JOURNAL OF ADVANCED TRANSPORTATION
J. Adv. Transp. 2015; **49**:267–278
Published online 5 June 2014 in Wiley Online Library (wileyonlinelibrary.com). DOI: 10.1002/atr.1273

Whether to enter expressway or not? The impact of new variable message sign information

Hongcheng Gan[1]* and Xin Ye[2]

[1]*Department of Transportation Engineering, University of Shanghai for Science and Technology, Shanghai, China*
[2]*Civil Engineering Department, California State Polytechnic University, Pomona, CA, U.S.A.*

SUMMARY

This study develops a random effect panel data logit model that identifies the factors that influence expressway users' decision behavior under a new arterial road variable message sign information service. The new information service provides travel time of both an expressway route and an alternate arterial road route. It is based on the data collected from a stated preference survey of Shanghai drivers. Correlations within repeated choices by the same respondent were addressed. The results show that the random effect model performs well in addressing repeated observations and evidences the existence of common unobserved random factors affecting route choice behaviors of the same respondent. It is shown that drivers' decisions can be significantly influenced by the new information service. Driving experience, travel time saving, and occurrence of expressway accidents serve as positive factors whereas number of traffic lights on the arterial road serves as a negative factor in choosing the arterial road. Private car drivers, employer-provided car drivers, and taxi drivers value number of traffic lights in a different way. Female drivers are more sensitive to expressway delays. Drivers with rich driving experience and female drivers are more sensitive to number of traffic lights.

KEY WORDS: route choice; random effect; panel data model; travel time; stated preference; variable message signs; expressway; arterial road

1. INTRODUCTION

The effectiveness of advanced traveler information systems (ATIS) depends highly on travelers' behavior in response to real-time information. It is well recognized that it is very important to indentify the factors that influence travelers' decision behavior under ATIS [1–43]. Research results in this challenging field can facilitate better investment, design, and operation of ATIS technologies.

Internationally, variable message signs (VMS), a common ATIS technology, have been widely used to manage the traffic on urban expressways accommodating a large amount of trips. In China, many big cities such as Shanghai, Beijing, Guangzhou, Hangzhou, Ningbo, Chengdu, and Suzhou have installed a lot of VMS on urban expressways. In Shanghai, VMS are even installed on the local streets (e.g., arterial roads) in the vicinity of expressway entrance, which notify the traffic condition of expressways. Figure 1 shows a real-world VMS in Shanghai, which is installed on an arterial road and displays traffic conditions of an elevated road (un-tolled urban expressway) over the arterial road. However, those arterial road VMS do not provide information about the arterial road (alternate route), which may limit their effectiveness regarding diverting the urban expressway traffic to local streets. As Shanghai Traffic Police Department reported on some newspapers [44], many outbound elevated roads (urban expressways) connecting the downtown and the suburb often have big delays, and their travel time is surprisingly much longer than the travel time of parallel arterial road under them during some traditional national holidays (e.g., the QingMing holiday during which a lot of people go to big

*Correspondence to: Hongcheng Gan, Department of Transportation Engineering, University of Shanghai for Science and Technology, Shanghai, China. E-mail: hongchenggan@126.com

Figure 1. Arterial road variable message signs in Shanghai.

cemeteries in other cities to hold a memorial ceremony for their families they lost). This situation is partially due to the fact that drivers are not so confident that they will be better off after diverting to an arterial road because they are not given any real-time information about alternate routes. A feasible way to help drivers make more informed decisions about expressway usage and alleviate expressway congestion is to update the existing arterial road VMS service in Shanghai. In this context, Shanghai is planning to provide a new arterial road VMS service that gives travel time information about both an urban expressway route and a competitive alternate arterial road route.

This motivates the need to understand drivers' route choice behavior in response to the new arterial road VMS service, because the effectiveness of VMS essentially depends on how drivers respond to information. This study therefore will investigate the factors that influence expressway users' decision behavior under the new arterial road VMS information. Because the new arterial road VMS service currently did not exist at the time of the study, only stated preference (SP) data were collected to model drivers' behavior in this study. In the SP survey, each respondent is asked to make repeated choices, thus raising the repeated observations issue (i.e., possible correlations among repeated choices of the same respondent). This issue was addressed reasonably in this study.

In the literature, many studies on travel behavior under ATIS exist. In terms of collecting data about traveler response to ATIS, many researchers used SP data from questionnaire surveys (e.g., [2–10, 13, 17, 19–22, 24–32]). Some other studies used SP data from travel simulator experiments (e.g., [33–39]). Others used revealed preference (RP) data (e.g., [11, 40–43]). In terms of modeling travelers' decision behavior under ATIS, the mainstream method applied in previous studies is discrete choice analysis based on random utility theories. The developed econometric models vary from simple multinomial logit models to sophisticated models with complex utility function specifications (e.g., [3, 4, 8, 17, 21, 30, 33, 34]. On the other hand, some scholars have demonstrated the usefulness of the prospect theory (PT) and the cumulative PT (CPT), which were originally proposed and developed in the psychology field [45, 46] regarding their capabilities in describing travelers' decision behavior under uncertainties (e.g., [5, 8, 14, 21]). These PT-based and CPT-based modeling approaches are still in such a relatively preliminary stage that, most exploratory studies are mostly descriptive, only address a small network, and generally acceptable explicit operational mathematical models have not been available so far. In contrast to the aforementioned discrete choice analysis approaches and PT or CPT approaches, a small number of researchers apply other approaches such as fuzzy logic [38] and regret theory [13] to reveal travel behavioral mechanism. However, no generalized conclusions can be obtained from such a limited number of literatures. This paper thus applies the mainstream discrete choice analysis methodology to model urban expressway users' decision behavior under the new arterial road VMS information.

