A STUDY OF HIGHWAY DRIVERS' DEMAND OF REAL-TIME TRAFFIC INFORMATION FOR MAIN TRAVELLING HIGHWAYS AND ALTERNATIVE ROUTES

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ABSTRACT

A computer-aided survey was designed and conducted face-to-face to obtain the demand and reasonable pricing of customized real-time traffic information under three traffic conditions for highway drivers in Taiwan. Bivariate ordered probit models were estimated to investigate factors that significantly influence the demand of traffic information both for main travelling highways and secondary alternative routes. The results indicated that the demand of traffic information for non-recurrence condition was the strongest. Basic information was the main type for normal and recurrence conditions, while dynamic travel time prediction was the one for non-recurrence condition. The estimation results from bivariate ordered probit models showed that both the way of providing information (node to node) and higher willingness to pay for information will increase the demand for traffic information for main travelling highways and secondary alternative routes. Finally, the significant and positive correlations of models imply the fact that the higher demand of traffic information for main travelling highway is, so is the secondary alternative routes.
Keywords: customized real-time traffic information, pricing, bivariate ordered probit model.

1. INTRODUCTION

ATIS (Advanced Traveler Information Systems) refer to systems that integrate advanced communication technologies to assist in trip planning, acquire travel-related information, reduce travel time, and lower travel cost. These technologies include Dynamic Message Signs (DMS), Highway Advisory Radio (HAR), Global Positioning System (GPS), Geographic

Information System (GIS), in-vehicle navigation system, wireless communications, TV and radio reports of route conditions, travel service information, and Integrated Service Digital Network (ISDN).

ATIS can provide highway drivers real-time traffic information before and during their trips. It is therefore important to study the effects of real-time traffic information on drivers' behaviour. There have been many studies focused on drivers' behaviour in response to real-time traffic information (Abdel and Abdalla, 2004; Adler, 2001; van Driel et al., 2007; Jou et al., 2004, 2005, 2007; Khattak et al., 2003; Liu and Mahmassani, 2000; Srinivasan and Mahmassani, 2003), however, little research paid attention to the aspect of "customized" real-time traffic information.

The primary concept underlying one-to-one marketing is the emphasis on differentiation of service in light of the varying needs of customers. The objective of customization is to create customer values, satisfy the individual's need and avoid unnecessary waste and expenditure of producers (Lin, 2007). Vaughn (1999) mentioned that driver's needs should be understood by using a customer database first before developing a model for travel time planning. Each customer's trips and route preferences within a specific time should be collected using a learning mechanism and then incorporated into the database to provide customized travel time planning. Chung (2004) further indicated that customized information shall be more personalized and can be transferred via interactions. Hence, private companies or public departments in some countries, such as the United States and the United Kingdom, have offered the opportunities to provide real-time traffic information according to travellers' specific requests, i.e., the customized real-time traffic information (CRTTI). Although there are many technologies as mentioned above can provide CRTTI, only in-vehicle navigation system is our main focus in this study.

A computer-aided survey was designed and conducted face-to-face in rest areas along highways to obtain the demand and pricing for CRTTI under different traffic conditions from the perspective of highway drivers in Taiwan. Three traffic conditions, smooth, recurrent congested, non-recurrent congested, were included in this survey to investigate their influences on CRTTI's demand. A framework known as contingent valuation method, (CV) offers a way of investigating the driver's willingness to pay (WTP) for CRTTI. In addition, respondents are further asked to specify two routes which are the most often and second often travelled (main and alternative routes). Because the number of information demanded are ordered-scale data and practically there are correlations between information demanded on both routes, bivariate ordered probit model that can capture the correlation between two dependent variables (routes) is applied in this paper. The variables influencing the demand for CRTTI on these two routes can also be investigated.

The remainder of this paper is organised as follows: Section 2 explains the methodology of bivariate ordered profit model. Section 3 describes questionnaire design and presents data analysis results. Section 4 provides the model estimation results. Conclusions and suggestions are proposed in Section 5.

2. MODEL FRAMEWORK

Ordered probit model is derived from binary probit model and assuming that error term is standard normal distribution (Mckelvey and Zavoina, 1975). The basic framework is given in Eq.(1).

$$y^{*} = \beta^{'} x + \varepsilon \tag{1}$$

Where y^{*} is an unobserved latent and continuous choice, in this study, it is defined as the number of real-time information needed by highways' drivers. β is the vector of parameters to be estimated; and x and ε are vectors of explanatory variables and error term, respectively. In this study, the number of CRTTI needed by highways' drivers is observed as a discrete category (y_i), given as follows:

$$y_i = \begin{cases} 0, \; if \;\; y_i^{*} \le 0 \\ 1, \; if \;\; 0 < y_i^{*} \le \mu_1 \\ 2, \; if \;\; \mu_1 < y_i^{*} \le \mu_2 \\ 3, \; if \;\; \mu_2 < y_i^{*} \le \mu_3 \\ \vdots \\ J, \; if \;\; \mu_{J-1} < y_i^{*} \end{cases} \tag{2}$$

