours <sup>a</sup>	The number of days	4.86
	Primary trip purpose, peak hours		
	Work	Indicator for work	0.92
	School	Indicator for school	0.05
	Child care/child's school	Indicator for child care/child's school	0.01
	Recreation/social	Indicator for recreation/social	0.01
	Shopping	Indicator for shopping	0.01
	Medical	Indicator for medical	0.01
	Secondary trip purpose, peak hours		
	Work	Indicator for work	0.08
	School	Indicator for school	0.16
	Child care/child's school	Indicator for child care/child's school	0.17
	Recreation/social	Indicator for recreation/social	0.18
	Shopping	Indicator for shopping	0.28
	Medical	Indicator for medical	0.13
	Transportation mode		
	Automobile (car, truck, van)	Indicator for automobile	0.90
	Public transportation	Indicator for public transportation	0.09
	Walk	Indicator for walk	0.01
	Bicycle	Indicator for bicycle	0.01
	The most often used highways		
	Interstate Highway 35 (I-35)	Indicator for I-35	0.44
	US-360 (Capital of Texas)	Indicator for US-360	0.04
	US-71 (Ben White Boulevard: West-Bee Cave)	Indicator for US-71 West	0.03
	US-71 (Ben White Boulevard: East-Bastrop)	Indicator for US-71 East	0.07
	US-183 (Research Boulevard: North)	Indicator for US-183	0.15
	Loop 1 (Mopac Expressway)	Indicator for Loop 1	0.29
	US-290 East (Elgin/Manor)	Indicator for US-290 East	0.05
	US-290 West (Dripping Springs/Oak Hill)	Indicator for US-290 West	0.05
	FM-2222	Indicator for FM-2222	0.04
	Parmer Lane (FM 734)	Indicator for Parmer Lane	0.05
	Familiar with the roadway system to find alternative routes	0-no, 1-yes	0.91
	The average travel time (min)		
	Outbound trip	Time (min)	34.7
	Homebound trip	Time (min)	39.4

**Table 1** continued

Type	Variable	Description	Mean
The average distance, miles			
Outbound trip	Distance (in miles)	18.9	
Homebound trip	Distance (in miles)	18.9	
Traveler	Age	Age (in years)	45.3
	Male gender (female as base)	Indicator for male gender	0.40
	Household characteristics		
	Household size	The number of persons	2.67
	The number of drivers	The number of licensed drivers	2.03
	The number of vehicles	The number of vehicles	2.16
	Any children ages 0–11 years	0-no, 1-yes	0.28
	Household income	0-Less than \$14,999, 1-\$15,000 to \$24,999, 2-\$25,000 to \$34,999, 3-\$35,000 to \$49,999, 4-\$50,000 to \$74,999, 5-\$75,000 to \$99,999, 6-\$100,000 to \$149,000, 7-\$150,000 or more	4.89
	Zip code	Current zip code	N/A
	Employment status (unemployed as base)		
	Employed full-time	Indicator for employed full-time	0.92
	Employed part-time	Indicator for employed part-time	0.03
	Student	Indicator for student	0.02
	Retired	Indicator for retired	0.03
	Education level (low education as base)		
	Medium education	Indicator for bachelor's degree	0.44
	High education	Indicator for master's degree or higher	0.22

<sup>a</sup> Including both morning and afternoon peak hours

## Data analysis

In addition to the travelers' demographic attributes, key questions about traveler commuting patterns were included in the survey. The collected data indicated that about 74.3 % of the respondents commute 5 days per week at an average distance of 37.8 miles including both homebound and outbound trips per day. Work is selected as the primary trip purpose by 92 %. For secondary trip purposes, 28 % name shopping, followed by recreation/social (18 %), and child care/child's school (17 %). About 90 % selected automobile, including passage cars and pickup trucks, as the most commonly used travel mode. Totally, 88 % commute on at least one of the major freeway corridors, including I-35, Loop 1, and US Highway 183 in the Austin area.