DOI: 10.1002/atr

So far, most previous studies only investigated the effects of expressway VMS on expressway users' route choice behavior. Many previous studies showed that VMS have impacts on route choice decisions and the impact may depend on VMS messages, driver characteristics, and situational factors, although they may have different findings due to differences in VMS technology, culture, road network, research context, and so on.

However, the understanding of expressway users' route choice behavior with the presence of the dynamic information about both expressway and local streets provided by arterial road VMS seems to be limited. This is partially due to that real-world arterial road VMS that provide dynamic information about both expressway and local streets are rare in the world. In the literature, there does exist an RP-data-based arterial road VMS study in USA that showed that arterial road VMS are more helpful and effective than expressway VMS in diverting expressway users and alleviating expressway congestion [42]. However, this US arterial road VMS study did not explicitly address travel time information about both expressway and local streets.

Although there are many studies on travel behavior under ATIS, fewer studies accounted for correlations among repeated observations. A recent review was given in [24]. While developing discrete choice models of travel behavior under ATIS, approaches applied to address repeated observations in previous studies include mixed logit (e.g., [34, 43]), multinomial probit (e.g., [3, 34]), normal mixing distributions (e.g., [25]), generalized estimating equations (e.g., [24, 31]), and mixed linear models (e.g., [39]). In contrast to the aforementioned studies, this study proposes a random effect panel data logit model to address correlations among repeated observations of the same respondent.

Given the aforementioned context, the main contribution of this study is the following. It uses the discrete choice analysis methodology to investigate Shanghai urban expressway users' decision behavior under the new arterial road VMS information (i.e., travel time of both an elevated expressway and its competitive parallel arterial road alternative) through developing a random effect panel data logit model that addresses correlations among repeated observations of the same respondent.

This study has obtained insightful results that have implications for future deployment of the new arterial road VMS information service and modeling of driver response behavior.

Main conclusions of this study follow. First, the new arterial road VMS information service has significant impacts on expressway users' en route decisions on whether to enter expressway or not, and the impacts depend on driver attributes and VMS information. Second, the proposed random effect panel data logit model performs well in addressing correlations between repeated choices by the same respondent. Third, the heterogeneity of driver behavior regarding sensitivity to number of traffic lights and travel time savings is revealed by the developed panel data model.

The rest of this paper is organized as follows. First, it describes the SP survey method of collecting behavioral data about drivers' decision under the new arterial road VMS information. Second, it presents the modeling methodology and develops the random effect panel data logit model for identifying factors that affect drivers' route choice response to the new arterial road VMS information based on the collected SP data. Next, it discusses the model estimation results. Last, concluding remarks are given.

2. METHODOLOGY

2.1. Survey design

Because the new arterial road VMS information service currently does not exist in Shanghai, this study applied the SP approach to collect data about travelers' route choice decision behavior under the new VMS information. A questionnaire survey was executed to collect behavioral data.

The SP experiment was designed on the basis of a hypothetical trip that reflects the situation of a typical real-life commuting trip in downtown Shanghai. The hypothetical trip is depicted in Figure 2. There are two alternate routes for respondents to choose. They are an un-tolled elevated expressway route and an arterial road (a local street) route. There is an arterial road VMS at the diversion point (i.e., the upstream of the entrance of the elevated expressway) on the arterial road. The travel time of the expressway and the travel time of the local street are displayed on the VMS, which is intended to help drivers make more informed decisions on whether to enter the expressway.

DOI: 10.1002/atr

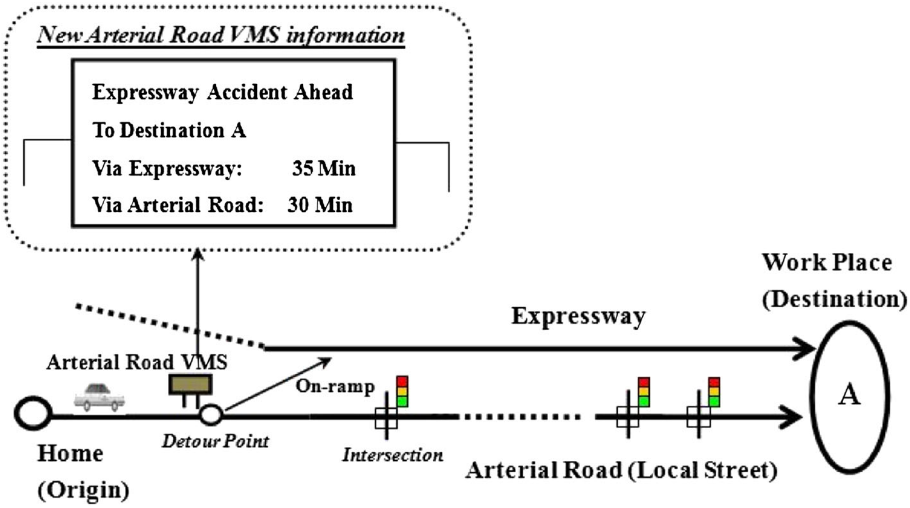

Figure 2. Hypothetical journey in the stated preference survey.

