Modeling Impacts of Traffic Information on Driver's Route Choice Decision: An Empirical Analysis of Bangkok Expressway's Motorists

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Abstract: Variable Message Signs (VMS) are typically utilized to display traffic information and are expected to help motorists plan and make better decision for their travel. The objective of this study is to evaluate motorist's awareness and decision regarding text message and color-coded traffic information on the VMS display. Samples are taken from Bangkok motorists by means of questionnaire surveys. Results from ordered discrete modeling reveal that altering various message types on the VMS has no effect on driver's route choice at 95 percent confidence level. However, the color-coded traffic information can significantly influence driver's decision. Others significant variables include driving frequency, daily distance traveled, and awareness of pre-trip traffic information. The current findings could help developing appropriate contents for VMS display that are useful, correct, and consistently meet motorist's demand.

Keywords: Variable Message Sign, Bangkok Expressway, Discrete Choice Model; Route Choice Decision

1. INTRODUCTION

Variable Message Sign (VMS) is a common tool for traffic engineers to disseminate traffic-related information to motorists. The VMS can be simply an electronic matrix sign board displaying text messages, or can be displayed in color showing both text messages and graphical traffic information. Typical information shown to motorists often includes traffic conditions, accidents, incidents, or work zones on highway segments. An appropriate installation of VMS is expected to help motorists plan and make better decision choice for their travel.

This study focuses on route choice decision of motorists as a result of traffic information shown on VMS system. Although several past studies have investigated VMS in various aspects, this paper argues that providing more traffic information to motorists may not be necessarily beneficial to motorists. Different types of VMS could yield different impacts regarding route choice selection, and too much VMS information may potentially lead to confusion and would result in a smaller diversion rate. In addition, the effects of socioeconomic and travel characteristics could be regarded as major determinants for route choice diversion.

The main objective of this study is to evaluate motorist's awareness and decision regarding VMS traffic information. Samples are taken from Bangkok motorists who drive on expressway system by means of questionnaire surveys. Two types of VMS are considered, namely, text-only VMS and color-coded VMS. Similarities and differences in terms of stated route diversion are discussed from the ground of ordered probability modeling.

The outline of the paper is as follows. The first section lays out the overview of study background and objectives. The second section presents extant literature, followed by research methodology in the third section. Findings are presented in the forth section, including both descriptive statistics and modeling results. Lastly, research summary and limitation are discussed.

2. LITERATURE REVIEW

Variable Message Sign can be considered as a tool under the Advanced Traveler Information System (ATIS), a key component in the Intelligent Transport System (ITS). Numerous past studies examined the impact of traffic information. Polydoropoulou *et al.* (1996), for instance, conducted a study on how travelers would respond to different traffic information. Based on a questionnaire survey of commuters in California Bay Area, results indicated that factors affecting travel decision changes due to unexpected delays include delays on the usual route, travel time on alternative routes, perceived level of congestion on alternative routes, and information sources. In addition, quantitative delay information on both current and alternative routes was found to be significant to diversion decision. Along similar lines of research, Muizelaar and Arem (2006) investigated motorist's preference of traffic information content. A multinomial modeling analysis of Dutch samples collected from internet survey showed that suggestion on alternative route was the most preferred content, followed by location, length and cause of traffic delay.

In terms of VMS research, Chatterjee *et al.* (2002) focused on driver's responses to VMS information. The data was collected from a sample of motorists in London and analyzed using logistic regression models. From this study, although the VMS information was perceived to be useful, only one-fifth of the respondents would make a route diversion. In Shanghai, China, Gan *et al.* (2005) presented the VMS system consisting of graphical VMS and surface-street VMS. The effectiveness of graphical VMS in assisting drivers in both route choice selection and en-route diversion was noted, particularly under severe congestion or incident conditions. In a similar vein, Erke *et al.* (2007) investigated the effects of VMS on route choice, speed and braking behavior by comparing a field experiment while messages were displayed on the VMS and while there was nothing shown on the signboard. An empirical analysis of the field data confirmed that VMS was effective in rerouting traffic.

