Drivers' Context-sensitive Adaptation Behavior to the Occurrence of Traffic Accidents on Expressways under Individualized Dynamic Travel Information†

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Focusing on the individualized dynamic traffic information, this study applies a stated preference (SP) survey and a data mining technique called Exhaustive CHAID to evaluate the heterogeneous effects of the information on drivers' adaptation behavior to the occurrence of traffic accidents in the context of expressway. Three decision scenes are targeted: before departure, on the way to expressway and on expressway. SP survey is designed to reflect the influence of each respondent's different driving experience and preference for travel information on the SP responses. Different from existing studies, several new types of traffic information are additionally examined. Taking the expressway of West NEXCO, Japan as an example, 10,000 SP responses were collected for each scene. Analyses identified about 30 adaptation patterns with considerably different influencing information contents.

Key Words : *individualized travel information, large-scale SP survey, traffic safety*

1. INTRODUCTION

Serious negative impacts of traffic accidents are represented not only by the large amount of property losses and human injury and fatality tragedies, but also the huge amount of travel time losses, follow-up accident recurring and so on. It is expected that effective countermeasures of ITS-based real-time accident information provision play various important roles in solving the above negative impacts (Bonsall, 2000). Information provision studies about how to provide valuable information and whether or not display reliability information to drivers become more and more important in the current traffic accident information studies.

To date, various traffic safety studies linked with the influence of information provision on drivers' adaptation behavior have been conducted. The prevalent utility-based approach assumes that people make the choice based on the general idea of maximum utility achievements from economic analysis method. In line with such consideration, a series of utility-based discrete choice models, e.g., MNL model (Kusakabe et al. 2012), binary logit model (Abdel-aty, 1997; Hato et al. 1999), and mixed logit model (Ben-Elia and Shiftan, 2010), have been widely employed. However, one of the disadvantages of this approach is that it is difficult to effectively and flexibly identify heterogeneous adaptation behaviors to the occurrence of traffic accidents as well as the nested structure of influencing factors.

Under such circumstances, focusing on the expressway in Japan, this study examines how individualized dynamic traffic information influences drivers' adaptation behavior under different decision scenes and contexts. In addition to conventional traffic information, several new types of traffic information related to the occurrence of traffic accidents are also considered. To investigate the effects of such information, the stated preference (SP) survey is useful. Since the SP survey asks respondents hypothetical questions, it becomes important how to enhance the reliability of SP responses. It is also true that heterogeneity exists with respect to drivers' various choice decisions. To properly deal with the above issues, this study designs an SP survey with individualized values of SP attributes by reflecting respondents' actual driving experience based on a pilot survey conducted in 2011. Reflecting the results of the pilot survey, the SP survey is implemented. Both the pilot and SP surveys collected the relevant information from 2,500 respondents, where in the SP survey 30,000 SP responses are collected. To capture the heterogeneous responses of drivers, a data mining approach called Exhaustive CHAID is applied.

This paper is organized as follows. In Section 2, the SP survey is briefly described, followed by an aggregation analysis of data in Section 3. Exhaustive-CHAID analyses are conducted in Section 4. Finally, the study is concluded in Section 5.

2. SURVEY

The survey objective is to investigate the effects of dynamic traffic information on driver's adaptation behavior to the occurrence of traffic accidents at different location scenes: "Before departure", "On the way to expressway", and "On expressway", based on a stated preference (SP) survey.

The features of the SP survey are

(1) Real-time traffic warning information is dealt with, including accident condition and impact information, and available alternative travel mode.

(2) A large-scale pilot survey with 2,500 participants was first conducted. The attributes included in the SP survey are selected from the pilot survey. Especially, values of the attributes are specified for each respondent.

(3) The 2,500 participants in the pilot were asked to participate in the SP survey. As a result, 78% participated (the remaining respondents were newly recruited). Each respondent was asked to answer four SP cards for each of the above three scenes. In other words, each respondent answered 12 SP questions in total.

(4) The above sample size was decided to represent the whole driver population in the administration area (Yamaguchi, Hiroshima, Okayama, Shimane and Tottori Prefectures) of the Chugoku Regional Branch, West Nippon Expressway Company Limited (West NEXCO), Japan.

Details are described below.