The travel scenario as described by text instructions on the questionnaire follows. A respondent is driving on the arterial road such as ZhongshanBei Road for a commuting trip from his home to his workplace in a weekday morning. When the respondent reaches the detour point, he sees the arterial road VMS displaying the elevated expressway's travel time and the arterial road's travel time. The respondent will make a route choice decision in response to VMS messages.

The designed VMS messages include three parts: (1) travel time of the expressway route; (2) travel time of the arterial road route; and (3) cause of expressway delay. The wording style of the arterial road VMS is similar to that of the VMS installed on the elevated expressway in Shanghai, so that the new VMS information could easily be understood by the respondents.

The attribute levels and values of alternatives were specified on the basis of discussions with officials and operators in the Shanghai expressway network traffic management center and on the VMS message usage record in the computer database, so as to give respondents a realistic feeling of the hypothetical journey. For a typical 30-minute around-expressway journey, the range of (0, 10) minutes is considered reasonable for expressway delays by traffic management center operators, which is also justified by the VMS message usage record. To this end, cause of expressway delay (C) contains two levels: congestion and accident. Expressway travel time (T) takes two values: 35 and 40 minutes. That is, two levels of expressway delay (i.e., 5 and 10 minutes) are used in the SP survey. Considering the typical spacing of traffic lights for Shanghai arterial roads, the number of traffic lights on the local street (L) takes two values: 10 and 20. Expressway travel time, number of traffic lights on the local street route, and cause of expressway delay are controlling factors in the SP experiment.

Given the aforementioned setting of attribute values for three controlling factors, the complete factorial design [47] was adopted to generate a total of eight ($2 \times 2 \times 2$) choice scenarios. The eight choice scenarios follow.

Scenario 1: T = 35; **C** = congestion; **L** = 10.
Scenario 2: T = 35; **C** = accident; **L** = 10.
Scenario 3: T = 40; **C** = congestion; **L** = 10.
Scenario 4: T = 40; **C** = accident; **L** = 10.
Scenario 5: T = 35; **C** = congestion; **L** = 20.
Scenario 6: T = 35; **C** = accident; **L** = 20.
Scenario 7: T = 40; **C** = congestion; **L** = 20.
Scenario 8: T = 40; **C** = accident; **L** = 20.

The respondents were required to respond to each scenario and make a choice between two routes.

An SP questionnaire survey was conducted in July 2009. Random sampling approach was adopted. The survey location is an underground garage in a shopping mall. Some of the drivers were questioned

DOI: 10.1002/atr

in their cars because they were leaving from the garage at the time of interview. The others were interviewed after they parked their cars and came out of their cars. Respondents can choose to complete the questionnaire by themselves or choose to answer the experimenter who read questions to them. This depends on the respondent's preference. A total of 228 drivers participated in the questionnaire survey. Those respondents who did not fully complete all the SP choice questions were removed. To this end, the data set available for model development contains 1512 (189 × 8) choice observations.

The data collected through the SP experiment include driver attributes (e.g., gender, age, frequency of expressway use, and driving experience) and route choice decisions.

2.2. *Survey results*

Table I shows driver characteristics of the sample.

The aforementioned statistics show that slightly more than one fourth (26.5%) of the sample are drivers of an employer-provided car. In China, a person at a high hierarchy level in a governmental agency or a state-owned enterprise or a company may be allowed to use a car owned by his or her employer.

According to the 2010 statistic from Chinese ministry of public security [48], the ratio of private car and employer-provided car is 2.88 : 1 (i.e., 25.7% of employer-provided car). In big Chinese cities such as Shanghai, Beijing, and Guangzhou, the percentage of employer-provided cars may be even higher. Therefore, the percentage of employer-provided cars in the sample does reflect a typical Shanghai situation. In our sample, almost 10% of the respondents are taxi drivers. This reflects the real situation in Shanghai. Taxi is usually comfortable and timesaving; thus, a lot of white collars or those working in the downtown with a parking price will choose to take a taxi to their workplace. In addition, the sample includes drivers with various degrees of driving experience and has a reasonable coverage of age. In terms of expressway use, nearly half of the sample has rich experiences of using expressways (about 48%). To this end, the driver sample provides sufficient variation in attribute variables for model estimation.

2.3. *Model development*

Now, we develop an econometric model for predicting a driver's route choice probability under the new arterial road VMS information, using the collected SP data.

2.3.1. *Modeling methodology*

The data used for modeling analysis belongs to panel data because each individual in the survey responded to questions in eight different scenarios. While analyzing SP behavior data, it is important to recognize the correlation between repeated choices by the same individual. To account for the correlation between repeated observations, this paper develops a random effect panel data logit model instead of a traditional cross-sectional model to make the econometric model more accurate. The econometric model can be formulated as follows:

$$U_{it} = \beta_0 + \boldsymbol{\beta}_1 \boldsymbol{x}_i + \boldsymbol{\beta}_2 z_t + \sigma n_i + \varepsilon_{it} \tag{1}$$

Table I. Driver characteristics of the sample.

Attribute	Range	% of sample	Attribute	Range	% of sample
Gender	Male	67.7%	Driver type	Private car driver	64.0%
	Female	32.3%		Employer-provided car driver	26.5%
Age	19–30	37.0%		Taxi driver	9.5%
	31–40	46.6%	Expressway use frequency	Almost every day	47.6%
	>40	16.4%		2–3 days per week	37.6%
Driving experience	0–5	42.3%		Seldom	14.8%
	>5	57.7%			

Private car is owned by a driver himself or herself. Employer-provided car is not owned by a driver but assigned by his/her employer for business purpose.

