BENEFIT OF TRAVELER INFORMATION BOARDS (VMS)*

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1. Introduction

Advanced Traveler Information Systems (ATIS) is one of the components of Intelligent Transport Systems (ITS) and Information Technology (IT) that provide information to the driver in order to get a better performance in the roads, such as reduce uncertainty in travel and waiting times and provide more safety. ATIS can provide private information through "route navigators", as well as public information through "variable message signs" (VMS), internet, mobile phones and electronic kiosks.

The objective of this paper is to estimate and to analyze the economic benefits of ATIS by adopting the behavioral modeling developed by Bonsall (1995[1)], 1999[2)], 2001[3)]), which uses the logit model for route choice and to analyze the behavior of users when ATIS is provided. The change of utility level without and with provision of information is the key point to find the value of information. Such value of information is given by the difference in maximum expected utilities in the case of logit modeling for route choice.

In previous researches, P. Bonsall used the logit model in order to express driver's route choice in presence of VMS (Bonsall[1)] *et al.* 1995). Some of the conclusions he found about VMS (Bonsall[2)] *et al.* 1999) are: a) messages which include a quantified description of the effect of the problem have been seen to be more influential than signs giving directional advice or a description of the cause of the problem. b) The effectiveness of a message will depend on the proportion of the passing drivers for whom it is relevant, the relative attractiveness of the potential diversion route and the local traffic conditions. c) The most important characteristic of the drivers is their level of familiarity with the network, in order to respond to VMS appropriately. Bonsall represents uncertainty adding a term to the generalized cost equation (Bonsall[3)] *et al.* 2001). The generalized cost is based on the mean and the standard deviation of cost components while this paper adopts the definition of benefit based on the maximum expected utility. Chatterjee[4)] *et al.* (2002) proposed a stated preference (SP) method and a logistic regression model to determine the probability of route diversion to the driver using VMS for a study in London. Al-Deek[5)] *et al.* (1998) combined the binary logit model with a queuing analysis. The conclusions and results of his paper showed that ATIS will reduce average travel times according to the increase of market penetration, but he didn't analyze its effects on reliability in which this study focus on. Kobayashi[6)] *et al.* (1995) found the value of information for three types of information systems: a) Forecasted travel time, b) recommended route to be chosen and c) whether congestion is expected or not. He used a quasi-linear utility function in which the preferences of drivers are neutral. In this study we incorporate a risk avert behavior, therefore the utility function takes an exponential form.

2. Example to be studied

In order to understand the estimation of the value of information we describe a typical example of ATIS on the route 457-286 for a trip between two cities of Tohoku region in Japan: Sendai and Yamagata as fig.1. Suppose that drivers want to travel from Sendai to Yamagata and they start their trip on route 48.

Without information, they will face two situations when they arrive to the intersection between routes 48 and 457: a) to continue the trip through route 48 (let's call route 2) or to divert to route 457-286 (let's call route 1). We assume that before arriving to the intersection of routes 1 and 2 a "variable message sign" (VMS) is showing the state of route 1: "slippery" or "normal condition", due to snow or hard rain. Route 2 is in a state of normal condition constantly. Let's

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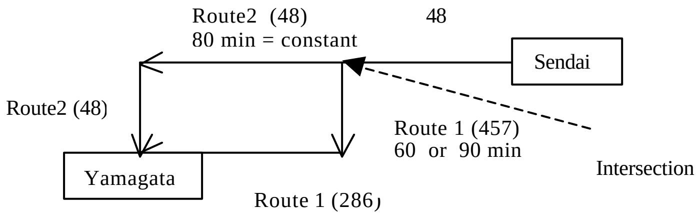

Fig. 1 Routes to be studied

suppose the driver is able to estimate exactly the travel times to arrive into Yamagata using route 1 or route 2 as shown in Table 1.

Table 1. Travel cost, travel times and state for routes 1 and 2

Use of route	State of route	Travel cost (yen/trip)	Travel time (min)
Route 1	Normal condition	TC_{11}	TT_{11}
Route 1	Slippery	TC_{12}	TT_{12}
Route 2	Normal condition constantly	TC_2	TT_2

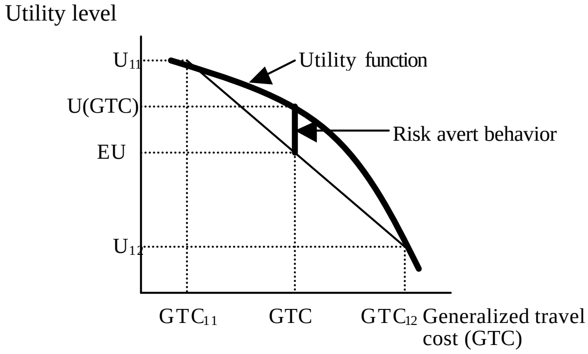

Fig. 2 Shape of utility function

We assume that $TT_{12} > TT_2 > TT_{11}$ and $TC_2 > TC_{12} = TC_{11}$

In order to save time, the driver with information (see Table 1) has two choices: in the case that the route 1 is slippery he is going to use route 2, which provides a less travel time. Otherwise he is going to use route 1.