Where $\mu_1, \dots, \mu_{J-1}$ are parameters to be estimated and J is the number of CRTTI needed by highways' drivers. Assuming that the error term ε_i is normally distributed with N(0,1). The probabilities of number of CRTTI needed by highways' drivers are shown as Eq.(3):

$$\begin{aligned} P(y_i = 0) &= \int_{-\infty}^{-\beta_i^{'} x_i} \phi\left(\varepsilon_i\right) d\varepsilon_i = \Phi(-\beta_i^{'} x_i) \\ P(y_i = 1) &= \int_{-\beta_i^{'} x_i}^{\mu_1 - \beta_i^{'} x_i} \phi\left(\varepsilon_i\right) d\varepsilon_i = \Phi(\mu_1 - \beta_i^{'} x_i) - \Phi(-\beta_i^{'} x_i) \\ P(y_i = 2) &= \int_{\mu_1 - \beta_i^{'} x_i}^{\mu_2 - \beta_i^{'} x_i} \phi\left(\varepsilon_i\right) d\varepsilon_i = \Phi(\mu_2 - \beta_i^{'} x_i) - \Phi(\mu_1 - \beta_i^{'} x_i) \\ &\vdots \\ P(y_i = J) &= \int_{\mu_{J-1} - \beta_i^{'} x_i}^{\infty} \phi\left(\varepsilon_i\right) d\varepsilon_i = 1 - \Phi(\mu_{J-1} - \beta_i^{'} x_i) \end{aligned} \tag{3}$$

Where ϕ and Φ are the standard normal probability density and cumulative distribution functions, respectively.

The bivariate ordered probit model is an extension of the univariate ordered probit model. Two dependents variables are considered, y_{1i} and y_{2i}, with two random error terms, ε_{1i} and ε_{2i}, normally distributed and correlated between each other. The general form of probability is given as Eq.(4):

$$
\begin{aligned}
&\Pr\left(k_i \le y_{1i} \le l_i,\ m_i \le y_{2i} \le n_i\right)\\
&= \int_{\mu_{2,\,m_i-1}-\beta_2 x_{2i}}^{\mu_{2n_i}-\beta_2 x_{2i}} \int_{\mu_{1,\,k_i-1}-\beta_1 x_{1i}}^{\mu_{1l_i}-\beta_1 x_{1i}} \phi_2\left(\varepsilon_{1i},\varepsilon_{2i},\rho\right) d\varepsilon_{1i} d\varepsilon_{2i}\\
&= \Phi_2\left(\mu_{1l_i}-\beta_1 x_{1i},\mu_{2n_i}-\beta_2 x_{2i},\rho\right)\\
&\quad -\Phi_2\left(\mu_{1,k_i-1}-\beta_1 x_{1i},\mu_{2n_i}-\beta_2 x_{2i},\rho\right)\\
&\quad -\Phi_2\left(\mu_{1l_i}-\beta_1 x_{1i},\mu_{2,m_i-1}-\beta_2 x_{2i},\rho\right)\\
&\quad +\Phi_2\left(\mu_{1,k_i-1}-\beta_1 x_{1_i},\mu_{2,m_i-1}-\beta_2 x_{2i},\rho\right)
\end{aligned} \tag{4}
$$

Supposing y_{1i} and y_{2i} are discrete observed categories which represent the numbers of CRTTI needed by highways' drivers for main and alternative routes, respectively. The log-likelihood function of bivariate model considering both main and alternative routes is given as Eq.(5):

$$
\begin{aligned}
LL = &\sum_{i\in main} \ln\left\{\Phi\left(\mu_{1l_i}-\beta_1 x_{1i}\right)-\Phi\left(\mu_{1,k_i-1}-\beta_1 x_{1i}\right)\right\}\\
&+\sum_{i\in alter} \ln\left\{\Phi_2\left(\mu_{1l_i}-\beta_1 x_{1i},\mu_{2n_i}-\beta_2 x_{2i},\rho\right)\right.\\
&-\Phi_2\left(\mu_{1,k_i-1}-\beta_1 x_{1i},\mu_{2n_i}-\beta_2 x_{2i},\rho\right)\\
&-\Phi_2\left(\mu_{1l_i}-\beta_1 x_{1i},\mu_{2,m_i-1}-\beta_2 x_{2i},\rho\right)\\
&\left.+\Phi_2\left(\mu_{1,k_i-1}-\beta_1 x_{1_i},\mu_{2,m_i-1}-\beta_2 x_{2i},\rho\right)\right\}
\end{aligned} \tag{5}
$$

Where main and alter are the numbers of CRTTI needed by highways' drivers for main and alternative routes, respectively. The parameters, β_1, $\mu_{1,\cdot}$, β_2, and $\mu_{2,\cdot}$ and ρ are to be estimated, by the maximum likelihood estimation (MLE) method.

To provide more insight into the implications of the bivariate ordered probit estimation results, elasticities of demand on quantities of CRTTI are analyzed for both main and alternative routes. The elasticity of continuous independent variables is given as:

$$
\begin{aligned}
E_{x_{ain}}^{\Pr(y_{ai}=j)} &= \frac{\partial \ln \Pr\left(y_{ai}=j\right)}{\partial \ln x_{ain}}\\
&= \frac{\phi\left(\mu_{a,j-1}-\beta_a x_{ai}\right)-\phi\left(\mu_{aj}-\beta_a x_{ai}\right)}{\Phi\left(\mu_{aj}-\beta_a x_{ai}\right)-\Phi\left(\mu_{a,j-1}-\beta_a x_{ai}\right)}\beta_{an} x_{ain}
\end{aligned} \tag{6}
$$

Where x_{ain} is the nth explanatory variable of driver i and β_{an} is the corresponding coefficient estimate of main route (a=1) and the alternative route (a=2). A pseudo-elasticity is calculated for the indicator independent variables to provide an approximate elasticity. The pseudo-elasticity is defined as follows:

$$E_{x_{ain}}^{\Pr(y_{ai}=j)} = \frac{\left\{\left(\Phi\left[\mu_{aj} - \left\{\beta_a x_{ai} + \beta_{an}\left(1 - x_{ain}\right)\right\}\right] - \Phi\left[\mu_{a,j-1} - \left\{\beta_a x_{ai} + \beta_{an}\left(1 - x_{ain}\right)\right\}\right]\right) - \left[\Phi\left\{\mu_{aj} - \left(\beta_a x_{ai} - \beta_{an} x_{ain}\right)\right\} - \Phi\left\{\mu_{a,j-1} - \left(\beta_a x_{ai} - \beta_{an} x_{ain}\right)\right\}\right]\right\}}{\Phi\left(\mu_{aj} - \beta_a x_{ai}\right) - \Phi\left(\mu_{a,j-1} - \beta_a x_{ai}\right)} \quad (7)$$