The survey data indicated that only 13.3 % of travelers never seek traffic information during their peak-hour trips. Most report that they respondents do use traffic information to facilitate their trip planning and routing optimization—about 49.6 % seek traffic information fairly often or very often. When seeking traffic information to determine travel conditions, the travelers show particular interests in the information regarding accident

**Table 2** Information and tolling variables

Type	Variable	Description	Mean
Information	How often seek information during peak hours <sup>a</sup>	0-never, 1-sometimes, 2-fairly often, 3-very often	1.46
	Current mode of receiving traffic information		
	Radio	Indicator for radio	0.88
	TV	Indicator for TV	0.36
	Local newspaper	Indicator for newspaper	0.04
	Internet	Indicator for Internet	0.15
	Dynamic Message Signs (DMS)	Indicator for DMS	0.12
	Preferred mode of receiving traffic information		
	Radio	Indicator for radio	0.77
	TV	Indicator for TV	0.19
	Local newspaper	Indicator for local newspaper	0.02
	Internet	Indicator for Internet	0.18
	DMS	Indicator for DMS	0.36
	In-vehicle navigation system (VNS)	Indicator for VNS	0.16
	The stage of seeking Information		
	Pre-trip	Indicator for pre-trip	0.50
	En-route	Indicator for en-route	0.77
	Type of information content sought		
	Road work	0-very unlikely, 1-unlikely, 2-neutral, 3-likely, 4 very likely	2.18
	Lane closure	0-very unlikely, 1-unlikely, 2-neutral, 3-likely, 4 very likely	2.34
	Road hazard warnings	0-very unlikely, 1-unlikely, 2-neutral, 3-likely, 4 very likely	2.05
	Accident locations	0-very unlikely, 1-unlikely, 2-neutral, 3-likely, 4 very likely	3.05
	Congested roads	0-very unlikely, 1-unlikely, 2-neutral, 3-likely, 4 very likely	2.76
	Estimated travel time	0-very unlikely, 1-unlikely, 2-neutral, 3-likely, 4 very likely	1.87
	Weather conditions	0-very unlikely, 1-unlikely, 2-neutral, 3-likely, 4 very likely	2.54
	Impacts of traffic information on the trip		
	Choose an alternative transportation mode	Indicator alternative transportation mode	0.03
Delay departure time	Indicator for delay departure time	0.04	
Leave earlier than planned	Indicator for leave earlier than planned	0.17	
Choose an alternate route	Indicator for an alternate route	0.70	
Cancel trip	Indicator for cancel trip	0.01	
No impact	Indicator for no impact	0.05	
Tolling	Willing to choose a toll road for time savings	0-no, 1-yes	0.46
	The minimum time savings to pay for using toll road	Time (min)	11.3
	How much be willing to pay	Toll (in dollars)	\$0.82

<sup>a</sup> Including both morning and afternoon peak hours



locations (likely or very likely to be sought by 80.3 %), road congestions (70.1 %), weather conditions (59.5 %), and lane closures (56.9 %).

In terms of the major modes of receiving traffic information, 88 % cite the radio system as their most frequently used means of acquiring traffic information. At 36 %, the second most frequent traffic information source is the TV system. However, travelers’ preferred modes for traffic information acquisitions differ considerably. The respondents show greater interest in receiving information via the radio system (77 %) and roadside Dynamic Message Signs (DMS) (36 %) than via other means. Note that the survey indicated higher demands for DMS and internet usage than are currently observed (36 vs. 12 % for DMS, and 18 vs. 15 % for internet) due to their dynamic information delivery capabilities. However, cell phone usage is not included in this study due to the obvious safety concerns about sending and receiving text messages or talking on cell phones, even with headsets (Olson et al. 2009).

The questions are also designed to investigate the potential impacts of traffic information on traveling decisions. For example, to address the question “how does the traffic information you’ve received impact your travel,” about 70 % stated that they would select an alternate route, 17 % report they would leave earlier than planned, and 5 % noted no impacts on their traveling decisions (Table 2). These data imply that traffic information dissemination, including network-wide travel time, congestion level, incident, and construction activity, can significantly influence travelers’ judgment of anticipated travel time and finally determine their routing and toll road usage behavior.

