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Development of a Hierarchical Integrated Choice and Latent Variable Model for Understanding Travelers' Acceptance of Variable Message Signs

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Abstract

The Technology Acceptance Model (TAM) is a robust and well-known model for investigating users' acceptance of information technology. This study aims to develop a framework that integrates TAM into a route switching model of travelers' response to Variable Message Signs (VMS). In addition to the parsimonious TAM constructs (perceived usefulness, perceived ease of use and behavioral intention), the model is extended with latent variables that are specific to travelers' response to VMS (perception of information quality, attitude towards road diversion and familiarity with the network). In line with the hierarchical relationships inherent in TAM, the model takes into account the causal relationships among the latent variables. All hypothesized relationships are based on strong theoretical and empirical background. The obtained framework is then incorporated into a route switching model to form a hierarchical integrated choice and latent variable model for traveler's response to VMS. The proposed framework is tested with Stated Preference data with repeated observations from 339 road users in Dalian, China. The results show that travelers' perception of information quality has a positive effect on perceived usefulness, perceived ease of use and attitude towards road diversion. Familiarity with the road network has a positive effect on attitude towards road diversion. Perceived ease of use and attitude towards road diversion have positive effects on perceived usefulness and behavioral intention. Perceived usefulness also positively affects behavioral intention. Attitude towards road diversion and behavioral intention have a positive impact on route switching behavior. Furthermore, individual characteristics also influence travelers' attitudes and perceptions.

Keywords: Technology Acceptance Model; Route Switching Behavior; Hybrid Choice Models; Attitudes; Perceptions

1. Introduction

Advanced Traveler Information Systems (ATIS) can help better manage the traffic by providing guidance to road users. ATIS have proven to be a viable congestion reduction strategy compared to other short-term and less effective alternatives such as congestion pricing and the construction of new infrastructure. Previous studies have demonstrated that ATIS can help reduce travel time disutility and improve network performance (Jou et al., 2005; Shah et al., 2003; Toledo and Beinhaker, 2006). Variable Message Signs (VMS) can collect and disseminate real-time information to motorists and could bring the change of behavior necessary for an efficient use of the traffic. In the context of route choice behavior, this change of behavior could lead to the road users' diversion from their current or habitual route. For this reason, many studies have used diversion rate to investigate travelers' response and evaluate the effectiveness of ATIS. However, studies conducted in various areas of the world have shown that the diversion rate upon reception of VMS information is not high enough to ensure an optimal distribution of the traffic (Chatterjee et al., 2002; Gan and Ye, 2012; Li et al., 2014; Zhong et al., 2012). Though several strategies for improving the effectiveness of VMS have been suggested, the more recent studies do not show any increase in the diversion rate (Li et al., 2014; Ma et al., 2014). Since the effectiveness of ATIS is highly dependent on travelers' response, the inability of the proposed methods to significantly affect travelers' behavior could be due to a limited understanding of the decision-making process in response to VMS.

Several studies have investigated travelers' response to VMS using different data collection and modeling methodologies. These studies have identified the main factors affecting route switching behavior in response to VMS. In addition to travel time, travelers' response to VMS is affected by socioeconomic factors such as age, gender and income and trip characteristics such as route choice style and freeway use frequency (Gan and Ye, 2012; Jou et al., 2005; Ma et al., 2014; Peeta and Ramos, 2006; Zhong et al., 2012). Previous studies also found that road conditions such as incident on intended route and location of incident have a strong effect on travelers' response to VMS (Chatterjee et al., 2002; Gan and Ye, 2012). Travelers' attitudes and perceptions of information reliability can also affect their response to VMS (Choocharukul, 2008; Ma et al., 2014; Madanat et al., 1995). In terms of methodology, improvements in both model formulation and computational capability have led to the development of more flexible error structures and made possible the inclusion of latent psychological factors in the traditional discrete choice models (DCM). The integration of these methods is known as integrated choice and latent variable or hybrid choice model (Ben-akiva et al., 2002; Walker and Ben-Akiva, 2002). In addition to observed explanatory variables, hybrid choice models (HCM) also explain a large portion of population heterogeneity by taking into account the effects of more intangible factors (attitudes and perceptions). Empirical studies have shown that HCM have higher explanatory and predictive power than the traditional DCM (Márquez et al., 2015; Prato et al., 2012; Tsirimpa et al., 2010; Yáñez et al., 2010). HCM have been widely adopted in the transportation arena to examine route choice behavior (Prato et al., 2012; Tsirimpa et al., 2010), mode choice(Vredin Johansson et al., 2006; Yáñez et al., 2010), traffic safety(Cantillo et al., 2015; Márquez et al., 2015), departure time choice (Thorhauge et al., 2016), etc.

More recently, studies on mode choice behavior have adopted more complex HCM formulations by taking into account the hierarchical relationships among the latent variables. Using well established concepts in psychology and social sciences, these studies showed how social interactions and the hierarchical model of cognition influence the formation of travel mode choices (Kamargianni et al., 2014; Paulssen et al., 2014). Kamargianni et al. (2014) demonstrated how parents' attitude towards walking affects teenagers' attitude towards walking, which in turn influences their mode choice behavior. Drawing from the values-attitudes hierarchical relationship (Homer and Kahle, 1988), Paulssen et al. (2014) showed how enduring beliefs (values) affect the formation of more prone-to-change psychological factors (attitudes), which in turn affect mode choice. The use of such methodology has two advantages. First, though hierarchical models from psychology and behavioral science (e.g. the Theory of Planned Behavior, the Technology Acceptance Model) have been widely adopted in the transportation arena (Chen and Chen, 2011; Larue et al., 2015; Roberts et al., 2012), the majority of the studies mainly focus on the formation of intention and not the actual behavior. These models usually adopt a structural equation model or multiple regressions to investigate how the relationships among the psychological factors affect the intention to perform a behavior, but not the behavior itself. In other words, they do not include the latent variables in the choice model. Second, the hierarchical formulation of HCM is more realistic as it gives a more complete and accurate representation of the decision-making process. As a result, it has a higher explanatory power than more simplistic formulations that do not account for such relationships (Kamargianni et al., 2014).

However, to the best of the authors' knowledge, hierarchical HCM have not been applied to examine route choice behavior. This study adopts the simple but robust Technology Acceptance Model (Davis, 1989) to investigate the decision-making process going from travelers' beliefs about VMS to the actual behavior. The Technology Acceptance Model (TAM) assumes that an individual's intention to adopt an information system (here VMS) is determined by two salient beliefs: his perceived usefulness and ease of use of the given system. In addition to these three TAM constructs, we enriched the model with latent psychological factors which are specific to travelers' response to VMS (information quality, attitude towards road diversion and familiarity with the network). The inclusion of the new constructs into the existing model is based on strong theoretical and empirical background and follows the hierarchical process inherent in TAM. The obtained framework is tested using Stated Preference data with repeated observations from 339 road users in Dalian City, China.

The remainder of this paper is organized as follows. Section 2 introduces the TAM framework and presents the research hypotheses. Section 3 describes the hierarchical hybrid choice model. Section 4 describes the data. Section 5 presents the model specification, the results and their implications. Finally, Section 6 concludes this paper with a summary of the findings and limitations and directions for future research.