3. DATA SURVEY AND ANALYSIS

3.1 Questionnaire design and survey

3.1.1 Questionnaire design

To survey highway drivers' willingness to pay for CRTTI, a questionnaire was designed using computer language C#. This questionnaire consisted of three parts, including (1) socioeconomic characteristics, (2) trip characteristics, and (3) contexts of CRTTI. The survey process is illustrated in Figure 1 and explained as follows:

1. Socioeconomic characteristics:

This part collected each respondent's basic data including gender, age, education background, marital status, occupation, job position, working schedule, average monthly income, number of vehicles possessed, and dwelling place.

2. Trip characteristics:

This part collected the trip characteristics related to highway drivers, including the main purpose of frequent highway trips, access and exit interchanges, frequency of using highways, familiarity with traffic conditions, traffic conditions occurred most, tendency to take alternative routes in the event of congestion, and familiarity with other alternative routes (national highways, expressways, provincial roads or regional roads).

Respondents were also asked about whether they have installed an in-vehicle navigation system. Those with an in-vehicle navigation system were required to answer the following additional questions: (a) Is your navigation system equipped with a TMC receiver? If yes, are you satisfied with the TMC function? (b) Are you satisfied with the current in-vehicle navigation system, and how often do you use it for highway trips? Besides, respondents were also asked about w whether in-vehicle navigation system should be assisted by real-time traffic information, which levels of roads should be covered in the provision of real-time traffic information, and what kind of information presentation method they prefer (from node to node or from current position to the destination).

3. Contents of CRTTI:

Drivers' willingness to pay for CRTTI was surveyed through following steps: (a) Respondents were asked about whether they were willing to pay for real-time traffic information in different conditions of traffic follows (smooth, recurrent congestion, and non-recurrent congestion). (b) Drivers who stated that they were willing to pay for real-time traffic information were then asked to select the real-time traffic information they preferred to receive when driving on the main route and on the alternative route, respectively. There were five types of real-time traffic information, including basic information, dynamic estimation of travel time, delay of travel time, route navigation (with no time delay information), and others (available for respondents to fill in the type of traffic information they preferred). (c) Respondents were then asked to evaluate their willingness to pay for each type of traffic information they have ticked by using CV method (please refer to Joseph (2002) for more details). It shall be noted that the basic information includes the free flow speed, weather conditions, traffic control, road construction, traffic accident, and road sections with pits or objects fallen from vehicles, and delay of travel time is the difference between dynamic estimation of travel time and travel time of free flow.