Therefore the information provided for the driver is useful, because it will make him/her select the route with less travel time and increase his/her utility level.

3. Formulation of the model

We follow the case of study in which we have the choice for using route 1 or using route 2 under two states of the world: "normal condition" and "slippery" for route 1, while normal condition constantly for route 2. Suppose that every situation (i,j) gives us a different utility level depending on the situation depicted by Table 1.

Under uncertainty and applying the Von-Neumann and Morgenstern[7)] (1944) theory, the expected utilities EU without information "using route 1" (EU_1^B) and "using route 2" (EU_2^B) according to Table 1 are respectively:

$$EU_1^B = p^B U_{11} + (1-p^B) U_{12} \quad (1)$$

$$EU_2^B = U_2 \quad (2)$$

where: p^B =Probability of "normal condition" for route 1, 1-p^B =Probability of "slippery" for route 1,
U_{ij} = Utility of route i; i = 1 or 2; j = 1 or 2, where 1 is "normal condition" and 2 is "slippery".

We assume that the state of route is unknown for the case of "without any information". Nevertheless, based upon a strong belief, previous experience and Bayes theorem, we assume that drivers know the objective probability of the state of each route. Its value will be between 0 and 1 (never 0 and never 1, because the driver is not sure with certainty about the state of the road). With information we assume that the driver "knows the state of the road with certainty". This means that the probability of normal condition will take a value of 1 and the probability of slippery will take a value of 0. In summary: without information: $0 < p^B < 1$. We also assume that the information is perfect, this means that it doesn't contain any uncertainty and mistake. Drivers can't change the decision of making the trip once they decided to travel even if the state is slippery (i.e they must continue the trip no matter the state of the route). Therefore, the expected utilities with information for route 1 when is "slippery" and when is "normal condition" are eqs. 3 and 4 respectively:

$$EU_1^{AS} = U_{12} \quad (3) \qquad EU_1^{ANS} = U_{11} \quad (4)$$

We assume that the utility has an exponential form (See fig. 2), (Luenberger[8)] 1998) due to we are analyzing it under a risky world. We take in consideration two variables: travel cost and travel time. We also consider that the driver's behavior is "risk avert", i.e. EU<U(GTC), then our assumption of utility takes the form:

$$U_{ij} = -\exp(a_1 TC_{ij} + a_2 TT_{ij}) \tag{5}$$

where: TC_{ij} = Travel cost, TT_{ij} = Travel time, a_1 , a_2 = Parameters of utility function

The probability of choice without (P_1^B) and with (P_1^A) informat. is defined by logit model using the expected utility:

$$P_1^B = \frac{\exp(qEU_1^B)}{\exp(qEU_1^B) + \exp(qEU_2^B)} \tag{6}$$

$$P_1^A = \frac{\exp(qEU_1^A)}{\exp(qEU_1^A) + \exp(qEU_2^A)} \tag{7}$$

(1) Definition of benefit of information

We define the maximum expected utility (MEU) as the log-sum function derived in the Logit model (Ben–Akiva and Lerman[9] 1985) by the following equation:

$$MEU_{1\,or\,2}^B = g\frac{1}{q}\ln\sum_{i=1\,or\,2}\exp(qEU_i^B) + (1-g)\frac{1}{q}\ln\sum_{i=1\,or\,2}\exp(qEU_i^B) = \frac{1}{q}\ln\sum_{i=1\,or\,2}\exp(qEU_i^B) \tag{8}$$

Then, the maximum expected utility after information is given by:

$$MEU_{1\,or\,2}^A = g\frac{1}{q}\ln\sum_{i=1\,or\,2}\exp(qEU_i^{ANS}) + (1-g)\frac{1}{q}\ln\sum_{i=1\,or\,2}\exp(qEU_i^{AS}) \tag{9}$$

g represents the previous annual share of state of "normal condition" and we assume is equal to the occurrence probability of "normal condition" p^B.