2. Theoretical background and research hypotheses

2.1. The Technology Acceptance Model (TAM)

TAM (Davis, 1989) is one of the most popular frameworks for understanding users' acceptance of information technology. The model assumes that future system use is determined by the individual's intention to adopt the information technology, which, in turn, is determined by his/her attitude towards using the system. Intention is defined as the individual's perceived probability that he/she will use the technology. Attitude represents the individual's positive or negative feeling towards using the technology (Fishbein and Ajzen, 1975) and is assumed to have a positive effect on the intention to adopt the given technology (Davis, 1989). Davis also argues that an individual's attitude towards using a technology is determined by two salient beliefs: perceived usefulness and perceived ease of use. Perceived usefulness is the extent to which an individual believes that using a particular information system would improve his/her job performance. Perceived ease of use is defined as the extent to which an individual believes that using a particular information system would be free effort. Both constructs are assumed to positively affect attitude (Davis, 1989). Furthermore, perceived ease of use is assumed to have a direct and positive effect on perceived usefulness. However, Davis et al. (1989) found that perceived usefulness and perceived ease of use had a significant direct effect on intention while attitude only partially mediated the effect of perceived usefulness on intention. Thus, attitude towards using the technology was removed from the parsimonious version of TAM (Davis and Venkatesh, 1996) (see Fig. 1).

TAM is a simple but robust model and has been widely adopted in the transportation arena. The main reason for that is its ability to predict future system use and the possibility to take into account human factors in the investigation of travelers' response to road guidance systems, which could help develop more user friendly systems. TAM has been adopted to study drivers' acceptance of in-vehicle navigation systems (Chen and Chen, 2011, 2009), safety warning systems (Larue et al., 2015; Roberts et al., 2012) and web-based ATIS (Lin et al., 2014). In these studies, the relationships hypothesized in the parsimonious TAM have all been supported. Thus, we adopt TAM to investigate travelers' response to VMS and propose:

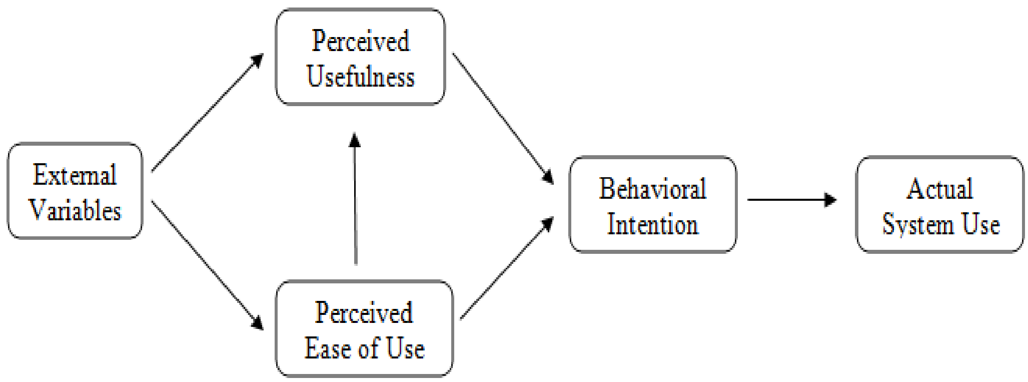

Fig. 1 Parsimonious TAM (Davis and Venkatesh, 1996)

H1: Perceived usefulness has a positive effect on the intention to use VMS.
H2: Perceived ease of use has a positive effect on the intention to use VMS.
H3: Perceived ease of use has a positive effect on perceived usefulness.

In the context of this study, these assumptions mean that travelers who perceive VMS information as useful and easy to use are likely to accept it.

Davis et al. (1989) have also shown that intention has a direct and positive effect on future system use. In the case of descriptive information (description of all available routes), system use could mean using the information provided by VMS to assess the different alternatives available to the driver. In the case of prescriptive information (information with guidance on the best routing strategy), system use would mean diverting in response to the suggestion provided by VMS. The VMS used in this study may also provide guidance. So, we can expect travelers who intend to use VMS to be more likely to divert in response to it. Therefore, we hypothesize:

H4: Intention to use VMS information has a positive effect on route switching behavior.

However, research in the transportation area has also shown that TAM helps better explain the behavior if enriched with domain-specific variables (Chen and Chen, 2011; Roberts et al., 2012). Thus, in the context of travelers' route switching behavior in response to VMS, we decided to extend TAM with familiarity with the road network, attitude towards road diversion and information quality.

2.2 Attitude towards road diversion

It is important to clarify the difference between the attitude used in early versions of TAM and attitude towards road diversion. The early versions used "Attitude towards using the system", which was found to have little effect in the decision-making process (Davis et al., 1989). However, attitude towards road diversion is more specific to route switching behavior and has been proven to have a direct effect on the behavior. Attitude towards road diversion could be defined as the travelers' positive or negative feelings about diverting. Research on mode choice (Paulssen et al., 2014; Vredin Johansson et al., 2006) and route choice behavior (Madanat et al., 1995) has demonstrated that the more positive the attitude towards a behavior, the higher the probability to perform such behavior. Thus, we hypothesize:

H5: Attitude towards road diversion has a positive effect on route switching behavior.

Furthermore, travelers who have a positive attitude towards diverting are more likely to search for the information that could help them make a better decision. Thus, unlike those with static route choice style (who never change route), travelers with a positive attitude towards road diversion would be more likely to find VMS useful and would have higher intention to use it. Therefore, we propose:

H6: Attitude towards road diversion has a positive effect on the intention to use VMS.
H7: Attitude towards road diversion has a positive effect on perceived usefulness.

2.3. Information quality

The concept of information quality is adopted from DeLone and McLean (1992) who argued that information quality is one of the main determinants of information system success. Information quality refers to road user's perception of the output displayed by VMS and is characterized by attributes such as accuracy, timeliness and completeness (Lin et al., 2014). These attributes are also among the main determinants of travelers' acceptance of ATIS (Ma et al., 2014; Peeta and Ramos, 2006). Results from previous studies have shown that information quality has a direct and positive effect on perceived usefulness and perceived ease of use (Ahn et al., 2007; Chang et al., 2005; Lin et al., 2014). That is, when the information is of good quality, it can help travelers make better routing decisions, thus strengthening their perception of usefulness. Furthermore, when the VMS displays all the details needed to make an informed decision (completeness), it requires less effort from the traveler, thus strengthening their perceived ease of use of the information system. Therefore, we propose:

H8: Information quality has a positive effect on perceived ease of use.
H9: Information quality has a positive effect on perceived usefulness.

In addition, adoption is a continuous process in which attitudes and perceptions affect system use, but system use also affects attitudes and perceptions (Ghazizadeh et al., 2012). For example, if a traveler is initially convinced by the information quality, he/she may divert in response to it. However, at the end of his/her trip, he/she will compare the expected and final outcome of his/her decision. If he/she is satisfied with the outcome, he/she is likely to develop a more positive perception of information quality and divert in his/her future trips. In the information system domain, this phenomenon is referred to as continuous usage. If this positive perception persists, the traveler will likely continue to divert, and over time, develop a more positive attitude towards road diversion. Thus, information quality can positively affect attitude towards road diversion. This assumption is supported by Matthijs and Brookhuis (2008), who, using the information-processing paradigm (McGuire, 1972), showed how elements of information quality (e.g. accuracy) could affect the formation of attitudes and the subsequent behavior. Thus, we hypothesize:

H10: Information quality has a positive effect on attitude towards road diversion.