**Nested logit model specification and estimation**

In this study, a nested multinomial logit model was developed to analyze survey data and extract insight into toll road utilization in support of traffic information dissemination. Two decision variables, toll road usage and traffic information usage, are particularly emphasized in the two-layer nested Logit model. The toll and non-toll road usage preferences were defined by the tolling variable “Willing to choose a toll road for time savings” (0-no denotes non-toll road usage, and 1-yes denotes toll road usage). The frequency of traffic information usage was distinguished by the traffic information variables “How often seek traveler information during peak hours” (infrequent traffic information usage includes 0-never and 1-sometimes, and frequent traffic information usage consists of 2-fairly often and 3-very often). In this study, a utility maximization nested logit (UMNL) model was established with two groups of toll and non-toll road usage and two alternatives of frequent and infrequent traffic information usage in each group. The UMNL model probability that alternative *n* in group *m* is chosen is

$$P_n = P_{n/m} \times P_m \tag{1}$$

where,

$$P_{n/m} = \frac{e^{V_{n/m}/\mu_m}}{\sum_{n' \in N_m} e^{V_{n'}/\mu_m}} \tag{2}$$

$$P_m = \frac{e^{V_{Tm} + \mu_m \Gamma_m}}{\sum_{m'=1}^M e^{V_{Tm'} + \mu_{m'} \Gamma_{m'}}} \tag{3}$$

and

**Table 3** Nested logit model specifications for toll road usage supported by traveler information

Variable <sup>a</sup>	Coef.	SE	T ratio	P value
<i>Lower level variables</i>				
Constant				
T-FTI constant	-8.704	0.936	-9.298	0.000
NT-FTI constant	-8.523	1.037	-8.218	0.000
Current mode of receiving traffic information				
Radio (specific to NT-FTI)	1.398	0.509	2.745	0.006
Preferred mode of receiving traffic information				
Internet (specific to T-FTI)	0.954	0.338	2.824	0.005
VNS (specific to T-FTI)	-0.596	0.342	-1.745	0.081
Stage of seeking traveler Information				
Before-trips (specific to T-FTI)	1.726	0.341	5.069	0.000
Before-trips (specific to NT-FTI)	1.515	0.350	4.326	0.000
En-route (specific to T-FTI)	0.911	0.384	2.371	0.018
En-route (specific to NT-FTI)	0.732	0.429	1.704	0.088
Traveler information content sought				
Accident (specific to T-FTI)	0.700	0.189	3.708	0.000
Accident (specific to NT-FTI)	1.025	0.153	6.721	0.000
Warnings (specific to NT-FTI)	0.471	0.125	3.756	0.000
Congestion-road (specific to T-FTI)	0.475	0.169	2.808	0.005
Average time spent in traveling				
Homebound trip (specific to T-FTI)	0.030	0.007	4.112	0.000
Outbound trip (specific to NT-FTI)	0.016	0.009	1.737	0.082
Household size				
The number of persons (specific to NT-FTI)	0.158	0.090	1.761	0.078
Household income				
Household-income (specific to NT-FTI)	-0.204	0.083	-2.470	0.014
Transportation mode				
Automobile (specific to T-FTI)	1.214	0.456	2.664	0.008
Impacts of traffic information on trips				
Choose an alternate route (specific to T-FTI)	0.515	0.281	1.834	0.067
Delay departure time (specific to NT-FTI)	-0.734	0.361	-2.033	0.042
<i>Upper Level Variables</i>				
Age				
Age (specific to TollRoadPreference)	-0.132	0.043	-3.072	0.002
Education level				
Edu-high (specific to TollRoadPreference)	0.428	0.183	2.336	0.020
Gender				
Male (specific to TollRoadPreference)	-0.318	0.160	-1.993	0.046
Current mode of receiving traffic information				
DMS (specific to TollRoadPreference)	0.470	0.242	1.945	0.052
Newspaper (specific to TollRoadPreference)	-0.869	0.460	-1.890	0.059
$\mu_{NT}^b$	0.370	0.166	2.230	0.026

**Table 3** continued

Variable <sup>a</sup>	Coef.	SE	T ratio	P value
$\mu_T^c$	0.572	0.175	3.267	0.001
L (constants) <sup>d</sup>		-988.287		
L (convergence) <sup>e</sup>		-798.403		
$\rho_{bar}^{2, f}$		0.182		