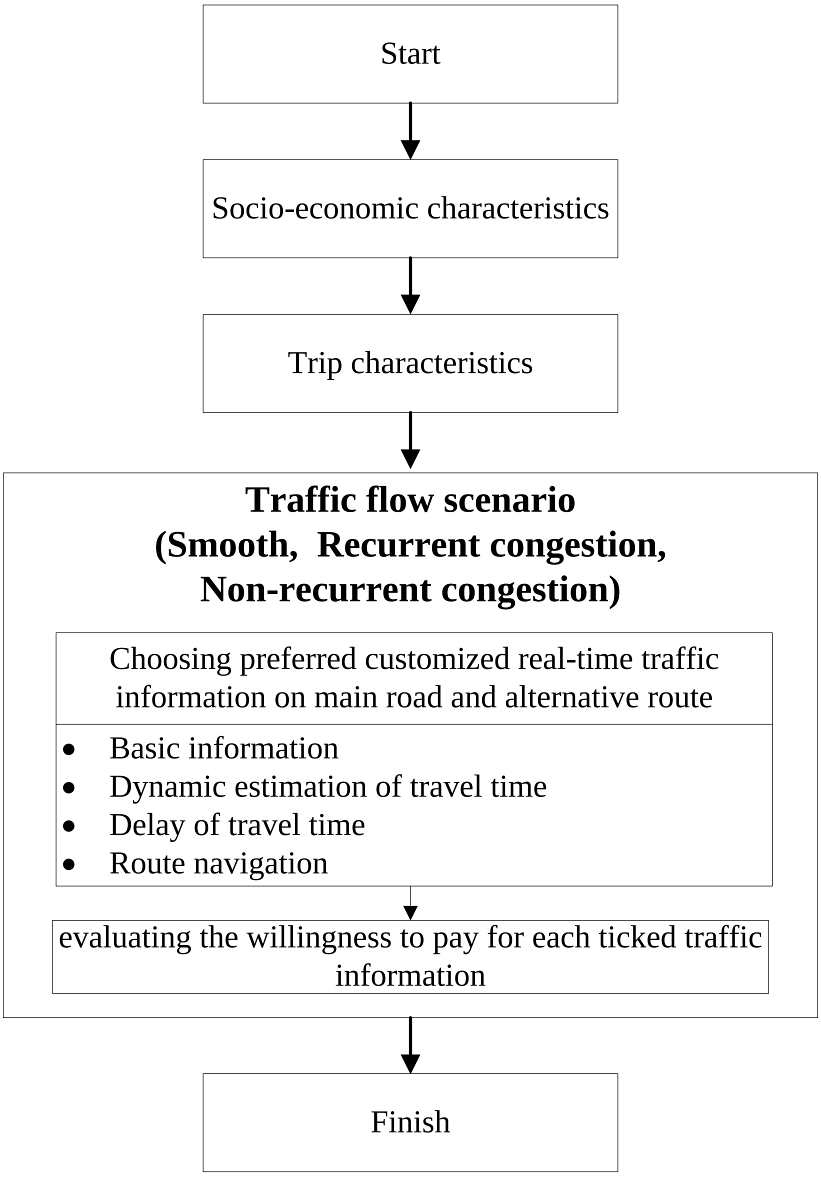

Figure 1 –Flow chart of the driver's response in questionnaire

3.1.2 Data survey

The data were collected through interviews with respondents at rest areas of national highways using a computer-aided questionnaire. The selected rest areas included Tai-an service area and Hsinyin service area on national highway 1 and Chingshui service area and Dongsan service area on the national highway 3. The survey was conducted on weekdays (Mon.~Fri.) in 2009. A total of 451 respondents were collected, and 446 of them were valid.

3.2 Data analysis

1. Socioeconomic characteristics:

The results of the respondents' socioeconomic characteristics are shown in Table 1. The samples comprise of mainly male drivers (83%), mostly aged 31~40 (33%). The second and third largest age groups are 21~30 years old (29%) 41~50 years old (24%). Most of the respondents possess only one vehicle. Most of them have received university (37%) or college education (21%), and 56% are married. In terms of job positions, general employees constitute the largest group (47%), while supervisors constitute the second largest (28%). The difference between respondents working flexible hours and those working fixed hours is 12.8%. Most of the respondents have fixed working hours. Their average monthly income concentrates in the range of $625~1,563 (60%), and the overall average is $1,548. Besides, 70% of the respondents own the vehicle they use for the current trip.

2. Trip characteristics:

The analysis result of trip characteristics is presented in Table 2. Most of the respondents use national highways mainly for business (44%) and leisure (35%) purposes. 72% of them are either "familiar" or "fully familiar" with route conditions. In their experience of using national highways, traffic conditions are mostly "very smooth" (27%) and "smooth" (53%). When asked about the frequency of using national highways, about 78% stated that they use them at least one time per month, and only 14% said they use them at least one time per day. It can be inferred that most highway drivers use highways on a regular basis but may be uncertain about detailed and dynamic changes in traffic conditions on highways. They may have better driving experiences if provided with real-time traffic information. The further analysis of their decisions in the event of congestion yields a noticeable result. About 51% of the respondents will take alternative routes (including those who always and usually will), and about 40% will not. This result shows that the majority of drivers will divert to alternative routes in the event of congestion on highways. If provided with CRTTI, they may be more likely to divert to alternative routes. As a result, the total travel time of individual drivers can be reduced. This can be one of the solutions to congestion in highway systems. In terms of familiarity with alternative routes, only 19% of the respondents are either "unfamiliar" or "very unfamiliar" with alternative expressways, and 30% are "very unfamiliar" with local routes. It can be inferred that drivers on highways are more likely to directly take alternative routes in face of congestion. Hence, drivers' behaviour in this highway system is an intriguing and practical issue.

Table 1 Socioeconomic characteristics of respondents

Variable	Item	Sample (%)	Variable	Item	Sample (%)
Gender	Female	74(16.6)	Education	Junior high or below	17(3.8)
	Male	373(83.4)		Senior high	84(18.8)
Age	18-20	8(1.8)		Junior college	95(21.3)
	21-30	130(29.1)		Campus	165(36.9)
	31-40	149(33.3)		Graduate school or above	86(19.2)
	41-50	108(24.2)	Marriage	Single	197(44.1)
	51-60	48(10.7)		Married	250(55.9)
	Above 61	4(0.9)	Personal monthly income (USD)*	Below 313	27(6.2)
Career position	Supervisor	123(27.5)		313-625	23(5.2)
	Responsible person	39(8.7)		625-938	87(19.8)
	Others	28(6.3)		938-1250	101(23)
	Job waiting	12(2.7)		1250-1563	76(17.3)
	Student	34(7.6)		1563-1875	39(8.9)
	Employee	211(47.2)		1875-2188	20(4.6)
Working time	Flexible time	195(43.6)		2188-2500	17(3.9)
	Fixed shift	252(56.4)		2500-2813	4(0.9)
Car ownership	0	54(12.1)		2813-3125	30(6.8)
	1	318(71.1)		3125-4688	5(1.1)
	2	58(13.0)		4688-6250	6(1.4)
	3	13(2.9)		6250-7813	1(0.2)
	4	4(0.9)		Above 7813	3(0.7)

*1 US$ = 32 NT$ (Central bank of the republic of Taiwan, 2008)

The analysis of drivers' satisfaction with in-vehicle navigation systems indicates that most of them give a neutral response (53%), and about one third of them (33%) are unsatisfied. This finding reveals that there is still room for further improvement and development of navigation systems in Taiwan. The analysis of drivers' use of TMC-equipped navigation systems shows that only 31% of the drivers have a TMC-equipped navigation device, and most of them are neither unsatisfied nor satisfied with TMC (66%). In general, most of the drivers still access real-time traffic information from VMS, radio or by calling the centre for route conditions. Therefore, through research of CRTTI and analysis of impacts of highway drivers' use of CRTTI, we can provide an important reference on planning of information providing strategies and planning of future policies.

Besides, most of the respondents (25%) stated that they use navigation systems 2 out of 10 times they drive on highways. This is an expected finding, because highway networks are simpler for drivers to divert to alternative routes and most respondents are familiar with other highway systems. Regarding the question about whether in-vehicle navigation devices should be assisted by real-time traffic information, most respondents (64%) agree (including "necessary" and "very necessary"). In terms of coverage of traffic information, about 50% of the respondents mention that the coverage should be extended to at least local roads.