DOI: 10.1002/atr

In the utility function, "i" is the driver index and "t" is the scenario index; $\boldsymbol{x}_i$ is a vector of explanatory variables changing across drivers but not changing across scenarios (e.g., gender, age) and "$\boldsymbol{z}_t$"is a vector of variables changing across scenarios but not changing across drivers (e.g., travel time saving, number of traffic lights on the arterial road). "n_i" is a random effect changing across drivers but not changing within the same driver. "n_i" is specified to capture the effects of common unobserved random factors on the choice behavior of the same driver. "σ" is a coefficient indicating the standard deviation of the random effect variable. "ε_{it}" is a random variable changing across both individuals and scenarios. "n_i" and "ε_{it}" are assumed to be standard normally and logistically distributed, respectively. "β_0", "$\boldsymbol{\beta}_1$", and "$\boldsymbol{\beta}_2$" are model coefficients.

The binary choice variable $y_{it} = 1$ (choose arterial road) when $U_{it} > 0$; $y_{it} = 0$ (choose expressway) when $U_{it} < 0$. Thus, conditional on "n_i", one may have

$$P(y_{it} = 1|n_i) = \frac{\exp(\beta_0 + \beta_1 x_i + \beta_2 z_t + \sigma n_i)}{1 + \exp(\beta_0 + \beta_1 x_i + \beta_2 z_t + \sigma n_i)} \tag{2}$$

$$P(y_{it} = 0|n_i) = \frac{1}{1 + \exp(\beta_0 + \beta_1 x_i + \beta_2 z_t + \sigma n_i)} \tag{3}$$

Equations (2) and (3) can be summarized as follows:

$$P(y_{it}|n_i) = [P(y_{it} = 1|n_i)]^{y_{it}}[P(y_{it} = 0|n_i)]^{(1-y_{it})} \tag{4}$$

For unconditional probability function, the conditional probability function needs to be integrated over the probability density function of "n_i":

$$P_i = \int_{-\infty}^{+\infty} \phi(n_i) \prod_{t=1}^{T} P(y_{it}|n_i) dn_i \tag{5}$$

Here, $T = 8$, representing eight different SP scenarios for each respondent. Gaussian–Hermite integral method [49] is employed to evaluate the integral in Equation (5) as

$$P_i \approx \sum_{k=1}^{K} \left[w_k \phi(z_k) \prod_{t=1}^{T} P(y_{it}|z_k) \right] \tag{6}$$

In this study, 10 points are chosen to support the integral evaluation (i.e., $K = 10$). Values for w_k and z_k can be found in the APPENDIX. Finally, the log-likelihood function over the entire sample can be formulated as

$$LL = \sum_{i=1}^{N} \ln(P_i) \tag{7}$$

In this study, model coefficients are estimated in Gauss System.

2.3.2. *Model estimation results*

The potential explanatory variables include driver attributes (e.g., age, gender, years of driving experience, driver type, and expressway use frequency), scenario variables (e.g., travel time saving, cause of expressway delay, and number of traffic lights on the arterial road), and all interactive terms of driver attributes and scenario variables. All the variables remaining in the final model take statistically significant coefficients.

Table II provides model estimation results. The variables that are statistically significant in the final model include the following:

- "Driving experience is less than 5 years" (dummy);
- "using expressway less than two times per week" (dummy);
- "travel time savings";
- "expressway delay is caused by accident" (dummy);

DOI: 10.1002/atr

Table II. Model estimation results for the random effect panel data logit model.

Variable	Coefficient	T-test	Significance
Constant	−1.3962	−2.228	0.0259
Driving experience is less than 5 years	−2.6106	−4.943	0.0000
Using expressway less than two times per week	2.8695	4.390	0.0000
Travel time savings (minutes)	0.3228	4.181	0.0000
Expressway delay is caused by accident	1.1487	6.340	0.0000
Number of traffic lights on arterial road	−0.2286	−5.937	0.0000
Travel time savings × male driver	−0.1390	−1.884	0.0595
Number of traffic lights × driving experience is more than 10 years	−0.1169	−3.767	0.0002
Number of traffic lights × male driver	0.1516	4.414	0.0000
Number of traffic lights × employer-provided car driver	0.1029	2.621	0.0088
Number of traffic lights × taxi driver	−0.1473	−3.005	0.0027
σ	2.6546	4.917	0.0000
Model statistics and goodness-of-fit measurement			
Sample size		189 × 8	
Log-likelihood value at convergence		−651.154	
$\rho^2(0)$		0.3787	
adjusted $\rho^2(0)$		0.3672	
$\rho^2(c)$		0.2965	
adjusted $\rho^2(c)$		0.2825	

- "number of traffic lights on arterial road";
- interaction term "travel time savings × male driver";
- interaction term "number of traffic lights × male driver";
- interaction term "number of traffic lights × driving experience is more than 10 years";
- interaction term "number of traffic lights × employer-provided car driver"; and
- interaction term "number of traffic lights × taxi driver".