Finally, the value of information under uncertainty in terms of maximum expected utility is:

$$B = MEU_{U1\,or\,U2}^A - MEU_{U1\,or\,U2}^B \tag{10}$$

In order to obtain the value of information in monetary terms we use the concept of "option price (OP)", Graham D.S.[10] (1981). OP is defined as the amount of increase in price level an individual would be compensated to give up the project (i.e. without information) that will give him the same utility level if the project is carried out (i.e. with information) (Morisugi[11] *et al.* 1996). Then the OP represents the value of information and we define it as the value of OP satisfying the following equation:

$$MEU_{1\,or\,2}^B(TC + OP, TT) = MEU_{1or\,2}^A(TC, TT) \tag{11}$$

Where $U_{ij}(TC_{ij}, TT_{ij})$, and using the above equations we replace in eq. (11) and obtain:

$$\frac{1}{q}\ln\left\{\begin{array}{l}\exp\left\{q\left\langle p^B\left[-\exp^{a_1(TC_{11}+OP)+a_2TT_{11}}\right]+(1-p^B)\left[-\exp^{a_1(TC_{12}+OP)+a_2TT_{12}}\right]\right\rangle\right\}+\\ \exp\left\{q\left(-\exp^{a_1(TC_2+OP)+a_2TT_2}\right)\right\}\end{array}\right\} =$$
$$p^B\frac{1}{q}\ln\left\{\exp\left\{q\left(-\exp^{a_1TC_{11}+a_2TT_{11}}\right)\right\}+\exp\left\{q\left(-\exp^{a_1TC_2+a_2TT_2}\right)\right\}\right\}+$$
$$(1-p^B)\frac{1}{q}\ln\left\{\exp\left\{q\left(-\exp^{a_1TC_{12}+a_2TT_{12}}\right)\right\}+\exp\left\{q\left(-\exp^{a_1TC_2+a_2TT_2}\right)\right\}\right\} \tag{12}$$

4. Numerical example and results

This study shows a numerical example based on fig. 1. The distance for route 1 is 55 km and for route 2 is 75 km. We assume that a car will use 1 liter of gasoline per 10 km. If the cost of gasoline is 100 yen/lt, then the travel cost per trip of a driver who uses route 1 is 550 yen/trip and 750 yen/trip for the person who uses route2.

The estimation of parameters for the utility function was carried out using the logit model. The value of the benefit of information when the state of the road is slippery or not in route 1 was calculated from eq. (12). We considered two cases: the first one with a probability of route 1 in normal condition p^B=0.6 and the second one p^B=0.4. After performing the correspondent calculations the results are shown in Table 2.

The values of information for case 1 and case 2 are 261 yen/trip and 343 yen/trip, respectively. These values look reasonable and are similar to a level of a toll fee. In order to obtain the annual benefit we assumed a traffic volume of 8600 veh/day for route 2 according to the census 1997 and 152 days in a year of snow season. The annual benefit (AB) for the existing traffic is estimated with the following equation:

$$AB = B * Traffic\ volume * Days\ of\ snow\ in\ a\ year \tag{13}$$

The annual benefit values are: 340 million yen/year for case 1 and 448 million yen/year for case 2. If we assume that the induced or generated traffic will duplicate due to the implementation of VMS, then the annual benefit for both routes will be 510 million yen/year for case 1 and 672 million yen/year for case 2.

Table 2. Data and value of information for the numerical example

	DATA									PARAMETERS		VALUE OF INFORMATION
	q	p^B (Normal condition)	$1-p^B$ (Slippery)	TC11 (yen/trip)	TT11 (min)	TC12 (yen/trip)	TT12 (min)	TC2 (yen/trip)	TT2 (min)	a1	a2	B=OP (yen/trip)
Case 1	0.05	0.6	0.4	550	60	550	90	750	80	0.00536	0.033136	261
Case 2	0.05	0.4	0.6	550	60	550	90	750	80	0.00536	0.033136	343

5. Conclusions

Using previous behavioral models like the Logit model, the Expected Utility theorem and the Option Price concept we developed a simple methodology to estimate the benefits for implementation of transportation projects, which can include the provision of information. We showed with a numerical example that this methodology is practical and can be applied to ATIS projects. The results showed that the values of information of variable message signs for the example that we studied are 261 yen/trip and 343 yen/trip for two different cases. We conclude that the higher is the probability of route 1 when is slippery e.g. $1-p^B = 0.6$, the higher is the value of information for this study.

For further research we would like to carry out an analysis of costs for the implementation of VMS for routes 1 and 2, and then perform a cost-benefit analysis for this project. We expect that the benefit-cost ratio will be larger than 1 indicating that the project with provision of information is feasible. As further research we also want to study other cases in which the type of information is imperfect, not always if the road is slippery or not, but also include range of times and analyze the behavior of the driver when there is a change of state of the world in more than one route. We want to consider also cases for the provision of information in public transportation like bus or train. Other important component that can be included in our analysis will be the provision of information in order to reduce traffic accidents.

One of the extensions of this paper is the analysis of a more general functional form for the utility function, because we would like to know what level of risk aversion the driver would adopt in practical life. If we can define which type of utility function is the appropriate, then we can calculate the benefits of information with more accuracy.

We also think that the estimation of the induced or generated traffic to know how many cars will use these routes if the project is implemented is necessary for the calculation of the annual benefit.

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