Apart from traffic contents, the design of traditional text VMS needs proper consideration of many factors such as font size, font color, and background color. Cao *et al.* (2002) studied such effects using experimental setting with computer-generated VMS on 18 subjects of different age and gender. The analysis of variance results showed a statistical significance on font color, driver's age and gender. Hesar *et al.* (2007) confirmed the influence of adding graphics to dynamic message signs. Statistical analysis of 127 respondents from Rhode Island revealed a preference of graphic-aided messages over text-only messages. In addition, a graphical image was advised to be placed on the left side of the text on dynamic message signs. From simulation experiment results, differences were found in response time between males and females, as well as in old and young drivers.

There are several literatures attempting to evaluate VMS in terms of driver's attitudes and perceptions. For instance, Ran *et al.* (2004) conducted a survey to determine user awareness and perception of VMS on Wisconsin's freeways. Findings showed that route diversion would be considered if the VMS displayed at least 15 minutes increase in travel time on the current route and the cause of traffic delay was due to a crash, construction, or traffic congestion. Choocharukul (2006) surveyed a samples of motorists in Bangkok and found that the VMS information on VMS boards were comprehensible and useful. In addition, the diversion decision depended primarily on the amount of information provided on the VMS. Specifically, motorists would be most willing to divert given that the cause of delay is due to traffic accidents. In another study, the same dataset has been analyzed using structural equation modeling in order to investigate effects of attitudes and socioeconomic and travel characteristics on route diversion (Choocharukul, 2008). Findings revealed a direct relationship between stated route diversion and two of the attitudinal variables, namely, VMS comprehension and perceived usefulness of the VMS.

From the extant literature, it is indubitable that traffic information shown to motorists through VMS could be of usefulness to some extent. However, responses to such information might vary conditioning on several settings, including VMS types and socioeconomic and travel characteristics of motorists. This field of research is not full-fledged and hence needs further investigation.

3. METHODOLOGY

3.1 Study Location

In this study route choice decision of motorists in Bangkok is investigated. The Bangkok expressway system is taken as a case study. We focus on motorists who travel from Din Daeng to Dao Khanong district, which is considered as one of the major origin-destination pairs for daily commuting trips. There are two possible alternatives to travel from Din Daeng to Dao Khanong on the expressway system. Motorists could drive on the shorter 12-km path along the 1st stage Chalerm Maha Nakhon Expressway (Route 1). Alternatively, the 15-km 2nd stage Si Rat Expressway (Route 2) could be used, which is slightly longer in distance but holds a smaller propensity of traffic congestion. Figure 1 illustrates the study location.

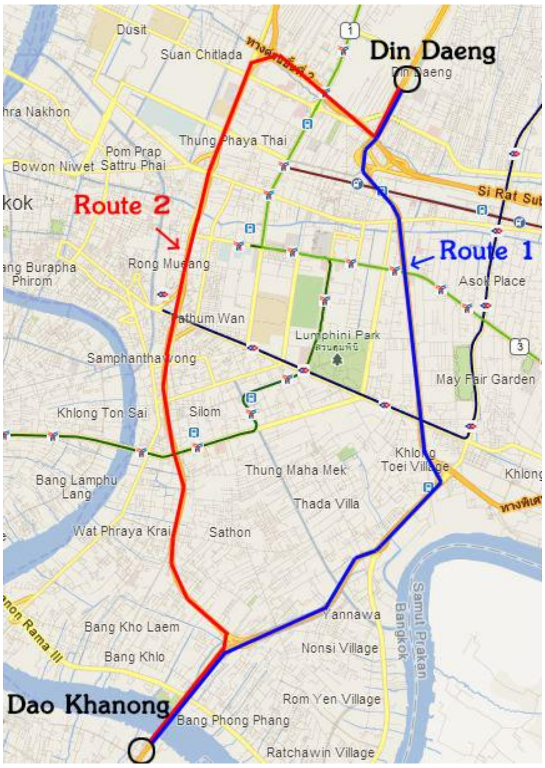

Figure 1. Study location

A questionnaire survey is utilized in the present study to capture impacts of traffic information on driver's route choice decision. The questionnaire contains four sections, including 1) socio-economic characteristics of respondents; 2) general attitudes and opinions towards VMS; 3) travel characteristics of respondents; and 4) stated preference questions regarding route choice decision.