2.4 Familiarity with the road network

Travelers are willing to divert to an alternate route if it helps them save time (Gan and Ye, 2012; Tsirimpa et al., 2010). However, travelers who are not familiar with the alternate route or the whole network may not know how to reach their destination via the alternate route. They may get lost and risk spending more time on the local street than those who stayed on their original route. Due to this risk, they are undecided or unwilling to divert (Ma et al., 2014). On the other hand, travelers who are familiar with the whole network can easily drive through any alternate route and reach their destination without problems. Thus, we can assume that travelers who are familiar with the road network have a more positive attitude towards road diversion. Therefore, we propose:

H11: Familiarity with the road network has a positive effect on attitude towards road diversion.

Furthermore, even though ATIS have many potential benefits, some travelers may not accept it if they believe they can achieve these benefits by themselves. For example, drivers who are familiar with the network may not rely on ATIS as they know the available alternatives and how to navigate through them. In some cases, they could even find a better way to avoid congestion by using shortcuts through back streets that the road guidance system did not know about (Bonsall and Parry, 1991). Such drivers would find their knowledge of the network superior to that of the road guidance system (Bonsall and Parry, 1991) and are less likely to comply with it. In other words, they may not find traffic information useful. Adler and McNally (1994) showed that travelers who are familiar with the network are less likely to use traffic information. This finding is also corroborated by Zhong et al. (2012) who found that familiar travelers are more reluctant to comply with VMS. Thus, we can assume that travelers who are familiar with the network would be less likely to find VMS information useful. This assumption is supported by Diop et al. (2019) who proved that familiarity with the network had a negative effect on travelers' perception of VMS usefulness. Thus, we hypothesize:

H12: Familiarity with the network has a negative effect on the perceived usefulness of VMS.

Fig. 2 shows the hypotheses formulated for this study.

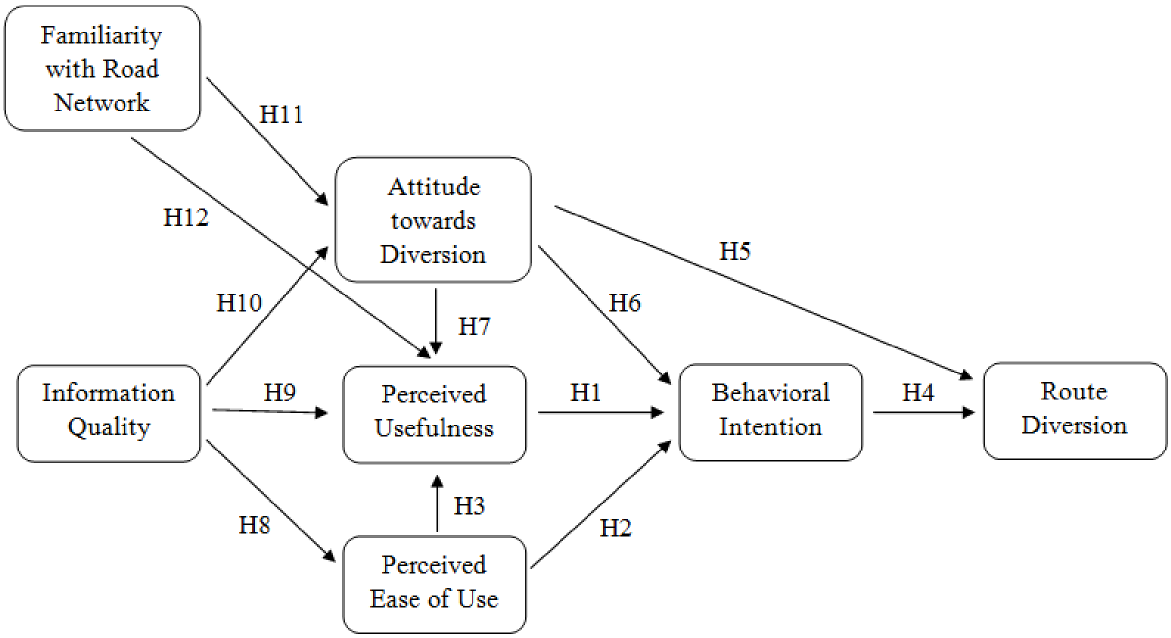

Fig. 2 Research hypotheses

3. Model formulation

This study develops a hierarchical HCM of travelers' response to VMS based on the relationships hypothesized in Section 2. A HCM consists of two models: a latent variable model and a discrete choice model. Each model can further be divided into a structural sub-model and a measurement sub-model. Fig. 3 depicts the HCM framework used in this study. The rectangles correspond to observed variables, the spheres represent latent variables, the solid arrows indicate structural equations, and the dashed arrows represent measurement equations.

Nomenclature	
E_n^*, X_n^*	Vectors of endogenous and exogenous latent variables, respectively
IE_n, IX_n	Vectors of indicators of latent variables
X_n	Vector of explanatory variables (socioeconomic and trip characteristics)
Z	Vector of route choice attributes (travel time, number of signals, etc.)
U_n	Vector of utilities
ω_n, ν_n, ε_n, ζ_n, ξ_n	Random disturbance terms
Σ_ω, Σ_ν, Σ_ε, Σ_ζ, Σ_ξ	Covariance of random disturbance terms
α, β, θ, γ, λ	Unknown parameters
y_n	Choice indicator