3. FINDINGS AND DISCUSSIONS

3.1. Correlations between repeated observations from the same respondent

As shown in Table II, the coefficient "σ" appears highly significant (*t*-value is 4.917), validating our econometric modeling method for panel data. This strongly evidences the existence of common unobserved random factors affecting the route choice behavior of the same respondent. Our modeling efforts showed that the random effect panel data logit model performs well in accounting for the repeated observations from the same respondent.

The study highlighted the importance of accounting for the correlation between repeated choices by the same respondent in the SP survey and has implications for future efforts in model estimations.

3.2. Discussions about model estimation results

The goodness-of-fit indices (e.g., adjusted $\rho^2(0) = 0.3672$) for the SP model shows that the overall SP model has a satisfactory performance. The coefficient of all the explanatory variables all takes intuitively correct sign. The influence of the explanatory variables is discussed in the succeeding text.

Intercept. The negative sign of the constant parameter (−1.3962) indicates that drivers have an intrinsic preference for expressway. This result reflects our SP experimental settings in which the respondents' primary route is the expressway.

Travel time saving. "Travel time savings" takes a statistically significant positive coefficient. Because the interactive term "travel time savings × male driver" is specified, this coefficient indicates that the more time savings a female driver can obtain after using arterial road, the less likely she will choose the original expressway route. The sensitivity to travel time savings is quantified by the coefficient magnitude 0.3228.

DOI: 10.1002/atr

The interaction term "travel time savings × male driver". The negative coefficient (−0.1390) of the term indicates that male drivers are less sensitive to expressway delay than female drivers. The coefficient magnitude of travel time savings for male drivers is actually 0.1838 (0.3228–0.1390), which is only 57% (≈0.1838/0.3228) of the one for female drivers. That is to say, female drivers may be more likely to choose the arterial road to avoid expressway delay. This is presumably because some male drivers may think that traffic will become normal when they reach the problem location and they actually will not encounter a delay. This result to some degree reflects the risk-aversion personality of Shanghai female drivers.

Driving experience. "Driving experience is less than 5 years" takes a highly negative coefficient −2.6106. Its negative impact is virtually equivalent to that from 8-minute time loss on female drivers (2.6106/0.3228 ≈ 8.0). This indicates that drivers with less driving experience are less likely to choose the arterial road under VMS. This is possibly because Shanghai drivers with less driving experience are more likely to use expressways as their commuting route as it is relatively easier to maneuver vehicles on expressways that are characterized of uninterrupted traffic flow and better geometric alignments.

Frequency of expressway usage. The highly positive coefficient 2.8695 of the dummy "using expressway less than two times per week" indicates that the less frequently a driver uses expressways, the more likely he will choose the arterial road. Its impact is virtually equivalent to that from 9-minute time saving on female drivers (2.8695/0.3228 ≈ 8.9). This is possibly because drivers using expressways infrequently are not so dependent on expressways while drivers using expressways frequently are more dependent on expressways or have a bias for expressways.

Cause of expressway delay. "Expressway delay is caused by accident" takes a positive coefficient 1.1487, and its impact is almost equal to 3.6 minutes of time saving to a female driver (1.1487/0.3228 ≈ 3.6). This indicates that drivers are more likely to choose the arterial road if VMS indicates occurrence of incident on the expressway. This finding is reasonable because when an expressway accident happens, a driver's perceived travel time uncertainty will increase, and he will be more reluctant to use expressway. This finding conforms with the findings of some previous studies (e.g., [26, 27]).

Number of traffic lights on the arterial road. Number of traffic lights on the arterial road is an important factor affecting drivers' route choice behavior. Although travel time of the arterial road is the same for all scenarios in the SP experiment, the number of traffic lights still matters with the driving psychological aspect. For example, drivers are generally not comfortable with frequent stops during driving. Moreover, more traffic lights may increase drivers' perceived travel time uncertainty. These negative effects on drivers' choosing the arterial road are reflected in the negative coefficient. This finding is consistent with previous studies (e.g., [24]). The magnitude of the coefficient is 0.2286, indicating that the impact from each traffic light is approximately equal to that from 0.7-minute time loss on female drivers (0.2286/0.3228 ≈ 0.7).

The interaction term "number of traffic lights × male driver". This term takes the positive sign. Thus, the coefficient of number of traffic lights for male drivers is actually −0.0770 (i.e., 0.1516–0.2286), which is only about one third of the coefficient −0.2286 for female drivers. This indicates that male drivers are less sensitive to number of traffic lights on the arterial road than female drivers. This is possibly because male drivers usually are more confident of their vehicle-maneuvering skills and are more adaptable in interrupted traffic flow situations as compared with female drivers.

The interaction term "number of traffic lights × driving experience is more than 10 years". This term takes the negative sign, and the coefficient is −0.1169. The coefficient of the number of traffic light for drivers with more than 10 years of driving experience is actually −0.3455 (i.e., −0.1169–0.2286), which is about 51% (≈[−0.3455 + 0.2286]/[−0.2286]) more negative than that for other drivers. This indicates that drivers with rich driving experience are more sensitive to number of traffic lights on the arterial road. This is possibly because drivers with rich driving experience know very well the fact that for a typical Shanghai arterial road, more traffic lights means a bigger travel time unreliability and heavier driving workload, and thus, they are more likely to avoid an arterial road with many traffic lights.