3.2 Experimental Design

In the stated-preference section of the survey questionnaire, scenarios are classified into three categories, i.e. text-only or conventional VMS, color-coded or graphical VMS, and a combination of both.

In terms of experimental settings for text-only VMS, although several information types can be displayed, for instance, cause of traffic delay, direction of travel, duration of traffic delay, and recommended diversion route, only two lines of traffic information are permitted due to the physical constraint of VMS board. Here, in addition to the direction of travel that is shown on every VMS setting, we define three additional text-content types that were found to be of significance to motorists (Choocharukul, 2006). In the first type, traffic problem is reported (e.g. *"Din Daeng to Dao Khanong -- Heavy Traffic on 1st Stage Expy"*). The second content introduces recommended diversion route (e.g. *"Din Daeng to Dao Khanong -- Use 2nd Stage Expy"*), while the third content offers quantitative delay to motorists (e.g. *"Din Daeng to Dao Khanong -- 2nd Stage Expy – xx mins faster"*). A combination of the three contents yields 7 (2^3 -1) scenarios for text-only VMS.

Table 1 presents experimental settings for color-coded VMS. Three colors, i.e. red, yellow, and green, are graphically used to represent levels of traffic congestion on each link of both alternatives. It has been confirmed in the past study that only three levels of colors representing traffic conditions is appropriate for the study area (Tangittinunt and Choocharukul, 2009). The eight scenarios were replicated such that they conform to typical traffic situations observed in the field.

Table 1. Experimental settings for color-coded VMS

Scenarios	Route 1				Route 2		
	1	2	3	4	5	6	7
1	Green	Green	Green	Green	Green	Green	Green
2	Yellow	Yellow	Yellow	Yellow	Green	Green	Green
3	Yellow	Yellow	Red	Yellow	Green	Green	Green
4	Red	Red	Red	Green	Green	Green	Green
5	Red	Red	Red	Green	Yellow	Green	Green
6	Red	Red	Red	Green	Yellow	Green	Yellow
7	Red	Red	Yellow	Green	Yellow	Green	Green
8	Yellow	Red	Yellow	Green	Yellow	Green	Green

Note: Red, yellow, and green colors indicate severe, moderate, and no traffic congestion, respectively.

To further understand the interaction between these two VMS types, the last category of experimental settings combines both color and textual information. Under this setting, a total of 49 combinations is possible (7 color-coded VMS scenarios excluding "no congestion" case x 7 text-only VMS scenarios). Figure 2 presents an example of the signboard. Each participant will be presented 7 scenarios, plus one scenario where no congestion exists in the system. The presentation of the "no congestion" case where all links display green is for the purpose of validating motorist's choice preferences among two possible routes on the expressway.