<sup>a</sup> Texts in brackets indicate the variables defined for these alternatives: [T-IFTI] Toll and infrequent information usage, [T-FIT] Toll and frequent information usage, [NT-IFTI] Non-toll and infrequent information usage, and [NT-FIT] Non-toll and frequent information usage

<sup>b</sup> Inclusive value for the nest of non-toll road usage

<sup>c</sup> Inclusive value for the nest of toll road usage

<sup>d</sup> Log likelihood function at constants

<sup>e</sup> Log likelihood function at convergence

<sup>f</sup> Log-likelihood Ratio Index

$$\Gamma_m = \ln \left( \sum_{n' \in N_m} \exp \left( \frac{V_{In'}}{\mu_m} \right) \right) \tag{4}$$

$$U_{Tm} = V_{Tm} + \varepsilon_{Tm} = (\beta x)_{Tm} + \varepsilon_{Tm} \tag{5}$$

$$U_{Im} = V_{Im} + \varepsilon_{Im} = (\beta x)_{Im} + \varepsilon_{Im} \tag{6}$$

$$U_{nm} = V_{Tm} + \varepsilon_{Tm} + V_{Im} + \varepsilon_{Im} = (\beta x)_{Tm} + (\beta x)_{Im} + \varepsilon_{Tm} + \varepsilon_{Im} \tag{7}$$

where,  $U_{nm}$  is the utility associated with traffic information usage alternative  $n$  in toll road usage nest  $m$ ;  $V_{Tm}$  is the regression item depending only on variables that describe nest  $m$ , and these variables vary over nests but not over alternatives within each nest;  $V_{In}$  is the regression item depending on variables that describe alternative  $n$ , and these variables differ over alternatives within nest  $m$ ;  $V_{Tm}$  and  $V_{In}$  are also called the systematic components of the utility functions;  $\varepsilon_{Tm}$  and  $\varepsilon_{In}$  are the random components;  $P_{n/m}$  is the probability of choosing alternative  $n$  conditional on choosing nest  $m$ ;  $P_m$  is the marginal probability of choosing nest  $m$  of which  $n$  is a member;  $N_m$  is the set of all alternatives include in nest  $m$ ,  $N_m = 2$ ;  $M$  is the number of all nests,  $M = 2$ ;  $\mu_m$  is the logsum or inclusive value parameter for nest  $m$ ;  $\Gamma_m$  is the logsum variable of nest  $m$ ;  $m = 1$  (non-toll road usage) or  $2$  (toll road usage);  $n = 1$  (infrequent traffic information usage) or  $2$  (frequent traffic information usage). The logsum parameter,  $\mu_m$ , reflects certain correlation among unobserved factors within each nest. The other model structure can be established by reversing the upper and lower levels of the model described in Equations (1)–(7). The toll road usage preference is nested within the information usage choice. The nested logit model specification can be formulated by Equation (1)–(7), but with subscripts  $T$  and  $I$  reversed, and subscripts  $m$  and  $n$  reversed. The appropriateness of the model structures can be validated and tested by the sample data and the inclusive value  $\mu_m$ , which should lie between 0 and 1 (Ben-Akiva and Lerman 1985). The parameters of the nested models were estimated by the standard maximum likelihood techniques. The statistic software package LIMDEP was used. Both nested logit models were tested and the estimation results of the model specification defined by Equations (1)–(7) are shown in Table 3.

## Discussion of results

### Nested logit model

Basically, a positive coefficient indicates a positive relationship between the probability of that specific choice and the independent variable, and vice versa. The value of the coefficient indicates the impact magnitude of the variable on that probability. The T-ratio and  $P$  values are the measurements for the variable significance. For the reversed model, the logsum parameters,  $\mu_{IF}$  and  $\mu_F$ , for the nest of infrequent information usage and the nest of frequent information usage, are estimated as 5.844 and 1.444, which are greater than 1 and do not favor this model specification. Fortunately, the results of the model structured by the upper toll-usage level and lower information-usage level show the model's appropriateness and validation in Table 3. Its logsum parameters,  $\mu_{NT}$  and  $\mu_T$ , for the nest of non-toll road usage and the nest of toll road usage, are equal to 0.370 and 0.572, which are significantly different from 0 (their  $P$  values are 0.026 and 0.001) and 1 (the corresponding  $P$  values are 0.000 and 0.015, respectively). These results verify the significance of the separated nests and support the notion of information usage nesting within toll road usage. As its goodness-of-fit measurement, the Log-likelihood Ratio Index (LRI) is 0.182, which indicates a reasonable fit. According to work by Domencich and McFadden (1975), LRI values between 0.2 and 0.4 correspond to R-squared values of 0.7 through 0.9 for a linear function. This result implies that traveler information dissemination can significantly impact toll road utilization, and they should be hierarchically and integrally studied. Therefore, our analysis and discussion are elaborated for this model specification.