Table 2 Trip characteristic description statistic (percentage in parenthesis)

Variable	Item	Sample (%)	Variable	Item	Sample (%)
Trip purpose	Leisure	158(35.3)	Highway usage	Seldom	98(21.9)
	Working related	198(44.3)		Once a month	82(18.3)
	Visiting relatives or friends	45(10.1)		Bi-weekly	45(10.1)
	Home	36(8.1)		Once a week	80(17.9)
	Others	10(2.2)		Every two to three days	79(17.7)
Familiar route condition	Completely unfamiliar	3(0.7)		Everyday	63(14.1)
	Unfamiliar	27(6.0)	Using alternative route	Not at all	57(12.8)
	Normal	94(21.0)		Seldom	123(27.5)
	Familiar	139(31.1)		Normal	40(8.9)
	Completely familiar	184(41.2)		Occasionally	149(33.3)
Served highway traffic condition	Awfully congested	5(1.1)		Often	78(17.4)
	Congested	13(2.9)	Familiar alternative highway routes	Completely unfamiliar	77(17.2)
	Normal	71(15.9)		Unfamiliar	9(2.0)
	Smooth	237(53)		Normal	31(6.9)
	Free moving	121(27.1)		Familiar	165(36.9)
Equipped in-vehicle navigation system	No	287(64.2)		Completely familiar	165(36.9)
	Equipped	160(35.8)	Familiar alternative routes	Completely unfamiliar	133(29.8)
Satisfaction level of in-vehicle navigation system	Very dissatisfied	1(0.6)		Unfamiliar	19(4.3)
	Dissatisfied	52(32.5)		Normal	15(3.4)
	Normal	84(52.5)		Familiar	181(40.5)
	Satisfied	18(11.3)		Completely familiar	99(22.1)
	Very satisfied	5(3.1)	Satisfaction level of TMC feature	Very dissatisfied	0(0.0)
In-vehicle navigation system with TMC feature	No	110(68.8)		Dissatisfied	4(8.0)
	Yes	Normal		Normal	33(66.0)
—				Satisfied	12(24.0)
				Very satisfied	1(2.0)

3. Information demands and prices

The respondents' demands for CRTTI and willingness to pay for each type of information are presented in Table 3, Table 4, and Table 5.

The respondents' demands for CRTTI in different conditions of traffic flows are analyzed in Table 3. Overall, in three traffic conditions, demands for information about the main route are greater than demands for information about the alternative route, and most of the respondents have no demand for CRTTI (information demand=0).

Table 3 the quantity demand of CRTTI under different traffic conditions (percentage in parenthesis)

Route	Quantity demand	Smooth	Recurrent congestion	Non-recurrent congestion
Main	0	369(82.6)	302(67.6)	234(52.3)
	1	18(4.0)	36(8.1)	57(12.8)
	2	21(4.7)	45(10.1)	67(15)
	3	12(2.7)	11(2.5)	23(5.1)
	4	27(6.0)	53(11.9)	66(14.8)
Alternative	0	375(83.9)	313(70)	257(57.5)
	1	20(4.5)	36(8.1)	56(12.5)
	2	16(3.6)	42(9.4)	52(11.6)
	3	12(2.7)	6(1.3)	21(4.7)
	4	24(5.4)	50(11.2)	61(13.6)
WTP sample (%)	—	76(17)	150(33.6)	215(48.1)

Respondents with no information demands in smooth flow of traffic account for the majority (83%). Recurrent congestion and non-recurrent congestion may increase highway drivers' information demands. Highway drivers' information demands significantly increase in the event of non-recurrent congestion, indicating that highway drivers are more likely to access real-time traffic information when uncertainty of external factors is high.

The types of real-time traffic information demanded by drivers in different flows of traffic are presented in Table 4. In the context with a normal flow of traffic or recurrent congestion, most respondents need the basic information (33%) and navigation information for the main route and the alternative route (27% and 29%). These figures manifest that drivers consider these two types of information (basic information + route navigation) as sufficient for driving on highways without any contingency. It can be inferred that information providers should prioritize these two types of traffic information in the provision of real-time traffic information. In the context with non-recurrent congestion, most respondents need mainly dynamic estimation of travel time (32%) and basic information (29%). Among the four types of traffic information, highway drivers in Taiwan are less favourable to travel time delay information. A plausible explanation is that this type of information is not most intuitive and thus inconvenient for use by drivers.

Table 4 Types of real-time traffic information demanded by drivers in different traffic conditions (percentage in parenthesis)

Route	Information category	Smooth	Recurrent congestion	Non-recurrent congestion
Main	Basic information	68(33.3)	125(33.7)	176(28.8)
	Dynamic travel time prediction	42(20.6)	79(21.3)	197(32.2)
	Dynamic travel time delay	39(19.1)	67(18.1)	96(15.7)
	Dynamic route guidance	55(27.0)	100(27.0)	143(23.4)
Alternative	Basic information	60(32.6)	111(32.8)	148(31.8)
	Dynamic travel time prediction	39(21.2)	72(21.3)	92(19.8)
	Dynamic travel time delay	31(16.8)	55(16.3)	83(17.8)
	Dynamic route guidance	54(29.3)	100(29.6)	142(30.5)

Respondents' willingness to pay for CRTTI in different traffic conditions is analyzed in Table 5. As shown in this table, the reasonable price of basic information is $0.338~0.369 per piece, the reasonable price of dynamic estimation of travel time is $0.319~0.363 per piece, the reasonable price of information about travel time delay is $0.319~0.397 per piece, and the reasonable price of route navigation is $0.309~0.338 per piece. The willingness to pay for each piece of CRTTI is approximately $0.175 higher than the average reasonable level. The willingness to pay for basic information is $0.497~0.547 per piece, the willingness to pay for dynamic estimation of travel time is $0.456~0.581 per piece, the willingness to pay for information about travel time delay is $0.488~0.622, and the willingness to pay for route navigation is $0.441~0.540 per service.