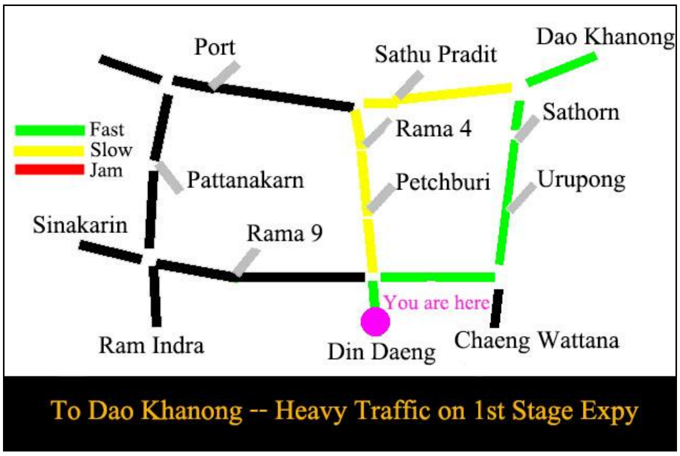

Figure 2. Example of color-coded and text VMS

3.3 Modeling Framework

To determine how motorists make route choice decision under various VMS settings, an ordered probability model is used to predict the probability of discrete data, i.e. five different choice decisions from "*Definitely stay on the same route*", "*Stay on the same route*", "*Uncertain*", "*Divert to alternative route*", and "*Definitely divert to alternative route*". The model can be derived by defining *z*, the unobserved dependent variable of theoretical interest that satisfies

$$z = \boldsymbol{\beta}\mathbf{X} + \varepsilon \tag{1}$$

Where $\mathbf{X}$ is a vector of socioeconomic and travel characteristic variables that determines the discrete ordering for each observation, $\boldsymbol{\beta}$ is a vector of estimable parameters, and ε is a random error term.

Let y be the observed route choice decision data, consisting of five categories. The relationship between y and z for each observation can be shown as follows:

$$\begin{aligned} y &= 1 \quad \text{if } z \le \mu_1 \\ y &= 2 \quad \text{if } \mu_1 < z \le \mu_2 \\ y &= 3 \quad \text{if } \mu_2 < z \le \mu_3 \\ y &= 4 \quad \text{if } \mu_3 < z \le \mu_4 \\ y &= 5 \quad \text{if } z > \mu_4 \end{aligned} \tag{2}$$

where μ_1, μ_2, μ_3 and μ_4 are the estimable thresholds that separate each level of y. If the error term is further assumed to be standardized normally distributed across observations with mean = 0 and variance = 1, i.e., $\varepsilon \sim$ N(0, 1), an ordered probit model estimating cumulative normal distribution of y from low to high has the form (Washington *et al.*, 1996):

$$\begin{aligned} P(y=1) &= \Phi(\mu_1 - \boldsymbol{\beta}\mathbf{X}) \\ P(y=2) &= \Phi(\mu_2 - \boldsymbol{\beta}\mathbf{X}) - \Phi(\mu_1 - \boldsymbol{\beta}\mathbf{X}) \\ P(y=3) &= \Phi(\mu_3 - \boldsymbol{\beta}\mathbf{X}) - \Phi(\mu_2 - \boldsymbol{\beta}\mathbf{X}) \end{aligned} \tag{3}$$

$$P(y=4)=\Phi(\mu_4-\boldsymbol{\beta}\mathbf{X})-\Phi(\mu_3-\boldsymbol{\beta}\mathbf{X})$$
$$P(y=5)=1-\Phi(\mu_4-\boldsymbol{\beta}\mathbf{X})$$

Where $\Phi(u)$ denotes the cumulative standard normal density function,

$$\Phi(\mu)=\frac{1}{\sqrt{2\pi}}\int_{-\infty}^{u} e^{-\frac{1}{2}w^2}\,dw \tag{4}$$

4. RESULTS

4.1 Descriptive Statistics

A total of 337 questionnaires were collected during August 2010 at the rest area near expressway toll plazas in Bangkok. Table 2 presents respondent's socio-economic characteristics. Most of the respondents are male and aged between 26 and 45 years. Approximately half of the respondents are college graduate.

In terms of travel characteristics, about half of the trips are work-related, while over one-third are commute trips. Over one-third of the respondents use the expressway between 6 and 10 times per week, while about 31 percent use the expressway more than 10 times per week. The high frequency of expressway usage could presumably signify expressway familiarity of motorists. Lastly, the majority of the respondents drive about 51-100 kilometers in a day.