### *Lower level: traffic information usage*

All the parameters for the significant variables with at least 90 % confidence levels are shown in Table 3. The alternative choice, T-FTI, indicates the toll road and frequent traveler information usage; T-IFTI denotes the toll road and infrequent traveler information usage; NT-FTI indicates the non-toll road and frequent traveler information usage; NT-IFTI denotes the non-toll road and infrequent traveler information usage. These parameters can provide statistically meaningful insights into the behavioral process of traffic information and toll road usage. For the variables at the lower level of traffic information usage, the alternative-specific constants for the alternatives of T-FTI and NT-FTI are  $-8.704$  and  $-8.523$ , which are significantly different from zero at the  $P = 0.01$  level of significance. The negative sign reflects the fact that majority of travelers tend to travel without frequently seeking traffic information. The T-FTI constant is less than the NT-FTI one. This result indicates that among the frequent traveler information group, the travelers slightly prefer to use non-toll roads. The current modes of receiving traffic information are closely related to travelers' preferences for toll road utilization. The coefficient of the variable Radio for the alternative of NT-FTI is 1.398 with a  $P$  value of 0.006. This result indicates that the increased usage of radio can effectively increase traffic information dissemination and usage, but will not encourage more toll road utilization. The other variables, DMS and Newspaper, have direct impacts on toll road usage preferences at the upper level, and their interpretations are provided in the next section. On the other hand, for the preferred modes of receiving traffic information, the coefficients of the variables, Internet for the T-FTI alternative and VNS for the T-IFTI alternative, are 0.954 ( $P$  value is 0.005) and  $-0.596$  ( $P$  value is 0.081), respectively. These results show travelers who tend to seek traffic information via internet are more likely to choose toll road.

However, while VNS could be a potentially effective mode for traffic information dissemination and usage, it cannot enhance toll road utilization. Most regular commuters are familiar with the network-wide daily traffic conditions and have a better understanding of the benefits of toll road usage. Thus, their VNS needs are not significant.

For frequent traffic information users, the coefficients of the alternative-specific variable En-route are significant for both the nests of toll and non-toll road usage. The variable in the utility of T-FTI has a greater coefficient of 0.911 ( $P$  value is 0.018) compared to the one for NT-FTI, 0.732 ( $P$  value is 0.088). This result indicates that the travelers who seek out en-route traffic information are more likely to use toll roads, although such preferences are slight (as illustrated by the minor difference in their relative magnitudes of coefficients). Analogous analysis can be conducted for the variable Before-trips. Additionally, the types of information content play important roles in determining toll road usage and information use frequencies. Increasing information dissemination regarding accident locations, road hazard warnings, and congested roads can significantly increase travelers' frequency of information compliance. However, only the information about congested roads is positively associated with an increased preference for using toll roads. The coefficient of the variable Congested Roads for the alternative T-FTI is 0.475 with a  $P$  value of 0.005, which verifies this argument. Additionally, different travelers' responses to traffic information can be connected with the preference of toll road usage. The coefficients of the variables Alternative-Route for the T-FTI alternative and Delay-Departure-Time for the NT-FTI alternative are 0.515 ( $P$  value is 0.067) and  $-0.734$  ( $P$  value is 0.042), respectively. These two coefficients reflect that frequent traffic information users are characterized by the tendency to choose an alternative route, and infrequent information users tend to delay their departure time when congestion information is available. It also means that the travelers who are willing to choose an alternative route or delay departure times given congestion possess a higher possibility of using toll roads than those choosing to cancel their trips or stick with their original plans.