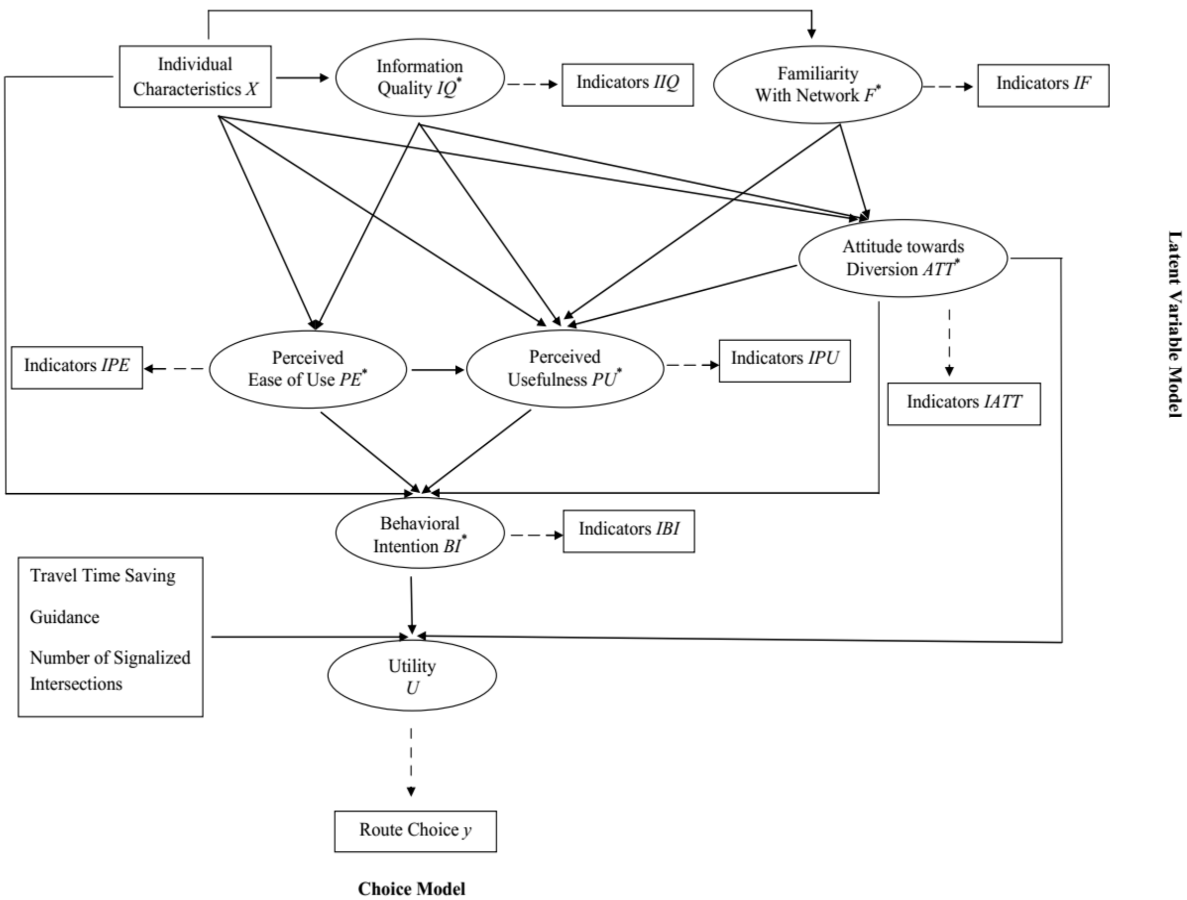

Fig. 3 Proposed Model Framework

3.1. The structural equations

The structural equation of the latent variable model defines the exogenous latent variables X_n^* as a function of individual characteristics.

$$X_n^* = g_1(X_n;\alpha) + \upsilon_n \qquad \upsilon_n \sim D(0,\Sigma_\upsilon) \tag{1}$$

The endogenous latent variables E_n^* are defined as a function of exogenous and/or endogenous latent variables and individual characteristics.

$$E_n^* = g_2(E_n^*, X_n^*, X_n;\beta) + \omega_n \qquad \omega_n \sim D(0,\Sigma_\omega) \tag{2}$$

The structural equation of the choice model describes the utilities as a function of latent variables and alternative attributes as follows:

$$U_n = V(Z, E_n^*;\theta) + \varepsilon_n \qquad \varepsilon_n \sim D(0,\Sigma_\varepsilon) \tag{3}$$

Where V, the deterministic component of the utility is linear in its parameters. Similar with some previous studies (Cantillo et al., 2015; Prato et al., 2012), we assume that the effect of the individual characteristics is mediated by the latent variables. Thus, the individual characteristics are not incorporated into the choice model.

3.2. The measurement equations

The measurement sub-model of the latent variable model relates the latent variables to indicators which can be obtained from survey questions.
The measurement equations of the exogenous latent variables X_n^* are written as follows:

$$IX_n = f_1(X_n^*;\gamma) + \xi_n \qquad \xi_n \sim D(0,\Sigma_\xi) \tag{4}$$

The measurement equations of the endogenous latent variables E_n^* are written as follows:

$$IE_n = f_2(E_n^*;\lambda) + \zeta_n \qquad \zeta_n \sim D(0,\Sigma_\zeta) \tag{5}$$

The measurement sub-model of the choice model links the latent utility to choice indicators obtained from survey questions. An individual n is assumed to choose the alternative i that maximizes his/her utility; therefore, the measurement equation of the choice model is written as follows:

$$y_{in} = \begin{cases} 1 & if \quad U_{in} \geq U_{jn} \quad \forall j \neq i \\ 0 & otherwise \end{cases} \tag{6}$$

Where y_{in} is the indicator corresponding to alternative i, U_{in} is the utility associated with alternative i for individual n.

3.3. The likelihood function

The likelihood of a given observation is the joint probability of observing the choice and the indicator for the latent variable. Since a latent variable is only known to its distributions, we integrate the probability over the distribution of the latent variables. If all error terms are independent, the likelihood function can be written as follows:

$$P(y_n, IX_n, IE_n | Z, X_n, \vartheta) = \int_{X_n^*}\int_{E_n^*} P(y_n | Z, E_n^*; \theta, \Sigma_\varepsilon) d_1(IX_n | X_n^*; \gamma, \Sigma_\xi) d_2(IE_n | E_n^*; \lambda, \Sigma_\zeta) h_1(X_n^* | X_n; \alpha, \Sigma_\upsilon) h_2(E_n^* | E_n^*, X_n^*, X_n; \beta, \Sigma_\omega) dE_n^* dX_n^* \quad (7)$$

Where $\vartheta = \{\theta, \Sigma_\varepsilon, \gamma, \Sigma_\xi, \lambda, \Sigma_\zeta, \alpha, \Sigma_\nu, \beta, \Sigma_\omega\}$ is the full set of parameters to be estimated, d_1 and d_2 are the density functions corresponding to the measurement equations, h_1 and h_2 are the density functions corresponding to the structural equations.
A more detailed explanation of the HCM can be found in Ben-akiva et al. (1999) and Walker and Ben-Akiva (2002).

4. Data collection

Two methods can be adopted to collect data on travel behavior: Stated Preference (SP) and Revealed Preference (RP). RP method analyzes the behavior in real-life situations, while SP method analyzes the behavior in hypothetical scenarios designed by the researcher. RP method is more realistic, but it is also expensive and time-consuming. Furthermore, RP can only observe the behavior in response to the VMS displayed during the survey period (Kawashima, 1991). SP, on the other hand, gives the analyst more control over the values of the attributes. For these reasons, this study adopts SP method.

The survey consists of three parts: participants' socioeconomic characteristics and trip characteristics, latent variables indicators and SP scenarios.

4.1. Participants

The participants were recruited in the parking lots near the shopping malls located between the origin (Dalian University of Technology) and the destination (City Center). All participants had to answer a screening question before being invited to join the survey. The screening question consisted of verifying whether or not they held a valid driver license. Participants who met that criterion were then asked to provide basic information such as their age, gender, driving years, income, and route choice style. 500 questionnaires were distributed and 339 valid answers were collected, indicating a 67.8% response rate. Table 1 shows a summary of the respondents' characteristics. Of all 339 participants, 63.13% are male, 36.87% female. The majority of the respondents are aged between 18 and 30. Regarding their income, most of the respondents receive a low income (62.54%), followed by mid-income (28.32%). Of the 339 respondents, 23.01% had driving years less than 1 year, 47.49% had driving years between 1 and 5 years, and 29.5% had more than years of driving experience. Of the 339 respondents, 15.04% use their experience to choose their route, 17.99% use traffic information only and 63.13% combine the information with their own experience.

4.2. Measurement scales

This section of the survey gathered information on travelers' attitudes and perceptions towards VMS and route diversion. All choice indicators were selected after a careful review of the literature and have all been validated in previous research. Each item was measured using a 5-point Likert scale ranging from "Strongly agree" to "Strongly Disagree".