Table 2. Respondent's socioeconomic and travel characteristic data

Attribute	Range	%	Attribute	Range	%
Gender	Female	29.7	Trip Purpose	Commute	37.7
	Male	70.3		Work-related	52.5
				Others	9.8
Age	< 26	8.1			
	26-35	45.4	Weekly Frequency of Expressway Usage	< 6 times	33.2
	36-45	30.1		6-10 times	35.7
	46-55	11.3		11-20 times	30.5
	≥ 55	5.1		>20 times	0.6
Education	High School or less	17.5	Daily Mileage (km)	< 51	26.7
	Some College	8.9		51-100	44.5
	College Graduate	54.3		101-200	20.2
	Post Graduate	19.3		> 200	8.6

4.2 Modeling Results

4.2.1 Text-only VMS

The model estimation results for text-only VMS are shown comparatively in Models 1.1 and 1.2 in Table 3. The overall goodness-of-fit measures are 0.005 and 0.127 for the first and second estimated models, respectively. In the first model, the effect of VMS contents on route choice decision is tested. At 95 percent confidence level, none of the contents is found to be of statistical significance.

The second model (Model 1.2) attempts to incorporate respondent's socioeconomic and travel characteristics. Significant variables include age of respondents, expressway usage frequency, car use frequency, driving speed, route frequency, and attitudes on the usefulness of VMS. Respondents of older age who drive and use expressway frequently are more likely to switch to the alternate route. On the other hand, those who drive at a higher speed and those who are familiar with the current route would have a higher tendency to stay on the current route. In terms of respondent's attitude, it is found that those who perceive the VMS to be useful will be more likely to trust the sign board and hence are more likely to divert to alternate route.

Table 3. Modeling results for text-only VMS

Variables	Model 1.1		Model 1.2	
	Coefficients	p-value	Coefficients	p-value
Traffic problem content on VMS (1 if yes, 0 otherwise)	0.206 (1.84)	0.066	-	n.s.
Recommended route content on VMS (1 if yes, 0 otherwise)	0.191 (1.70)	0.089	-	n.s.
Quantitative delay content on VMS (1 if yes, 0 otherwise)	0.088 (0.79)	0.431	-	n.s.
Age of respondents (years)	-	-	0.016 (2.25)	0.025
Expressway usage frequency (times/week)	-	-	0.038 (2.78)	0.005
Car use frequency (times/week)	-	-	0.316 (5.82)	0.000
Driving speed on expressway (km/hr)	-	-	-0.022 (5.32)	0.000
Route familiarity (1 if frequently use the study route, 0 otherwise)	-	-	-0.303 (2.28)	0.022
Usefulness of VMS (1 if agree, 0 otherwise)	-	-	0.536 (3.92)	0.000
Threshold μ_1	-1.456 (9.41)	0.000	-1.263 (1.99)	0.049
Threshold μ_2	-1.262 (8.47)	0.000	-1.020 (1.62)	0.091
Threshold μ_3	-1.123 (7.67)	0.000	-0.871 (1.39)	0.188
Threshold μ_4	-0.482 (3.42)	0.000	-0.154 (0.25)	0.478
No. of observations	630		588	
Log likelihood at zero	-482.796		-434.631	
Log likelihood at convergence	-480.192		-379.339	
ρ^2 / Corrected ρ^2	0.005 / 0.002		0.127 / 0.104	

Note: n.s. = not significant. Numbers in parentheses denote t-statistics.

4.2.2 Color-coded VMS

Table 4 presents modeling results for color-coded VMS. Under this setting, we test the effect of color-coded traffic information by assigning an ordinal score of 0, 1, and 2 representing congestion level on links associated with green, yellow and red color, respectively. Thus, a congestion level of 1.00 would indicate all links on a given path displaying red on VMS. On the other hand, a congestion level of 0.00 would represent a no-congestion situation on a given path, where all links display green. The relative index is used as one of the independent variables signifying the difference in congestion level between Route 1 and Route 2. In this study, it should be noted that Route 2 is always less congested than Route 1 in all scenarios as shown in Table 1, resulting in a non-negative value for this variable.