Compared to trip distance, travel time is better perceived by travelers as the primary trip performance indicator. As a significant variable, the average travel time of homebound and outbound trips is positively associated with traffic information usage. However, they demonstrate different preference patterns for toll road usage. The coefficient of the variable Homebound-travel-time is 0.030 ( $P$  value is 0.000) for the T-FTI alternative, and that of Outbound-travel-time is 0.016 ( $P$  value is 0.082) for the NT-FTI alternative. These coefficients show that the longer time needed for homebound trips can increase the likelihood of travelers using toll roads. However, the travel time of outbound trips shows its negative impacts on toll road usage. A longer outbound trip is associated with a reduced preference for toll road utilization. This result may be attributed to the decreased timeliness and reliability pressure of outbound trips driven by multiple primary and secondary trip purposes, such as shopping, recreation, and social activity in addition to work. Additionally, the significance of the variable Automobile is found to promote toll road and information usage in the model. Its coefficient is 1.214 with a  $P$  value of 0.008 for the T-FTI alternative. This finding indicates that the travelers selecting automobiles as their primary travel mode have higher preferences for using toll roads and more demands to acquire traffic information for their customized trips.

Some demographic features play important roles in determining traffic information usage and toll road usage also. For example, the variable Household-size (the number of persons) positively influences traffic information usage. However, the greater the number of persons in a household, the less likely they are to use toll roads. Another variable, Household-Income, is correlated with the increased preference for toll road usage.

However, travelers with high household incomes do not show as much need for traffic information acquisitions. These two variables, Household-size and Household-income, are reciprocally correlated by assuming that the average personal financial capability in transportation spending is pre-fixed in a household. Their coefficients with the opposite signs (0.158 for Household-size and  $-0.204$  for Household-income specific to the NT-FTI alternative) support such arguments. For high-income traveler groups, their high VOT enhances their tendency for toll road usage.

#### *Upper level: toll road usage*

Several statistically significant variables were identified at the upper level of the toll road usage preference nest and the estimation results imply their impacts on toll road usage. The more educated travelers with master's degrees or higher are more likely to pay tolls. Its coefficient is 0.428 for the nest of toll road usage with a  $P$  value of 0.020. This result can be explained by the likelihood that the travelers with higher education levels may have sufficient transportation spending for employment, and they value more travel time savings and greater trip reliability. The other variable, Age, has the negative coefficient, which indicates that young travelers tend to prefer use of toll roads more than older drivers. This could be because young individuals are more willing to accept new regulations and policies to facilitate their traveling. A similar analysis can be conducted for the variable Male. The negative sign of its coefficient indicates that being female can increase the willingness to use toll roads, which is consistent with the conclusion of Yan et al.'s studies (2002). Additionally, two significant variables, DMS and Newspaper, show the impacts of the current mode of receiving traffic information on travelers' preferences on toll roads. Their coefficient are 0.470 ( $P$  value: 0.052) and  $-0.869$  ( $P$  value: 0.059), respectively. These results show that the travelers who acquire traffic information through DMS are more likely to use toll roads. However, those selecting newspaper as their major mode of receiving traffic information are opposed to paying for toll road usage. Unlike DMS, which delivers dynamic information, newspapers generally convey static information, such as anticipated construction activities, special events, and weather conditions. Their impacts on traffic network operations are predictable, and travelers can better prepare and plan their routes to balance the trade-off between time and monetary costs. This finding implies that increasing dynamic traffic information dissemination via DMS can effectively attract more travelers to use toll roads and enhance toll facility utilization efficiency.

The analyses and discussions above interpret the associations among toll road utilization, traveler's commuting patterns and characteristics, as well as traffic information dissemination modes, contents, and stages. Some interpretations may be constrained by local geometric effects and unique traveling patterns in the surveyed Austin metropolitan area; however, we did not find significant localized variables, such as the most-used highways in Austin, in the nested logit model. Although extra research efforts are needed to generalize the proposed nested logit model to other situations, the model specifications and estimation results are transferable and applicable.

#### Travelers' attitudes toward toll roads and values of time

Accurate, timely, and complete traffic information may help travelers overcome their reluctance to use toll roads to achieve significant time savings and enhance trip reliability.