The interaction term "number of traffic lights × employer-provided car driver". This term takes a positive sign, and the coefficient of number of traffic lights for employer-provided drivers can be calculated as −0.1257 (0.1029–0.2286), which is about 55% (≈ −0.1257/−0.2286) of the coefficient for other types of drivers. It indicates that employer-provided car drivers are less sensitive to number of traffic lights on the arterial road as compared with other types of drivers. The possible reasons follow. Normally, the increase of number of traffic lights means more decelerations, stops, and accelerations near the intersections and may cause extra cost on fuel consumption and greater travel time uncertainty and bigger delays. In China, a person at a high hierarchy level in a governmental agency or a state-owned enterprise or a company may be allowed to use a car owned by his or her employer. For an employer-provided car driver, fuel cost usually can be reimbursed by their employers, and he or she will not be punished for late arrival caused by traffic delay in a commuting trip. Private car drivers ordinarily need to afford the fuel cost by themselves and are relatively more time-constrained in their commuting trips. Therefore, employer-provided car drivers may be less sensitive to number of traffic lights as compared with private car drivers.

The interaction term "number of traffic lights × *taxi driver*". This term takes the negative sign, and the coefficient of number of traffic lights for taxi drivers can be calculated as −0.3759 (−0.1473–0.2286), which is about 64% (≈ [−0.3759 + 0.2286]/[−0.2286]) more negative than that for other types of drivers. It indicates that taxi drivers are more sensitive to number of traffic lights on the arterial road. This is possibly due to the following facts. First, given the extensive coverage of expressways in Shanghai, both an expressway route and an arterial road route will be practical in many occasions. The expressway route is often a bit longer physically but time shorter as compared with the arterial road route. The fare for the expressway route is similar to or slightly higher than the fare for the arterial road route, given the pricing scheme for taxi industry. Second, passengers normally take a taxi for time saving and comfort and will usually ask the taxi driver to decide a route. Because the expressway route usually will both satisfy the need of passengers and benefit the taxi drivers' business, Shanghai taxi drivers naturally are more willing to choose expressways and avoid arterial roads as long as passengers allow them to decide the route.

Interestingly the aforementioned two findings indicate that different types of drivers value the attribute "number of traffic lights" in a different way, with employer-provided car drivers being the least sensitive, taxi drivers being the most sensitive, and private car drivers in between, to number of traffic lights. This finding may, to some degree, reflect some Chinese culture.

The aforementioned results show that the heterogeneity of driver behavior under new VMS information is well captured by the developed panel data model.

Some earlier studies also revealed that male drivers behave differently from female drivers in response to real-time traffic information (e.g., [26, 28, 29, 33, 41]). However, the difference in VMS response behavior among taxi, employer-provided, and private car drivers were rarely reported in the literature, partially due to that behavior data about taxi, employer-provided drivers were rarely collected in earlier studies. One of the authors' previous expressway VMS studies did reveal the difference in VMS response behavior among employer-provided and private car drivers [30], but it did not found a statistically significant difference between private car drivers and taxi drivers.

It is noted that some of the effects could well be localized (e.g., travel time saving × male driver, number of traffic lights × male driver, employer-provided car driver). The obtained results may only reflect specific situations of Shanghai in terms of culture, geometrical and physical characteristics of expressways and local streets, traffic flow patterns, institution, and so on.

4. CONCLUDING REMARKS

The random effect panel data logit model was developed to identify factors that affect drivers' route choice decisions under the new arterial road VMS information service that provides the travel time of both an expressway and its competitive arterial road alternative. This is based on the data collected from a SP survey of Shanghai drivers. Several substantive conclusions have been obtained in this study as summarized hereafter.

(1) Driving experience and travel time saving serve as positive factors in choosing the arterial road, whereas number of traffic lights on the arterial road serves as negative factor in choosing the arterial road.
(2) Expressway accident will increase the probability of choosing the arterial road.
(3) Interestingly, drivers value number of traffic lights differently, with employer-provided car drivers being the least sensitive, taxi drivers being the most sensitive, and private car drivers in between, to number of traffic lights.

DOI: 10.1002/atr

(4) Female drivers are more sensitive to expressway delays and are more likely to choose the arterial road.
(5) Drivers with rich driving experience and female drivers are more sensitive to number of traffic lights.
(6) Model estimation results strongly evidence the existence of common unobserved random factors affecting route choice behaviors of the same driver and show that the developed random effect panel data logit model is suitable to account for the repeated observations from the same respondent. This work highlights the importance of addressing correlations between repeated choices by the same respondent in an SP survey and has implications for future modeling efforts.

A potential limitation of SP-data-based travel behavior model is that actual behavior of respondents may not necessarily correspond to the stated choice in the survey. However, SP model is well recognized to be useful in understanding the general propensity of travelers in terms of travel choice decision under ATIS. Currently, the new arterial road VMS has not been deployed yet, thus making collection of RP data infeasible. In the future, once the new arterial road VMS service is put into operation, RP data can be collected to validate and enhance the developed behavior model.

Future exploration may also improve the survey design to include questions about the perception of the number of traffic lights on the arterial road and use perceived number of traffic lights as an explanatory variable while developing discrete choice models. Also, a comparative study of expressway VMS and arterial road VMS in terms of their impacts on expressway users' route choice is desired.

5. LIST OF SYMBOLS AND ABBREVIATIONS

ATIS	advanced traveler information systems
VMS	variable message signs
SP	stated preference
RP	revealed preference
PT	prospect theory
CPT	cumulative prospect theory

ACKNOWLEDGEMENTS

This work was partially supported by a project (no. 51008195) funded by National Natural Science Foundation of China, a Shanghai First-Class Academic Discipline project (no. S1201YLXK) funded by the Shanghai Government, and a human art and social science project (no. 1F-13-303-014) funded by University of Shanghai for Science and Technology.