Table 4. Modeling results for color-coded VMS

Variables	Model 2.1		Model 2.2	
	Coefficients	p-value	Coefficients	p-value
Difference in congestion level between Route 1 and Route 2	3.148 (11.42)	0.000	3.408 (11.41)	0.000
Trip purpose is commuting (1 if yes, 0 otherwise)	-	-	0.273 (2.02)	0.043
Pre-trip traffic information (1 if know, 0 otherwise)	-	-	0.470 (3.73)	0.000
Car use frequency (times/week)	-	-	0.205 (3.68)	0.000
Driving experience (years)	-	-	0.015 (2.03)	0.042
Driving speed on expressway (km/hr)	-	-	-0.012 (3.00)	0.003
Motorists usually observe color-coded VMS (1 if yes, 0 otherwise)	-	-	0.314 (1.88)	0.060
Threshold μ_1	0.2444 (1.84)	0.000	1.046 (1.59)	0.075
Threshold μ_2	0.342 (2.56)	0.000	1.149 (1.75)	0.070
Threshold μ_3	0.460 (3.41)	0.000	1.254 (1.91)	0.055
Threshold μ_4	1.029 (7.45)	0.000	1.865 (2.83)	0.004
No. of observations	552		512	
Log likelihood at zero	-549.944		-508.658	
Log likelihood at convergence	-477.843		-416.876	
ρ^2 / Corrected ρ^2	0.131 / 0.122		0.180 / 0.159	

Note: Numbers in parentheses denote t-statistics.

In Model 2.1, only the difference in congestion level between Route 1 and Route 2 is tested. It can be observed from the modeling results that this variable is statistically significant. Motorists on Route 1 would have a higher tendency to divert to Route 2 when the difference in congestion level between Route 1 and Route 2 is more pronounced. Therefore, the color-coded traffic information significantly affects route choice decision for motorists and can be used as an efficient way to manipulate traffic diversion. The overall goodness-of-fit measure, the rho-square value, is found to be 0.131.

In Model 2.2, the rho-square value of 0.180 is slightly higher than the previous model. Statistically significant socioeconomic and travel characteristic variables consist of trip purpose, pre-trip traffic information, car use frequency, driving experience, driving speed, and behavior of motorists whether or not the color-coded VMS is usually observed. Respondents who take the expressway for commuting purpose, have more driving experiences, and use car more frequently would have a higher probability to divert to the alternate route. On the other hand, those who maneuver at a higher speed on the expressway would prefer to stay on the current route. Under this model, the pre-trip information also appears to be of significance, i.e. respondents who get such information from sources like radio or Internet would be more likely to abide by the traffic information shown on VMS. In addition, the color-coded VMS would be more beneficial in terms of diversion for respondents who usually observe the VMS board.

4.2.3 Color-coded and Text VMS

Table 5 presents the modeling results when a combination of color-coded and text information are shown on VMS board. The first model includes text and color-coded contents, while the second model incorporates socioeconomic and travel characteristic variables. Under this situation, it can be observed that both color-coded traffic information and text message work in tandem, i.e. motorists would have a higher tendency to make a diversion when such combined traffic information is shown. In terms of text content displays, the recommended route information has the largest estimated coefficients, implying the highest propensity of route choice diversion when recommended route content is displayed on VMS.

As for the socioeconomic and travel characteristic variables, Model 3.2 indicates that significant variables include respondent’s occupation, frequency of expressway usage, daily distance traveled, and knowledge of pre-trip traffic information. Furthermore, when respondents usually observe the color-coded VMS and think that VMS has influence for their travel, a higher propensity of route diversion can be expected. The overall goodness-of-fit measures are found to be 0.041 and 0.068 for Models 3.1 and 3.2, respectively.

5. DISCUSSION AND CONCLUSION

It can be seen from the findings in this study that traffic messages shown on different types of VMS could yield different effects in terms of route choice decision. When only text messages are displayed on VMS, modeling results indicate that none of the traffic content considered in the present study, including traffic problem, recommended route and quantitative delay, is statistically significant at 95 percent confidence, although traffic problem and recommended route contents are significant at 90 percent confidence level. In contrast, the color-coded VMS displayed using three colors for three different degrees of traffic congestion is found to significantly affect route choice decision.