**Table 4** Traveler's willingness to choose toll roads by gender and income level

Variables	Willingness to choose toll roads if information is provided	
	No (%)	Yes (%)
Gender		
Male	59.7	40.4
Female	50.8	49.2
Household income level		
Less than \$34,000	59.2	40.8
\$35,000 to \$74,999	56.4	43.6
\$75,000 to \$149,000	51.4	48.6
\$150,000 or more	50.0	50.0

Generally, 45.7 % of the surveyed travelers report that they would choose toll roads for time savings indicated by received traffic information, and 54.3 % show toll roads are not under consideration. Further investigations show that the most cited reason against toll roads is “tax already paid.” Table 4 illustrates that the respondents' willingness to use toll roads is classified by the variables of Gender and Income-level. Gender is clearly an impact factor in toll road usage. The female travelers are more likely to choose toll roads than the males. Household income is another impact factor influencing travelers' preferences of toll roads. As the income level increases, the proportion of the respondents willing to use toll road also increases consistently. These conclusions directly verified the findings of the nested logit model results.

Time savings and trip reliability clearly motivate toll road utilization. The minimum anticipated time savings for using toll roads is classified into six categories: 5, 10, 15, 20, 25, and 30 min or more. About 24.3 % of the respondents who are supportive of toll road usage selected 5 min as the minimum requirements of time savings. Of the remaining responses, 42.2 % chose 10 min, 24.2 % chose 15 min, 5.3 % chose 20 min, and 4.1 % chose 25 and 30 or more minutes as their minimum anticipated time savings. The majority of the respondents evidently hope to save at least 5 to 15 min for paying to use toll roads. The average anticipated time saving is about 11.3 min. Compared to their average daily travel times (34.7 min for outbound trip and 39.4 min for homebound trip), the average anticipated time savings accounts for about 30 % of travelers' regular one-way commuting time on average. These findings are not only indicative for traffic information dissemination to facilitate toll road operations, but also advisory to tolling strategy development and overall toll facility operation optimization.

To quantify the attractiveness of toll roads and VOTs, the survey sought to determine how much travelers are willing to pay for the corresponding time savings of the previous questions. The tolls listed ranged from \$0.05 to \$50.00 with an average of \$2.14. Most respondents preferred to pay \$0.5 to \$2.00 (17.9 % would like to pay for \$0.5, 31.6 % \$1.00, and 9.4 % \$2.00). Based on the time savings and corresponding tolls, VOTs were computed. The mean value is about \$11.82 per hour, which is very close to the VOT value of \$12.00 per hour obtained from Bhat's commuter survey study in Austin (Bhat and Guo 2004). Although in-depth investigations on VOT calculations are beyond our study's scope, the results clearly indicate that travel time savings, reduced travel time uncertainty, enhanced trip reliability, and improved safety can considerably increase the attractiveness of toll roads.

## Limitations

The model development and estimation in our study had some limitations. First, the model assumes the unobserved disturbances are Gumbel distributed and further studies are needed to examine and verify this assumption in the context of congestion pricing supported by accurate, timely, and complete traffic information dissemination. Second, the stated preference survey lasted for 7 months but only 716 usable responses were obtained. More research efforts are recommended to collect more data to enhance the model estimation result reliability. Third, LRI, e.g. the McFadden's adjusted  $\rho^2$ , also called *Pseudo-R<sup>2</sup>* is used to quantify the goodness-of-fit of the proposed nested Logit model. However, this index is not a desirable goodness-of-fit measure due to the inherent heteroscedasticity of the error variance. Because of the different error variance for different values of criterion, a different measure of variance should be applied and a universal LRI may lead to misperception of logit regression results. Fourth, more studies are desirable to test the transferability and generality of the proposed model specifications and parameter estimation to toll road projects in similar traffic conditions. Additionally, the generality and transferability of the research findings should be examined before applying the proposed model to other situations. The data collected in the survey were analyzed for a comprehensive understanding of travelers' commuting patterns, routing behavior, demographic characteristics, and traffic information and toll road usage preferences. These opinion and preference data reflect the basic travel patterns and socio-economic attributes of the travelers and their attitudes toward traffic information and toll road utilization applied in this study. These analyses could serve as a benchmark for transferring the proposed nested Logit model specification to other situations. The model specifications and results should be transferable and applicable for the locations where the fundamental data analyses are consistent with that of this study. However, model calibration may need to be considered due to the statistical uncertainty of a series of complex impact factors.