Table 1 Socioeconomic and Trip Characteristics

Attributes	Frequency (N=339)	Percentage (%)
Gender		
Male	214	63.13
Female	125	36.87
Age group		
18-30	212	62.54
31-50	113	33.33
Over 50	14	4.13
Monthly income		
Less than 5,000 RMB	212	62.54
5,000-10,000 RMB	96	28.32
More than 10,000 RMB	31	9.14
Driving years		
Less than 1 year	78	23.01
1-5 years	161	47.49
More than 5 years	100	29.5
Route Choice Style		
Static	13	3.83
Information-Based	61	17.99
Experience-Based	51	15.04
Information-Experience-Based	214	63.13

Note 1RMB=0.14USD (August, 2018)

4.3. SP scenarios

The respondents were asked to imagine a commute between their home (near Dalian University of Technology) and their workplace at the city center (Zhongshan Square). They had two possible routes: a local street and an expressway (see Fig. 4). Fig. 5 shows the division of the network into different sections. The expressway is more direct, without signalized intersections and has a higher speed limit. Thus, travelers prefer the expressway for their commutes. But, in case of incident (congestion, accident, road maintenance, etc.), the VMS can help reduce the pressure on the expressway by redirecting the travelers to the local street. In this study, the travelers go through a VMS which is placed upstream the off-ramp and provides real-time information on both routes. The information is displayed in a color-coded format using three colors: green (free flowing), yellow (moderate congestion) and red (congestion). After seeing the message, the traveler may decide to stay on the expressway or divert to the local street.

In the experimental design, each color corresponds to a specific average speed (see Table 3). The correspondence between road color and speed was adopted from Zhong et al. (2012). In the SP experiment, the expressway is congested, therefore, slower. Thus, the speed on the two road sections of the expressway (e1 and e2) takes the following levels: yellow (moderate congestion) and red (congestion). The local street being faster, the speed on its two main sections (a2 and a3) takes the following levels: green (free flowing) and yellow (moderate congestion). The speed on the two smaller sections of the local street (a1 and a4) is kept constant to green for simplicity.

Furthermore, the information can be displayed with or without guidance on the best route (two levels) and the number of signalized intersections on the local street takes two levels (10 and 20). Thus, we have six attributes with two levels each (see Table 4), which gives us a full factorial design with 2^6=64 scenarios. Given this high number of scenarios, we simplified the design into a balanced orthogonal design of 16 scenarios. The design was then divided into four blocks of four scenarios.

Table 2 Attitudinal Indicators

Construct	Indicators	Wording
Attitude Towards Diversion	ATT1	For my commutes, I often change my planned route
	ATT2	I am willing to divert in order to avoid traffic congestion
Familiarity With Road Network	FAM1	I can describe familiar routes
	FAM2	I can describe the route to my own house
	FAM3	I am familiar with driving through local streets
Information Quality	IQ1	VMS provides accurate traveler information
	IQ2	VMS provides complete traveler information
	IQ3	VMS provides timely traveler information
Perceived Usefulness	PU1	Using VMS information helps me in avoiding congestion
	PU2	VMS information helps me in arriving to my destination on time
	PU3	VMS information helps me make better routing and departure time choices
	PU4	Overall, I find VMS information useful
Perceived Ease of Use	PEOU1	Using VMS information does not require a lot of mental effort
	PEOU2	It is easy to learn how to use VMS information
	PEOU3	VMS information is easy to understand
	PEOU4	Overall, I find VMS information easy to use
Behavioral Intention	BI1	I would consider using VMS information as long as it is available
	BI2	I will very likely use VMS information if it is available
	BI3	I would recommend others to use VMS information for their trips

Table 3 Road Colors and their Corresponding Average Speed

Color	Green	Yellow	Red
Speed (m/s)	8.1278	4.9222	2.0694

Table 4 Attributes and their Levels

Attributes	levels
VMS color on a2	Yellow, Green
VMS color on a3	Yellow, Green
VMS color on e1	Red, Yellow
VMS color on e2	Red, Yellow
Provision of Guidance	Guidance(1), No Guidance (0)
Number of Signalized Intersections	10, 20