Another noteworthy point in the study is observed when traditional text-only VMS is combined with graphical information. We found that motorists would be more likely to make a diversion when such combined traffic information is shown. Under this circumstance, the recommended route content is the most significant among three kinds of message contents. Nevertheless, it can be noticed that the goodness-of-fit measures are slightly lower than those color-coded VMS models. Therefore, text traffic contents should be employed with caution.

Table 5. Modeling results for color-coded and text VMS

Variables	Model 3.1		Model 3.2	
	Coefficients	p-value	Coefficients	p-value
Difference in congestion level between Route 1 and Route 2	1.166 (5.68)	0.000	1.233 (5.74)	0.000
Traffic problem content on VMS (1 if yes, 0 otherwise)	0.154 (1.99)	0.046	0.162 (2.02)	0.044
Recommended route content on VMS (1 if yes, 0 otherwise)	0.225 (2.90)	0.004	0.236 (2.91)	0.004
Quantitative delay content on VMS (1 if yes, 0 otherwise)	0.215 (2.74)	0.006	0.223 (2.72)	0.007
Occupation (1 if Owned business, 0 otherwise)	-	-	-0.298 (3.65)	0.000
Pre-trip traffic information (1 if know, 0 otherwise)	-	-	-0.286 (3.04)	0.002
Expressway usage frequency (times/week)	-	-	-0.018 (2.09)	0.036
Daily Distance Traveled (km)	-	-	0.002 (3.30)	0.001
Motorists usually observe color-coded VMS (1 if yes, 0 otherwise)	-	-	0.338 (3.33)	0.001
Motorist's opinion if VMS has influence on route choice decision (1 if yes, 0 otherwise)	-	-	0.321 (3.37)	0.001
Threshold μ_1	0.393 (4.14)	0.000	0.751 (4.53)	0.000
Threshold μ_2	0.442 (4.66)	0.000	0.806 (4.86)	0.000
Threshold μ_3	0.553 (5.81)	0.000	0.924 (5.56)	0.000
Threshold μ_4	0.831 (8.63)	0.000	1.208 (7.21)	0.000
No. of observations	1074		1018	
Log likelihood at zero	-1223.499		-1156.074	
Log likelihood at convergence	-1173.566		-1076.934	
ρ^2 / Corrected ρ^2	0.041 / 0.034		0.068 / 0.056	

Note: Numbers in parentheses denote t-statistics.

From the modeling results, certain socioeconomic and travel characteristics are found to have statistical importance. Route familiarly, car use frequency, and driving experience are examples of variables that could affect the propensity of route diversion. Besides, motorist's perceptions such as the usefulness of VMS are also found to be of statistical significance. Therefore, highway engineers and operators could potentially employ these factors to manage route choice selection on expressways. In addition, since the different diversion behavior is observed in different settings of VMS displays, it is sensible to pinpoint the most appropriate VMS layouts before field implementation. From the current study, using merely text VMS displays may not be advantageous to motorists in terms of route choice diversion.

It should be noted also that in reality motorists may not have perfect traffic information since some motorists may not observe or understand such VMS contents. This issue poses more challenges in effectively managing traffic diversion. Another important issue is the validity of traffic data. This study assumes that traffic information shown on VMS is accurate; however, in reality this situation might not be true.

The current study could help developing appropriate contents for VMS display that are useful, correct, and consistently meet motorist's demand. However, findings are yet definite and several aspects can be further examined in future research. First, congestion index used in the present study is basically obtained from the average of all links in a route. Motorist's decision to divert may possibly depend only on some specific links. Secondly, the ordered probit models used in the present study assume that decisions can be made in five ordinal degrees from "*Definitely stay on the same route*" to "*Definitely divert to alternative route*". Further study is needed to justify these categorical responses. Lastly, while certain variables have influence on route diversion, there are a number of motorists who are captive and do not change their travel route regardless of traffic contents shown on VMS. Such driving behaviors, perhaps due to route familiarity or driving habits, deserve further investigation.

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