## Conclusion

As an effective means of addressing congestion problems and transportation funding shortfalls, various congestion pricing policies have been proposed. Meanwhile, advanced traffic information dissemination systems, such as ATIS, have been developed to provide timely, accurate, and complete network-wide traffic information to facilitate travelers' trip planning and routing selections. This study investigates the effects of the provision of traffic information on toll road usage based on a stated preference survey conducted in central Texas. The survey measured representative public opinions about and preferences for toll road usage given various types of traffic information dissemination, as classified by mode, content, and timeliness categories. A nested logit model was developed to identify significant attributes of traffic information dissemination, traveler commuting patterns, routing behavior, and demographic characteristics, and analyze their impacts on toll road utilization. The model results were analyzed and discussed, and intuitive interpretations are offered to explain the model specifications and coefficients. The results revealed that the travelers using DMS systems as their major mode of receiving traffic information are more likely to choose toll roads. The potential toll road users indicated their desire to receive traffic information via internet. The information provided at both pre-trip and en-route stages can positively influence travelers' preferences of toll road usage. The information regarding accident locations, road hazard warnings, and congested roads is frequently



sought by travelers. Furthermore, high-quality information dissemination about congestion can significantly enhance travelers' preferences of toll road usage. Additionally, the model identified a series of statistically significant demographic and travel attributes, and their impacts on toll facility usage.

The research findings are important for guiding traffic information dissemination policy development and deployment. Because increasingly disseminating dynamic network-wide traffic information through internet and DMS systems can effectively enhance toll facility utilization, transportation agencies should consider broadcasting real-time traffic information via internet and more DMSs at appropriate locations as the major pre-trip and en-route information dissemination modes in order to attract more toll facility users. In order to maximize the effectiveness of traffic information dissemination, the highest priority should be given to the information delivery regarding accident locations, road hazard warnings, and congested roads. Especially, state and local transportation agencies should highlight congestion information distribution through internet and DMS, which will greatly satisfy potential toll road users' needs and enhance toll road utilization. Like many Departments of Transportation in other states, TxDOT is planning to expand its toll road systems and more travelers will be involved in toll facility utilization. Although travelers' preferences of toll road and information usage may vary due to other random unobserved factors, the significant variables identified by the proposed nested Logit model can provide in-depth insights in interpreting travelers' behavioral tendencies pertaining to toll road utilization in support of traffic information. The results of this study are useful to analyze the potential of traveler information dissemination to facilitate toll road utilization and also helpful to shape and develop future transportation toll system and transportation policy.

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## Author Biographies

**Dr. Guohui Zhang** is an Assistant Professor in the Department of Civil Engineering at the University of New Mexico. He obtains his Ph.D. from the University of Washington. His research interests include Intelligent Transportation Systems, large-scale transportation system modeling and simulation, and traffic safety analysis.

**Dr. Zhong Wang** is an Associate Professor in the School of Transportation and Logistics in the Dalian University of Technology. He obtains his Ph.D. from the University of Texas at Austin. His research interests include transportation system evaluation and decision making, transportation economics, sustainable transportation system planning.

**Dr. Khali R. Persad** is a Research Engineer and Assistant Director at Center for Transportation Research at the University of Texas at Austin. He obtains his Ph.D. from the University of Texas at Austin. His research interests include transportation planning and construction, traffic operation, sustainable transportation system planning.

**Dr. C. Michael Walton** is a Professor in the Department of Civil, Architectural and Environmental Engineering and holds the Ernest H. Cockrell Centennial Chair in Engineering at The University of Texas at Austin. He obtained his Ph.D. from the North Carolina State University and is a member of the National Academy of Engineering. His research interests include transportation systems engineering, planning, economics and policy analysis; intelligent transportation systems; intermodal/combined transport, commercial vehicle operations; and institutional arrangements.