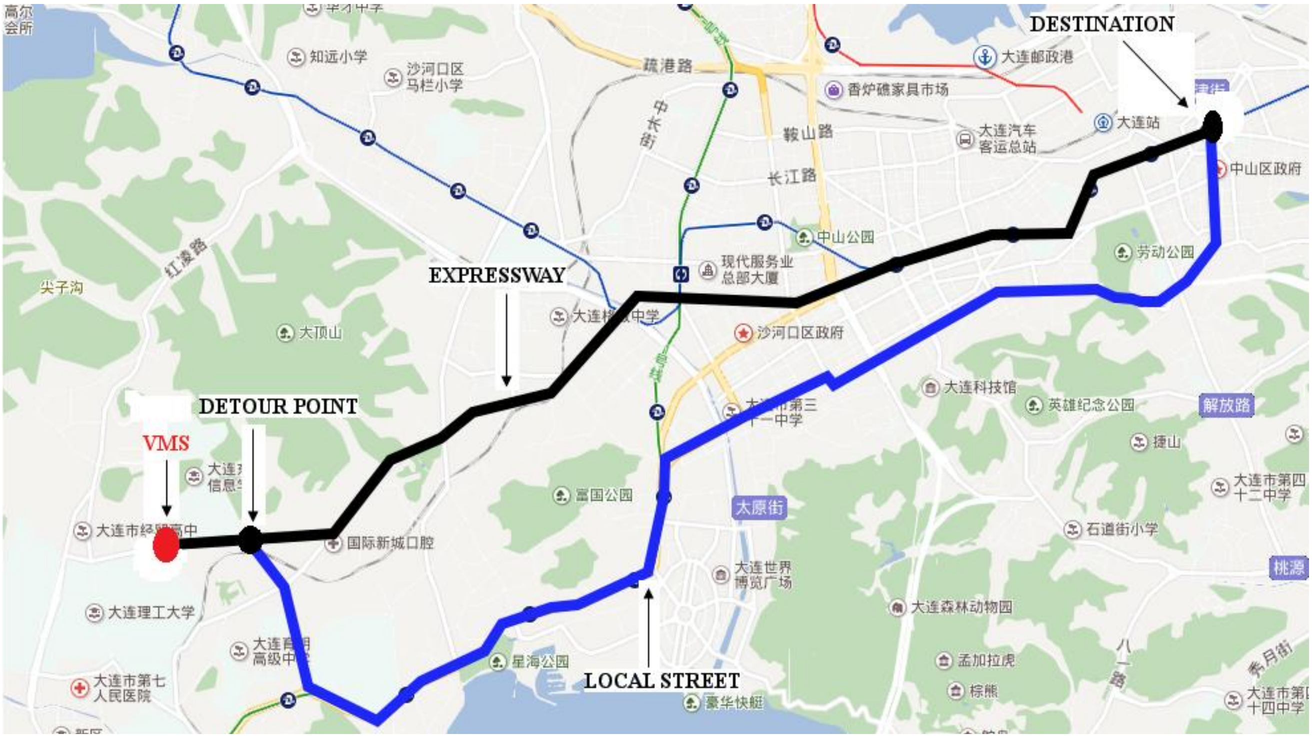

Fig. 4 Study Network

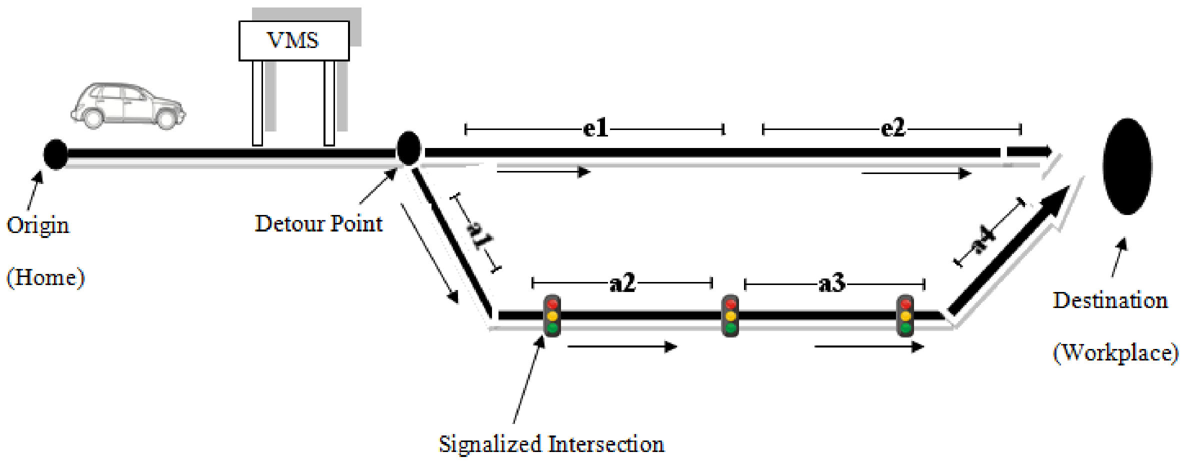

Fig. 5 Network Layout

In addition to the socioeconomic and trip characteristics and latent indicators, each respondent was given a block of four scenarios and was asked to indicate his/her choice preferences (stay on the expressway or divert). Thus, for the 339 respondents, we obtained a total of 1356 (339×4) observations. Fig. 6 shows examples of SP scenarios. In the actual survey, all scenarios are displayed in Chinese language. However, in order to better present the scenarios to the reader, some parts of the example were translated into English.

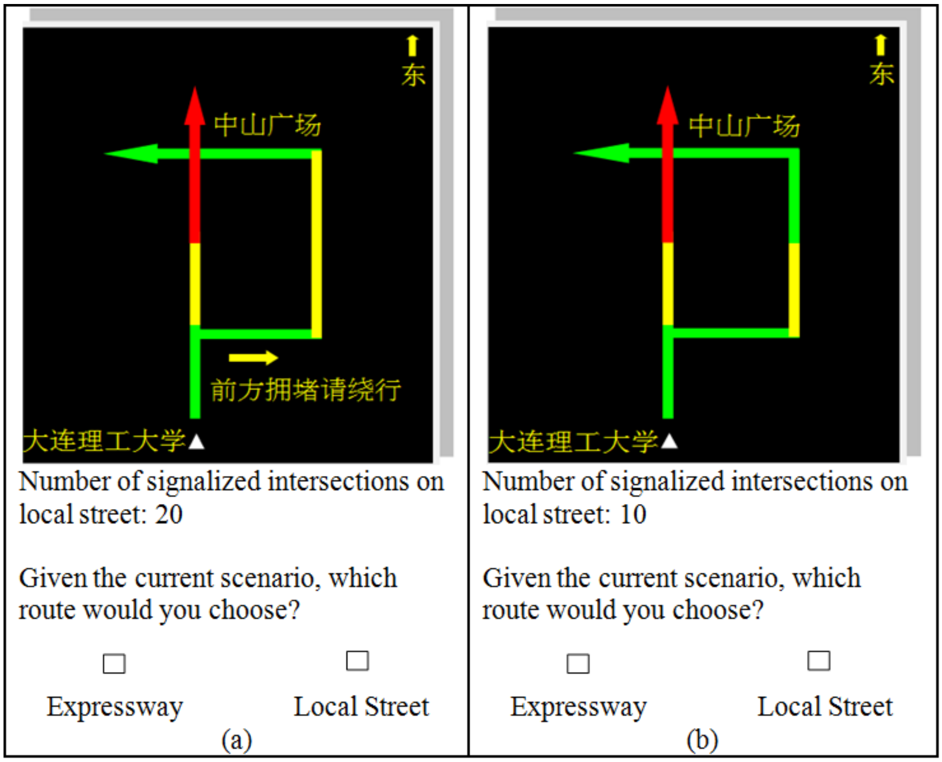

Fig. 6 Examples of SP Scenarios
(a) VMS with Guidance on the Best Route
(b) VMS without Guidance on the Best Route

5. Model estimation results and implications

5.1 Model specification

This section presents the model specification, estimation results and their implications. The choice model consists of two alternatives: staying on the expressway and diverting to the local street. The model takes into account the effects of travelers' attitudes and perceptions as well as the causal relationships among them (as hypothesized in Section 2). The structural equations of the latent variable model are defined as follows:

$$FAM_n = \alpha_{FAM} + \alpha_{X_n,FAM} \times X_n + \upsilon_{FAM,n} \tag{9a}$$

$$IQ_n = \alpha_{IQ} + \alpha_{X_n,IQ} \times X_n + \upsilon_{IQ,n} \tag{9b}$$

$$ATT_n = \beta_{ATT} + \beta_{X_n,ATT} \times X_n + \beta_{IQ,ATT} \times IQ_n + \beta_{FAM,ATT} \times FAM_n + \omega_{ATT,n} \tag{9c}$$

$$PEOU_n = \beta_{PEOU} + \beta_{X_n,PEOU} \times X_n + \beta_{IQ,PEOU} \times IQ_n + \omega_{PEOU,n} \quad (9d)$$

$$PU_n = \beta_{PU} + \beta_{X_n,PU} \times X_n + \beta_{IQ,PU} \times IQ_n + \beta_{PEOU,PU} \times PEOU_n + \beta_{ATT,PU} \times ATT_n + \omega_{PU,n} \quad (9e)$$

$$BI_n = \beta_{BI} + \beta_{X_n,BI} \times X_n + \beta_{PU,BI} \times PU_n + \beta_{PEOU,BI} \times PEOU_n + \beta_{ATT,BI} \times ATT_n + \omega_{BI,n} \quad (9f)$$

Where X_n are individual attributes, FAM_n, IQ_n, ATT_n, $PEOU_n$, PU_n, BI_n, are the latent variables corresponding to familiarity with road network, perception of information quality, attitude towards road diversion, perceived ease of use, perceived usefulness and behavioral intention, respectively; α and β are regression parameters, ν and ω are vectors of error terms associated with the latent variables. All individual characteristics are modeled using binary dummy variables, meaning that for each characteristic, the sub-group to which the individual belongs takes the value 1 while the other sub-groups take the value 0. For each characteristic, one sub-group was fixed to 0 to avoid redundancy. In this study, only the effects of age, gender and route choice style were taken into account. Age and gender are among the most commonly used variables when explaining attitudes and perceptions (Cantillo et al., 2015; Kamargianni et al., 2014; Paulssen et al., 2014; Tsirimpa et al., 2010; Yáñez et al., 2010). Route choice style was selected with regard to route switching behavior in response to VMS. The goal was to demonstrate how the way travelers choose their route affects their attitudes and perceptions towards VMS.