From the above figures, we can find that highway drivers can accept higher prices of CRTTI in the context with normal flows of traffic or in the context with recurrent congestion. Their willingness to pay for CRTTI in face of non-recurrent congestion is the lowest. A plausible explanation for this phenomenon is that drivers will take into account the total cost of receiving real-time traffic information. In the event of non-recurrent congestion, their information demands will be the highest, so the unit price of CRTTI they are willing to pay will be relatively lower.

Table 5 Respondents' willingness to pay for CRTTI in different traffic conditions (percentage in parenthesis)

Traffic condition	Information category	Samples (%)	Average reasonable price (USD)	Average WTP(USD)	Incremental (USD)
Smooth	Basic information	71(33.3)	0.344	0.547	0.203
	Dynamic travel time prediction	42(19.7)	0.363	0.581	0.219
	Dynamic travel time delay	40(18.8)	0.397	0.622	0.225
	Dynamic route guidance	60(28.2)	0.325	0.541	0.216
Recurrent congestion	Basic information	127(33.5)	0.338	0.497	0.159
	Dynamic travel time prediction	78(20.6)	0.331	0.494	0.163
	Dynamic travel time delay	69(18.2)	0.319	0.488	0.169
	Dynamic route guidance	105(27.7)	0.338	0.488	0.163
Non-recurrent congestion	Basic information	177(32.8)	0.369	0.534	0.166
	Dynamic travel time prediction	108(20.0)	0.319	0.456	0.138
	Dynamic travel time delay	101(18.7)	0.331	0.491	0.159
	Dynamic route guidance	154(28.5)	0.309	0.441	0.131

4. MODEL ESTIMATION RESULTS

The univariate and bivariate ordered probit models established in this paper are defined as follows: (1) S1 and S2 denote the demand for CRTTI about the main route and alternative route, respectively, in the context with a normal flow of traffic. (2) R1 and R2 denote the demand for CRTTI about the main route and alternative route, respectively, in the context with recurrent congestion. (3) NR1 and NR2 denote the demand for CRTTI about the main and alternative routes, respectively, in the context with non-recurrent congestion.

Variables are defined as follows and listed in Table 6: (1) Necessity of information assistance refers to whether the driver thinks that in-vehicle navigation devices should be assisted by real-time traffic information. This is a binary variable. 1 denotes that such assistance is necessary, while 0 denotes otherwise. (2) Information presentation method refers to how drivers prefer traffic information is presented. 1 denotes that the driver prefers information presented from node to node, while 0 denotes that the driver prefers information presented from the current location to the destination. (3) Willingness to pay: 1 denotes that the driver is willing to pay a certain amount of money for CRTTI, while 0 denotes otherwise.

Table 6 Description of explanatory variables

Variables	Descriptions
Male	1: male; 0: female.
Age	driver's actual age.
Living in north area	1: respondent lives in northern area; 0: otherwise.
Familiar alternative highway routes	1: driver familiar with alternative highway routes; 0: otherwise.
Familiar with other alternative routes	1: driver familiar with other alternative routes (excluding highways and expressways); 0: otherwise.
Highway traffic condition	1:extremely congested; 2: congested; 3: fair; 4: smooth; 5: extremely smooth
Car ownership	1: driving personal own car; 0: otherwise
Trip purpose- work	1: work; 0: otherwise
In-vehicle navigation usage	0: zero; 1: above two times; 2: three to five times; 3: six to nine times; 4: ten times. (out of ten times)
Using TMC feature	1: using In-vehicle navigation system with TMC feature; 0: otherwise.
In-vehicle navigation with RTTI support	whether the driver thinks that in-vehicle navigation devices should be assisted by RTTI. 1: such assistance is necessary, 0: otherwise.
Prefer node to node information provision	how drivers prefer traffic information is presented. 1: prefers information presented from node to node; 0: prefers information presented from the current location to the destination.
prone to pay for CRTTI	1: the driver is willing to pay a certain amount of money for CRTTI; 0: otherwise.
Average WTP for CRTTI	driver's willingness to pay for a certain amount of money for CRTTI (unit: USD)

The estimation results of the univariate ordered probit model are presented in Table 7. Results show that information demands vary across different flows of traffic. In the context with a smooth traffic (S1 and S2), older drivers on the main route (S1) are less inclined to receive diversified real-time traffic information. This is probably because older drivers have a slower information processing ability than younger drivers. Besides, drivers living in northern Taiwan tend to receive more CRTTI when driving on the alternative route. This tendency is caused by a relatively higher complexity of road networks connected to national highways in northern Taiwan. The analysis of respondents' familiarity with road systems reveals that drivers on the main route who are more familiar with other alternative routes (excluding highways and expressways) and drivers on the alternative route who are more familiar with highways (including expressways) are less likely to receive diversified real-time traffic information. These two types of drivers have lower demands for real-time traffic information mainly because they are capable of diverting to alternative routes without any assistance. In terms of respondents' perception of the necessity of information assistance, drivers who agree that route navigation devices should be assisted by real-time traffic information show a stronger tendency to access diversified real-time traffic information. This phenomenon is consistent with our prior knowledge that drivers who identify the importance of CRTTI are more likely to accept diversified information. Our survey also inquires each driver about the price of and their WTP for CRTTI. The model estimation results reveal that drivers willing to pay for and use traffic information and drivers willing to pay more for traffic information have a stronger tendency to use diversified traffic information. This finding highlights the importance and necessity of the research on users' willingness to pay for effective real-time traffic information.