REFERENCES

1. Rahman M, Wirasinghe SC, Kattan L. Users' views on current and future real-time bus information systems. *Journal of Advanced Transportation* 2012; **47**:336–354.
2. Hensher DA, Li Z, Rose JM. Accommodating risk in the valuation of expected travel time savings. *Journal of Advanced Transportation* 2013; **47**:206–224.
3. Jou RC, Lam SH, Weng MC, Chen CC. Real time traffic information and ITS impacts on route switching behavior of expressway drivers. *Journal of Advanced Transportation* 2004; **38**(2):187–223.
4. Razo M, Gao S. A rank-dependent expected utility model for strategic route choice with stated preference data. *Transportation Research Part C: Emerging Technologies* 2013; **27**:117–130.
5. Gao S, Frejinger E, Ben-Akiva M. Adaptive route choices in risky traffic networks: a prospect theory approach. *Transportation research part C: emerging technologies* 2010; **18**(5):727–740.
6. Razo M, Gao S. Strategic thinking and risk attitudes in route choice. *Transportation Research Record: Journal of the Transportation Research Board* 2010; **2156**:28–35.
7. Gao S, Frejinger E, Ben-Akiva M. Adaptive route choice models in stochastic time-dependent networks. *Transportation Research Record: Journal of the Transportation Research Board* 2008; **2085**:136–143.
8. Jou RC, Chen KH. An application of cumulative prospect theory to freeway drivers' route choice behaviours. *Transportation Research Part A: Policy and Practice* 2013; **49**:123–131.
9. Jou RC, Chen KH. A study of freeway drivers' demand for real-time traffic information along main freeways and alternative routes. *Transportation Research Part C: Emerging Technologies* 2013; **31**:62–72.
10. Jou RC. Modeling the impact of pre-trip information on commuter departure time and route choice. *Transportation Research Part B: Methodological* 2001; **35**(10):887–902.

11. Tseng YY, Knockaert J, Verhoef ET. A revealed-preference study of behavioural impacts of real-time traffic information. *Transportation Research Part C: Emerging Technologies* 2013; **30**:196–209.
12. Chorus CG, Molin EJ, Van Wee B. Use and effects of Advanced Traveller Information Services (ATIS): a review of the literature. *Transport Reviews* 2006; **26**(2):127–149.
13. Chorus CG, Arentze TA, Timmermans HJ. A random regret-minimization model of travel choice. *Transportation Research Part B: Methodological* 2008; **42**(1):1–18.
14. Xu H, Zhou J, Xu W. A decision-making rule for modeling travelers' route choice behavior based on cumulative prospect theory. *Transportation Research Part C: Emerging Technologies* 2011; **19**(2):218–228.
15. Viti F, Bogers E, Hoogendoorn S. Day-to-day learning under uncertainty with information provision: model and data analysis. In *16th International Symposium on Transportation and Traffic Theory, Maryland, US*., 2005, July.
16. Connors RD, Sumalee A. A network equilibrium model with travellers' perception of stochastic travel times. *Transportation Research Part B: Methodological* 2009; **43**(6):614–624.
17. Sun Z, Arentze T, Timmermans H. A heterogeneous latent class model of activity rescheduling, route choice and information acquisition decisions under multiple uncertain events. *Transportation research part C: emerging technologies* 2012; **25**:46–60.
18. Bonsall P. Modelling response to information systems and other intelligent transport system innovations. In: Hensher DA, Button KJ (Eds.) *Handbook of Transport Modelling*, 2nd ed., Handbooks in Transport 1 2nd ed. Elsevier: Amsterdam, 2008; 559–574.
19. Zhang L, Levinson D. Determinants of route choice and value of traveler information: a field experiment. *Transportation Research Record: Journal of the Transportation Research Board* 2008; **2086**:81–92.
20. Ben-Elia E, Di Pace R, Bifulco GN, Shiftan Y. The impact of travel information's accuracy on route-choice. *Transportation Research Part C: Emerging Technologies* 2013; **26**:146–159.
21. Ben-Elia E, Shiftan Y. Which road do I take? A learning-based model of route-choice behavior with real-time information. *Transportation Research Part A: Policy and Practice* 2010; **44**(4):249–264.
22. Zhong S, Zhou L, Ma S, Jia N. Effects of different factors on drivers' guidance compliance behaviors under road condition information shown on VMS. *Transportation research part A: policy and practice* 2012; **46**:1490–1505.
23. Lappin J, Bottom J. Understanding and predicting traveler response to information: a literature review. Volpe National Transportation Systems Center, 2001.
24. Abdel-Aty MA, Abdalla MF. Examination of multiple mode/route-choice paradigms under ATIS. *Intelligent Transportation Systems, IEEE Transactions on* 2006; **7**(3):332–348.
25. Abdel-Aty MA, Kitamura R, Jovanis PP. Using stated preference data for studying the effect of advanced traffic information on drivers' route choice. *Transportation Research Part C: Emerging Technologies* 1997; **5**(1):39–50.
26. Wardman M, Bonsall PW, Shires JD. Driver response to variable message signs: a stated preference investigation. *Transportation Research Part C: Emerging Technologies* 1997; **5**(6):389–405.
27. Chatterjee K, Hounsell NB, Firmin PE, Bonsall PW. Driver response to variable message sign information in London. *Transportation research part C: Emerging technologies* 2002; **10**(2):149–169.
28. Peeta S, Ramos JL, Pasupathy R. Content of variable message signs and on-line driver behavior. *Transportation Research Record: Journal of the Transportation Research Board* 2000; **1725**:102–108.
29. Lai KH, Wong WG. SP approach toward driver comprehension of message formats on VMS. *Journal of Transportation Engineering* 2000; **126**(3):221–227.
30. Gan H, Ye X. Urban freeway users' diversion response to variable message sign displaying the travel time of both freeway and local street. *IET Intelligent Transport Systems* 2012; **6**(1):78–86.
31. Gan HC, Bai Y, Wei J. Why do people change routes? Impact of information services. *Industrial Management & Data Systems* 2013; **113**(3):403–422.
32. Gan HC, Ye X, Fan BQ. Drivers' en-route diversion response to graphical variable message sign in Shanghai, China. In *Proc. 10th International Conference of Applications of Advanced Technologies in Transportation, Greece*. Oxford University Press, 2008, May.
33. Mahmassani HS, Liu YH. Dynamics of commuting decision behaviour under advanced traveller information systems. *Transportation Research Part C: Emerging Technologies* 1999; **7**(2):91–107.
34. Srinivasan KK, Mahmassani HS. Analyzing heterogeneity and unobserved structural effects in route-switching behavior under ATIS: a dynamic kernel logit formulation. *Transportation Research Part B: Methodological* 2003; **37**(9):793–814.
35. Yang H, Kitamura R, Jovanis PP, Vaughn KM, Abdel-Aty MA. Exploration of route choice behavior with advanced traveler information using neural network concepts. *Transportation* 1993; **20**(2):199–223.
36. Bonsall P, Firmin P, Anderson M, Palmer I, Balmforth P. Validating the results of a route choice simulator. *Transportation Research Part C: Emerging Technologies* 1997; **5**(6):371–387.
37. Koutsopoulos HN, Lotan T, Yang Q. A driving simulator and its application for modeling route choice in the presence of information. *Transportation Research Part C: Emerging Technologies* 1994; **2**(2):91–107.
38. Di Pace R, Marinelli M, Bifulco GN. Modeling risk perception in ATIS context through fuzzy logic. *Procedia-Social and Behavioral Sciences* 2011; **20**:916–926.
39. Chen WH, Jovanis PP. Driver en route guidance compliance and driver learning with advanced traveler information systems: analysis with travel simulation experiment. *Transportation Research Record: Journal of the Transportation Research Board* 2003; **1843**:81–88.