Due to the large number of latent indicators, only one measurement equation (for Information Quality) is shown as an example. The measurement equations of the latent variable model are written as follows:

$$I_{IQ,n} = \gamma_{0,IQ} + \gamma_{IQ} \times IQ_n + \xi_{IQ,n} \quad (10)$$

Where $I_{IQ,n}$ is a vector of latent indicators, IQ_n is the latent variable corresponding to perception of information quality, $\gamma_{0,IQ}$ is a vector of regression intercepts, γ_{IQ} is a vector of factor loadings, $\xi_{IQ,n}$ is a vector of error terms. The factor loading associated with the first indicator is set to 1 for identification. All indicators are considered as categorical variables and the measurements equations are estimated using ordered probit models. This approach is more appropriate for the categorical data (Likert scale) at hand (Daly et al., 2012).

The structural equations of the choice model are defined as follows:

$$U_{EXP,n} = ASC_{EXP} + \theta\_TTSAV \times TT\_SAV + \theta\_GUIDANCE \times GUIDANCE + \varepsilon_{EXP,n} \quad (11a)$$

$$U_{LOC,n} = \theta\_STOP \times NB\_STOP + \theta\_ATT \times ATT_n + \theta\_BI \times BI_n + \sigma_n + \varepsilon_{LOC,n} \quad (11b)$$

Where ASC_{EXP} is the alternative-specific constant associated with expressway, TT_SAV is the travel time saved through diverting and is equal to the difference between the travel time on expressway and travel time on local street, $GUIDANCE$ is a dummy variable that equals 1 if the information is provided with guidance, 0 otherwise, NB_STOP is the number of signalized intersections on the local street, ATT_n and BI_n are the latent variables representing the respondent's attitude towards road diversion and intention to use VMS, respectively, θ_TTSAV, $\theta\_GUIDANCE$, θ_STOP, θ_BI and θ_ATT are regression parameters, ε_n is a vector of error terms associated with the choice model, σ_n captures the correlation among repeated observations in the SP experiment.

The travel times are obtained by using the speed corresponding to the VMS color (see Table 3) and the distance on the road section (see Table 5) as follows:

$$T = \sum_{i=1}^{m} \frac{d_i}{s_i} \quad (12)$$

Where T is the total travel time on a given route, m is the number of road sections (2 for the expressway, 4 for the local street), d_i is the distance on road section i, and s_i is the speed on road section i.

Table 5 Distance Corresponding to Road Sections

Road Section	a1	a2	a3	a4	e1	e2
Distance (km)	2.5	4.7	4.1	2.4	6.0	4.5

The integrated choice and latent variable model is simulated using PythonBiogeme (Bierlaire, 2003). Several specifications were tested before obtaining our final model. After several trials, a stable model was obtained with 1000 Halton draws. Though the latent variable and discrete choice model were estimated simultaneously, we present them in two different tables for clarity. Due to length issues, the results of the measurement part of the latent variable model are not shown in this paper. Interested readers can contact the authors for more information about the measurement model.

5.2 Results

Table 6 shows the results of the structural component of the latent variable model.

Table 6 Results of the Structural Component of the Latent Variable Model (t statistics in parentheses)

Variables	FAM	IQ	ATT	PEOU	PU	BI
FAM			0.221		-0.167	
			(2.47)		(-2.02)	
IQ			0.514	0.571	0.347	
			(2.69)	(11.47)	(5.06)	
ATT					0.331	0.487
					(3.78)	(3..84)
PEOU					0.301	0.227
					(7.11)	(4.49)
PU						0.388
						(7.05)
Gender (female =0)						
Male	0.446	0.226	0.336	0.159	0.178	0.191
	(7.02)	(4.32)	(4.68)	(1.97)	(2.14)	(1.93)
Age (18-30=0)						
31-50	0.354	-0.208	-0.494	-0.134	-0.199	-0.115
	(2.25)	(-2.86)	(-2.83)	(-3.99)	(-2.04)	(-2.78)
Over 50	0.463	-0.414	-0.57	-0.537	-0.373	-0.655
	(4.828	(-6.14)	(-8.65)	(-8.44)	(-2.55)	(-3.82)
Route choice style (static=0)						
Experience-based	0.143	0.0413	0.02	0.228	-0.021	0.07
	(0.84)	(0.26)	(0.06)	(1.03)	(-0.08)	(0.26)
Information-based	0.388	0.34	0.421	0.387	0.310	0.431
	(2.67)	(4.08)	(5.26)	(5.97)	(3.32)	(3.48)
Information-experience-based	0.611	0.205	0.322	0.256	0.178	0.327
	(3.78)	(2.43)	(3.86)	(4.39)	(0.65)	(3.42)
Intercept	0.965	0.787	1.34	0.891	2.023	0.912
	(6.42)	(5.51)	(8.03)	(7.49)	(7.57)	(2.48)
Standard deviation of error term	0.513	0.263	0.103	0.418	0.307	0.007
	(10.43)	(4.71)	(2.64)	(12.79)	(5.48)	(0.20)

Note: IQ = Information Quality
FAM = Familiarity with Road Network
ATT = Attitude towards Road Diversion
PEOU= Perceived Ease of Use
PU= Perceived Usefulness
BI= Behavioral Intention

Table 6 shows that all hypothesized relationships are supported. Information quality has a positive effect on perceived usefulness, perceived ease of use and attitude towards road diversion (H8, H9 and H10). Familiarity with the road network has a positive impact on attitude towards diversion (H11) and a negative impact on perceived usefulness (H12). Attitude towards road diversion positively influences perceived usefulness and behavioral intention (H7 and H6). Perceived ease of use positively affects perceived usefulness and behavioral intention (H2 and H3). Perceived usefulness has a positive effect on behavioral intention (H1). Perceived usefulness has a stronger effect on behavioral intention than perceived ease of use, which is inconsistent with previous studies investigation traveler acceptance of road guidance systems (Chen and Chen, 2011; Roberts et al., 2012). However, Brown et al. (2002) found that when the use of an information system is mandatory, perceived ease of use tends to be the stronger predictor of behavioral intention. But the adoption of traffic information is not mandatory; travelers may decide to use it or ignore it. In this case, perceived usefulness is a stronger predictor of behavioral intention than perceived ease of use. Individual characteristics also influence travelers' attitudes and perceptions. Gender is positively associated with all six latent constructs, indicating that male drivers have more positive attitudes and perceptions regarding VMS than their female counterparts. This finding is supported by previous studies which found that male drivers are more likely to accept VMS (Jou et al., 2005; Peeta and Ramos, 2006). The parameter associated with age indicates that, as their age increases, travelers' attitudes and perceptions regarding VMS become less salient, but they become more familiar with the network. Older travelers are also known for being risk-adverse (Tsirimpa et al., 2010). This could explain their reluctance to adopt VMS. Jou et al. (2005) also found that older travelers are less likely to divert in response to VMS. The parameters associated with route choice style show that travelers who use *traffic information only* are less familiar with the network than those who combine traffic information with their experience. However, travelers who use *traffic information only* have more positive attitude, perception of usefulness, ease of use and have a stronger intention to use VMS than those who combine the information with their experience. Both of the aforementioned groups are more familiar with the network and have more positive attitudes and perception towards VMS than those with static route choice style. The findings on route choice style are consistent with previous research on travelers' response to VMS (Zhong et al., 2012)

Table 7 shows the results of the choice model component. As mentioned above, other specifications were tested before obtaining our final model. In order to demonstrate the need to account for the causal relationships among latent variables, we also developed a HCM in which all six latent factors were directly incorporated into the utility function. HHCM shows the results of the hierarchical hybrid choice model, HCM shows the results of the model without causal relationships.