Table 7 Ordered probit model estimation results (t-value in parenthesis)

Variable	S1	S2	R1	R2	NR1	NR2
Constant	-2.305(-2.88)	-1.412(-3.11)	-1.780(-6.88)	-1.939(-6.99)	-1.499(-5.91)	-1.630(-6.30)
Male	—	—	—	—	0.325(2.01)	0.252(1.608)
Age	-0.014(-1.30)	—	—	—	—	—
Living in north area	—	0.3516(1.63)	—	—	—	—
Familiar alternative highway routes	—	-0.190(-1.73)	—	—	—	—
Familiar with other alternative routes	-0.225(-1.84)	—	—	—	—	—
Served highway traffic condition	—	-0.256(-1.62)	—	—	—	—
Car ownership	—	—	0.265(2.00)	0.209(1.495)	—	—
Trip purpose- work	—	—	0.182(1.52)	0.268(2.094)	—	—
In-vehicle navigation usage	—	—	—	—	0.049(1.418)	—
Using TMC feature	—	—	—	—	—	0.307(1.77)
In-vehicle navigation with real-time information support	0.270(1.81)	—	0.264(4.27)	0.218(3.26)	0.191(3.32)	0.221(3.74)
Prefer node to node information provision	—	—	0.251(2.08)	0.247(1.91)	0.257(2.19)	0.367(3.14)
prone to pay for CRTTI	4.055(13.24)	3.430(12.81)	—	—	—	—
Average WTP for CRTTI	0.016(14.49)	0.007(2.04)	—	0.025(8.96)	0.031(12.02)	0.019(8.52)
Threshold μ_1	1.118(6.873)	0.730(5.82)	0.253(6.41)	0.323(6.52)	0.470(8.79)	0.415(8.44)
μ_2	2.000(13.03)	1.275(9.12)	0.646(10.36)	0.806(10.50)	1.105(15.13)	0.863(12.91)
μ_3	2.497(14.50)	1.740(10.57)	0.769(11.11)	0.894(10.93)	1.365(16.67)	1.093(14.23)
$LL(0)$	-311.7996	-294.7023	-465.7932	-436.5847	-588.5924	-553.9886
$LL(\beta)$	-115.2183	-137.6483	-449.1737	-371.2152	-491.6808	-493.7376
ρ^2	0.630	0.533	0.036	0.150	0.165	0.109
Samples	446					

In the contexts with recurrent congestion (R1 and R2), respondents who own the vehicles they drive are more inclined to receive diversified real-time traffic information. These respondents have higher acceptance of use of CRTTI probably due to a full control of the vehicles they drive. Another finding indicates that respondents on worktrips are more inclined to receive diversified real-time traffic information. This is also an expected finding. Drivers on worktrips will make use of real-time traffic information to reduce travel time and alleviate driving fatigue. In terms of respondents' perception of the necessity of information assistance, drivers who agree that route navigation devices should be assisted by real-time traffic information show a stronger tendency to access diversified real-time traffic information. This finding explains that, whether on the main route or on the alternative route, drivers who identify the importance of CRTTI are more inclined to use diversified information. In terms of information presentation method, node-to-node presentation method is a significant affecting factor. In other words, drivers agree that traffic information should be more intensively provided in the event of congestion to help them divert to alternative routes as early as possible. This finding is consistent with our prior knowledge. In addition, drivers with a higher willingness to pay for information are more likely to receive diversified real-time traffic information. It can be inferred that in face of recurrent congestion, drivers may be more willing to pay for information about alternative routes to reduce their travel time.

In the contexts with non-recurrent congestion (NR1 and NR2), male drivers, whether on the main route or on the alternative route, show a stronger tendency than female ones to receive CRTTI. A possible explanation is that male drivers have higher acceptance of new information or have more active driving behaviour, so they are more likely to make use CRTTI to avoid congestion. Drivers who use navigation systems at a higher frequency tend to access more diversified traffic information when driving on their main route. This is probably because the current navigation devices can provide a portion of information (about the main route) and their navigation functions can be enhanced by its capacity to receive instant information. Besides, drivers with a TMC-equipped navigation device tend to receive more CRTTI when driving on alternative routes. These drivers may have benefited from information delivered via TMC and are therefore more inclined to use it to receive real-time traffic information. The analysis of perception of necessity of information assistance yields similar results obtained in the context with recurrent congestion. Whether on the main route or on the alternative route, drivers who identify the importance of CRTTI are more likely to utilize diversified information. Finally, in face of non-recurrent congestion, drivers showing more willingness to pay for information are more likely to receive diversified information regardless of which route they are in. This finding once again highlights the importance of studying users' willingness to pay for effective real-time traffic information.

A bivariate ordered probit model is further established, and the estimation results are presented in Table 8 and Table 9.

Table 8 Bivariate ordered probit model estimation results (t-value in parenthesis)

Variable		S1	*E**	S2	*E**
Constant		-2.981(-5.81)	–	-2.570(-4.65)	–
In-vehicle navigation with CRTTI support		0.441(3.41)	0.06	0.329(2.39)	0.09
Average WTP for CRTTI		0.020(7.67)	0.07	0.009(4.08)	0.03
Threshold	μ_1	0.362(3.58)		0.277(3.70)	
	μ_2	0.817(7.31)		0.586(6.68)	
	μ_3	1.377(7.33)		1.617(4.16)	
LL(*0*)		-461.4224			
LL(*β*)		-278.4312			
ρ^2		0.397			
Correlation coefficient		0.451(173.86)			
Samples		446			

*The sample means of elasticity and pseudo-elasticity of fatality.