DOI: 10.1002/atr

40. Hato E, Taniguchi M, Sugie Y, Kuwahara M, Morita H. Incorporating an information acquisition process into a route choice model with multiple information sources. *Transportation Research Part C: Emerging Technologies* 1999; **7**(2):109–129.
41. Emmerink RH, Nijkamp P, Rietveld P, Van Ommeren JN. Variable message signs and radio traffic information: an integrated empirical analysis of drivers' route choice behaviour. *Transportation Research Part A: Policy and Practice* 1996; **30**(2):135–153.
42. Peng ZR, Guequierre N, Blakeman JC. Motorist response to arterial variable message signs. *Transportation Research Record: Journal of the Transportation Research Board* 2004; **1899**(1):55–63.
43. Tsirimpa A, Polydoropoulou A, Antoniou C. Development of a mixed multi-nomial logit model to capture the impact of information systems on travelers' switching behavior. *Journal of Intelligent Transportation Systems* 2007; **11**(2):79–89.
44. Shen WL. Use surface street + tunnel to avoid urban express congestion. XinMin News Paper, Shanghai, China, 2011-10-25.
45. Tversky A. Elimination by aspects: a theory of choice. *Psychological Review* 1972; **79**(4):281.
46. Tversky A, Kahneman D. Advances in prospect theory: cumulative representation of uncertainty. *Journal of Risk and Uncertainty* 1992; **5**(4):297–323.
47. Louviere JJ, Hensher DA, Swait JD. *Stated choice methods: analysis and applications*. Cambridge University Press: New York, NY, USA, 2000.
48. China National Bureau of Statistics. *2010 statistical yearbook*. China National Bureau of Statistics: Bejing, China, 2011.
49. Bhat CR. Quasi-random maximum simulated likelihood estimation of the mixed multinomial logit model. *Transportation Research Part B: Methodological* 2001; **35**(7):677–693.

APPENDIX

The Gauss–Hermite integral method uses the Hermite polynomials to deal with the integration interval of $(-\infty, +\infty)$. Gauss–Hermite method is formulated as

$$\int_{+\infty}^{+\infty} f(x)dx \approx \sum_{k=1}^{K} w_k f(z_k)$$

In the aforementioned formula, z_k and w_k are abscissae and weights. The following table provides 10-point abscissae and weights that are used in this study.

Table A1. Ten-point abscissae and weights.

k	z_k	w_k
1	−3.436159119	1.025451691
2	−2.532731674	0.820666126
3	−1.756683649	0.741441932
4	−1.036610830	0.703296323
5	−0.342901327	0.687081854
6	0.342901327	0.687081854
7	1.036610830	0.703296323
8	1.756683649	0.741441932
9	2.532731674	0.820666126
10	3.436159119	1.025451691

DOI: 10.1002/atr