In Table 7 attitude towards road diversion and behavioral intention to use VMS are positive significant, supporting H4 and H5. However, as can be seen in the model without hierarchical relationships, perceived ease of use, perceived usefulness, familiarity with network and information quality have little to no direct effect on route switching behavior. Their effects are mediated by attitude towards road diversion and behavioral intention as shown in Table 6.

The alternative-specific constant associated with expressway is positive. This indicates that there is an inherent reluctance to diverting to the expressway. The parameters associated with the level of service have the expected signs and corroborate previous studies (Abdel-Aty and Abdalla, 2004; Gan and Ye, 2012; Jou et al., 2005; Peeta and Ramos, 2006). The parameter associated with the number of signalized intersections is negative, indicating that, all else being equal, as the number of signalized intersections on the local street increases, the propensity to divert decreases. Though the local street is faster during congestion, the increased number of stops may affect travelers' perception of the travel time on the two available routes. As demonstrated by Zhao and Harata (2001), travelers' perception of travel time plays an important role in route choice behavior. The parameter associated with travel time saving is negative, indicating that the more time travelers can save through diverting, the higher the probability to switch to the local street. The parameter associated with guidance is negative, indicating that providing travelers with information on the best routing strategy increases the probability to switch to the local street.

Table 7 Results of the Choice Model Component (t statistics in parentheses)

	HHCM	HCM
Variables	With hierarchical relationships	Without hierarchical relationships
ASC_EXP	2.94 (6.43)	1.36 (3.11)
θ_BI (specific to local street)	1.56 (4.35)	1.96 (5.98)
θ_ATT(specific to local street)	0.582 (2.29)	0.401 (2.36)
θ_IQ (specific to local street)	-	0.471 (1.62)
θ_PEOU (specific to local street)	-	0.411 (1.75)
θ_PU (specific to local street)	-	0.091 (0.63)
θ_FAM (specific to local street)	-	0.113 (1.07)
θ_GUIDANCE (specific to expressway)	-0.110 (-5.09)	-0.111 (-5.11)
θ_STOP (specific to local street)	-0.372 (-4.69)	-0.384 (-4.75)
θ_TTSAV (specific to expressway)	-0.327 (-10.76)	-0.323 (-10.75)
σ (Error Component)	1.15 (32.84)	1.22 (41.45)
Statistics		
Number of observations	1356	1356
R-Squared	0.607	0.607
Adjusted R-Squared	0.605	0.605
Number of draws	1000	1000
Hit ratio (%)	82.7	82.3

5.3 Implications

Attitude and behavioral intention are the strongest determinants of route switching behavior. This shows the importance of accounting for the effects of latent psychological factors on travel behavior. Compared to a model without latent factors, the inclusion of the latent variables helps capture population heterogeneity and increases the explanatory power of the model.

The significant effect of information quality on perceived usefulness, perceived ease of use and attitude towards diversion indicates that ATIS providers should make more effort to reinforce travelers' perception of information quality. Since information quality is characterized by accuracy, timeliness and completeness, travelers need to be assured that the necessary efforts have been made so as to provide traffic information that is as accurate, timely and complete as possible. Providing complete information means displaying all the details needed to make an informed decision. Such information is more likely to be accepted by travelers (Peeta and Ramos, 2006).

Attitude towards diversion has a direct and indirect effect on route switching behavior. Thus, changing or reinforcing travelers' attitude towards road diversion could help increase the diversion rate. Attitude towards diversion is determined by information quality and familiarity with the network. Thus, in addition to improving information quality, more familiarity with the network could also positively affect travelers' attitude. Though familiarity comes with experience, the VMS display format could assist travelers in navigating through unfamiliar roads. Recent developments in the area of information technology have led to the implementation of Graphical Road Information Panels (GRIPs). GRIPs are a type of VMS that can display text message, graphical message, or a combination of both. In addition, GRIPs can display maps which can provide a representation of the network ahead. This could help travelers navigate through less familiar routes, thus giving them more confidence in diverting. GRIPs equipped with maps are both a traffic information source and a navigational system. Furthermore, GRIPs are more effective than the traditional VMS (Gan, 2010; Matthijs and Brookhuis, 2008). GRIPs are becoming more and more popular and have been implemented in Europe, Japan and certain parts of China (Gan, 2010; Matthijs and Brookhuis, 2008; Shalloe et al., 2014). However, many cities still use the traditional VMS. Adopting GRIPs could help these cities better mitigate traffic congestion.

Perceived usefulness is a stronger predictor of behavioral intention than perceived ease of use. Thus, more effort should be put on reinforcing or changing travelers' perception of VMS usefulness.

From a methodological standpoint, the results show that some latent factors may not have a direct effect on the behavior, but their impact may be mediated by other variables. Thus, studies that do not find a direct effect of the latent variables on the behavior should also examine their indirect effect through other variables. Furthermore, some latent factors may have a direct and indirect effect on the behavior. For example, attitude towards road diversion has a direct and indirect effect (through behavioral intention and perceived usefulness) on route switching behavior. Therefore, we can estimate the total effect of attitude on route switching behavior by adding up its direct and indirect effects.

However, the comparison of hit ratios shows no significant difference between the traditional and hierarchical HCM (82.3% vs 82.7%). Thus, even though there is a difference in terms of explanatory power, the two models exhibit the same predictive powers. The comparison of r-squared also shows no difference in terms of model fit.

6. Conclusion

ATIS have the potential to help travelers make informed decisions by providing them with real-time information on the available alternatives. However, their success depends highly on travelers' acceptance. Thus, in order to develop effective ATIS, it is important to be able to predict and understand travelers' response to the information provided. The objective of this study was to develop a comprehensive framework for travelers' response to VMS by integrating an extended TAM into the traditional route switching model. The model also accounted for the hierarchical relationships amongst attitudes and perceptions. The hierarchical HCM was tested using SP data from 339 road users in Dalian City, China.

The results show that combining robust and well-known frameworks such as TAM with the traditional discrete choice model is possible if the causal relationships among the latent factors are taken into consideration. However, these relationships must be based on a strong theoretical and empirical background. We also found that attitude towards diversion and intention have stronger effects on route switching behavior than the observed attributes. Furthermore, travelers' positive attitudes and perceptions regarding VMS lead to a higher acceptance of the information provided. Thus, ATIS providers should put more emphasis on how to affect travelers' attitudes and perceptions when designing the road guidance systems.

This study suffers from certain limitations. First, the data is cross-sectional, which means there is no way to evaluate the effectiveness of the policies drawn from the model. As pointed out by Chorus and Kroesen (2014), the use of cross-sectional data is one of the major limitations of many HCM based studies. Second some studies have investigated the interactions between the latent psychological variables and the choice attributes (Bekhor and Albert, 2014; Prato et al., 2012). Accounting for such interactions could help better explore the choice process. Our study only examined the interactions among latent factors and their effect on the choice model without interaction with attributes such as travel time saving. Finally, the hierarchical HCM only increased the explanatory power of the model; the predictive power did not increase significantly. Our future studies will address these issues. Despite these limitations, this study offers great insight from a theoretical and practical point of view. Though HCM have been adopted to investigate route choice behavior, the use of a hierarchical HCM to investigate route switching is a major contribution to the literature. Furthermore, hierarchical HCM have a promising future in travel behavior modeling as they offer a more realistic and more detailed representation of the actual behavior.

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