Table 9 Bivariate ordered probit model estimation results (cont.) (t-value in parenthesis)

Variable		R1	*E**	R2	*E**	NR1	*E**	NR2	*E**
Constant		-1.410 (-5.52)	–	-1.596 (-5.94)	–	-1.263 (-5.43)	–	-1.504 (-6.08)	–
In-vehicle navigation with CRTTI support		0.088 (1.23)	0.12	0.143 (2.00)	0.14	0.172 (2.79)	0.14	0.185 (2.79)	0.14
Prefer node to node information provision		0.286 (2.00)	0.66	0.201 (1.42)	0.48	0.143 (1.097)	0.32	0.327 (2.55)	0.56
Average WTP for CRTTI		0.018 (6.73)	0.04	0.007 (4.20)	0.02	0.017 (8.72)	0.04	0.007 (4.53)	0.02
Threshold	μ_1	0.454(4.29)		0.374(3.99)		0.554(6.59)		0.422(6.34)	
	μ_2	1.216(7.59)		1.122(6.23)		1.394(10.84)		1.084(9.28)	
	μ_3	1.526(7.05)		1.367(5.70)		2.070(10.592)		1.941(8.49)	
LL(*0*)		-665.8892				-896.8746			
LL(*β*)		-444.4373				-591.1408			
ρ^2		0.333				0.341			
Correlation coefficient		0.425(37.67)				0.421(47.64)			
Samples		446							

* The sample means of elasticity and pseudo-elasticity of demand for CRTTI

To obtain consistent and reasonable variables, variables are selected through trial and error. The common factors for different flows of traffic are perception of necessity of information assistance, information presentation method: node-to-node, and average willingness to pay for information. The above finding indicates that drivers who agree that navigation devices should be assisted by real-time traffic information are more inclined to receive diversified traffic information. In other words, building drivers' cognition of necessity of real-time traffic information should be prioritized in future applications of real-time traffic information, as it can significantly facilitate development of the applications. In the aspect of information presentation method, node-to-node section-based information should be provided to drivers in face of recurrent or non-recurrent congestion. This information presentation method can increase drivers' demands for information about the main route or the alternative route. Besides, drivers showing a higher average willingness to pay for information tend to use more customized CRTTI. Their demands for information about the main route and the alternative route are also stronger. Finally, through estimation of the bivariate ordered probit model, correlations between variables are found (all of them are greater than 0.4, and the null hypothesis is significantly rejected). These correlations suggest that in the choice of CRTTI, drivers' with a stronger demand for information about the main route also have a relatively high demand for information about the alternative route.

The pseudo-elasticities in Table 8 and Table 9 are computed for each traffic condition and for each variable. Both the number of CRTTI need by drivers for main and alternative routes of recurrent congested and non-recurrent congested conditions have higher elasticities with respect to the node to node information provision. The result suggests that drivers prefer node to node CRTTI provision will increase the probabilities by significant amount about 32% ~ 66%. Besides, the pseudo-elasticities in congested traffic conditions (both recurrent and non-recurrent) are higher than smooth traffic flow, confirming that the quantity demand of CRTTI provision is more needed in congestion traffic conditions.

5. CONCLUSIONS

In this paper, we modelled highway drivers' information demands in different traffic conditions using a bivariate ordered probit model. Our findings can be summarized as follows:

1. We first defined CRTTI and identified four types of real-time traffic information, including (a) basic information, (b) dynamic estimation of travel time, (c) travel time delay, and (d) route navigation. We also investigated the reasonable price of each type of real-time traffic information.

2. In terms of information demands, most drivers have no information demand in the context with a normal flow of traffic. Drivers' information demands increase when in face of congestion, especially non-recurrent congestion. This finding reveals that drivers are more willing to pay for real-time traffic information when uncertainty of external factors is high.

3. In the context with a normal flow of traffic or recurrent congestion, drivers on the main route and the alternative route need mainly basic information. In the context with non-recurrent congestion, drivers on the main route need mainly dynamic estimation of travel time. Among the four types of information, information about travel time delay is considered less important to drivers in Taiwan.

4. The average reasonable price of basic information is \$10.8~11.8 per piece, the average reasonable price of dynamic estimation of travel time is \$10.2~11.6 per piece, the average reasonable price of travel time delay information is \$10.2~12.7 per piece, and the average reasonable price of route navigation information is \$9.9~10.8 per piece. On average, the willingness to pay for CRTTI is \$5.6 higher than the average reasonable price of CRTTI.

5. Drivers who agree that navigation devices should be assisted by real-time traffic information in any context of traffic flows are more inclined to receive diversified traffic information. In other words, building drivers' cognition of necessity of real-time traffic information should be prioritized in future applications of real-time traffic information, as it can significantly facilitate development of the applications.

6. Node-to-node section-based information should be provided to drivers in face of recurrent congestion or non-recurrent congestion.

7. Drivers showing a higher average willingness to pay for information tend to use more CRTTI. This phenomenon implies that pricing of real-time traffic information can be one of the strategies for solving traffic congestions.

8. Pseudo-elasticities results show that drivers prefer node-to-node information provision will increase the demand on CRTTI in both congested conditions.

9. Finally, through estimation of the bivariate ordered probit model, we found correlations between variables. These correlations indicate that in the choice of CRTTI, drivers' with a stronger demand for information about the main route also have a relatively high demand for information about the alternative route.

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