2.1 Survey Design

Based on the pilot survey conducted in 2011, this study selected 12 attributes, each of which has two or three levels, including

1) accident condition information (two attributes): (1) location from entrance ramp to the accident site (hereafter, distance to site) (close or far) and (2) accident severity (fatal, no fatal, or no information));
2) accident impact information (two attributes): (3) queue length (long, short, or no information) and (4) queue changing trend (increase, decrease, or no information);
3) alternative route or travel mode information (three attributes): (5) ordinary road, (6) other expressway route, and (7) other travel modes; all the three attributes have the same three levels, i.e., yes, no, or no information; and
4) traffic measure information (five attributes): (8) traffic regulation (with/without regulation, or no information), (9) clearance time (long, short, or no information), (10) clearance time estimation accuracy (high or low), (11) probability of clearing away the traffic congestion at a certain clearance time (high (80%), low (60%)), and (12) time provision method (point information or interval information).

With the help of an orthogonal fractional factorial design, 24 SP profiles were obtained. In the SP survey, two types of trips are targeted, which are picked up from the trip information reported by respondents in the pilot survey as follows:

1) if a respondent had two or more trips with strong time constraint (e.g., commuting and business) and without strong time constraints (e.g., leisure and tourism), then two trips with and without time constraint are assigned.
2) If a respondent had two or more trips with the same type of trip purpose (with strong

time constraint or without strong time constraint), then two trips with same type are assigned.

3) If a respondent only used the expressway once within the last one year, the same trip is assigned with a different trip purpose.

Except for the probability of clearing away the traffic congestion at a certain clearance time, the values of other attributes are calculated by reflecting each respondent's reported information in the pilot survey: 1) trip information (e.g., entry and exit IC ramps, IC distances), 2) tolerance level of the length (distance and time) of traffic congestion, and 3) acceptable level of time information accuracy (travel time and clearance time etc.).

The adaptation alternatives are different depending on drivers' location scenes.

(1) "Before departure" & "On the way to expressway":

a) *no change* (use the expressway as scheduled); **b)** *change departure time* (use the expressway as scheduled, but change the scheduled departure time); **c)** *ordinary road* (give up using the expressway, instead, use the ordinary road); **d)** o*ther travel mode* (give up using the car, instead, change to use of other travel mode(s)); **e)** *Cancel the trip*.

(2) "On expressway":

a) *no change* (use the expressway as scheduled); **b)** *wait and see at SA/PA* (take a short rest at nearby service area (SA) or parking area (PA) for wait and see); **c)** *alternative expressway* (change to other alternative expressway); **d)** *ordinary road detour* (get out of the expressway at nearest exit ramp to avoid the accident affected area and then detour to the expressway); **e)** *ordinary road* (give up using the expressway, instead, use the ordinary road); **f)** *other travel mode* (give up using the car, instead, change to use of other travel mode(s)); **g)** *Cancel the trip*.

In the SP survey, each respondent was asked to answer two SP questions (randomly selected from the above 24 SP profiles) for each trip and each of the three location scenes, i.e., 12 SP questions in total.

2.2 Survey Implementation

Both the pilot and SP surveys were implemented via the Internet with the help of a major Internet survey company in Japan, which had more than 1.4 million registered panelists at the time of survey. Since this is a part of joint research with the Chugoku Regional Branch of West NEXCO, 2,500 respondents were randomly selected from those panelists residing in the five prefectures in the Chugoku Region, who used the expressway at least once within the past one year. The sample size was decided to represent the whole driver population using the expressway within the Chugoku Region. The SP survey was done in 2012 by first inviting all the 2,500 respondents and as a result, 1,923 respondents participated in the SP survey. To meet the required sample size, the remaining 577 respondents were newly recruited. By making use of the advantages of Internet-based survey, there is no missing value in the collected questionnaires. Each respondent was asked to answer four SP cards with respect to all the three scenes, resulting in 10,000 SP responses for each scene and 30,000 SP responses in total.

3. AGGREGATION ANALYSIS

Respondents included in the SP survey are drivers aging from 18 to 70 years old, with 78.4% of whom falling in the age band of 20~60 years old. Number of male drivers (1,249) is nearly equal with that of female drivers (1,251). It is observed that for the scenes of "Before departure" & "On the way to expressway", each adaptation option takes nearly the same share, where about 54% of respondents chose to give up using the expressway (46% to use ordinary road, 4% to use other travel mode(s) and 4% to cancel the trip) based on the information provision. For drivers who were already on the expressway, about 28% of them chose not to use the expressway (23% to use ordinary road, 1% to use other travel mode(s) and 4% to cancel the trip). In the scene of "on expressway", 21% of respondents prefer to "wait and see at SA/PA". Interestingly, about 30% of respondents answered not to change their trip plans in the three scenes, respectively, suggesting that these drivers might be captive users of expressways, and about 4% chose to cancel their trips, implying that they might be an unshakable risk avoiders.

4. ANALYSIS BASED ON EXHAUSTIVE CHAID APPROACH

To derive representative adaptation patterns to the occurrence of traffic accidents under the information

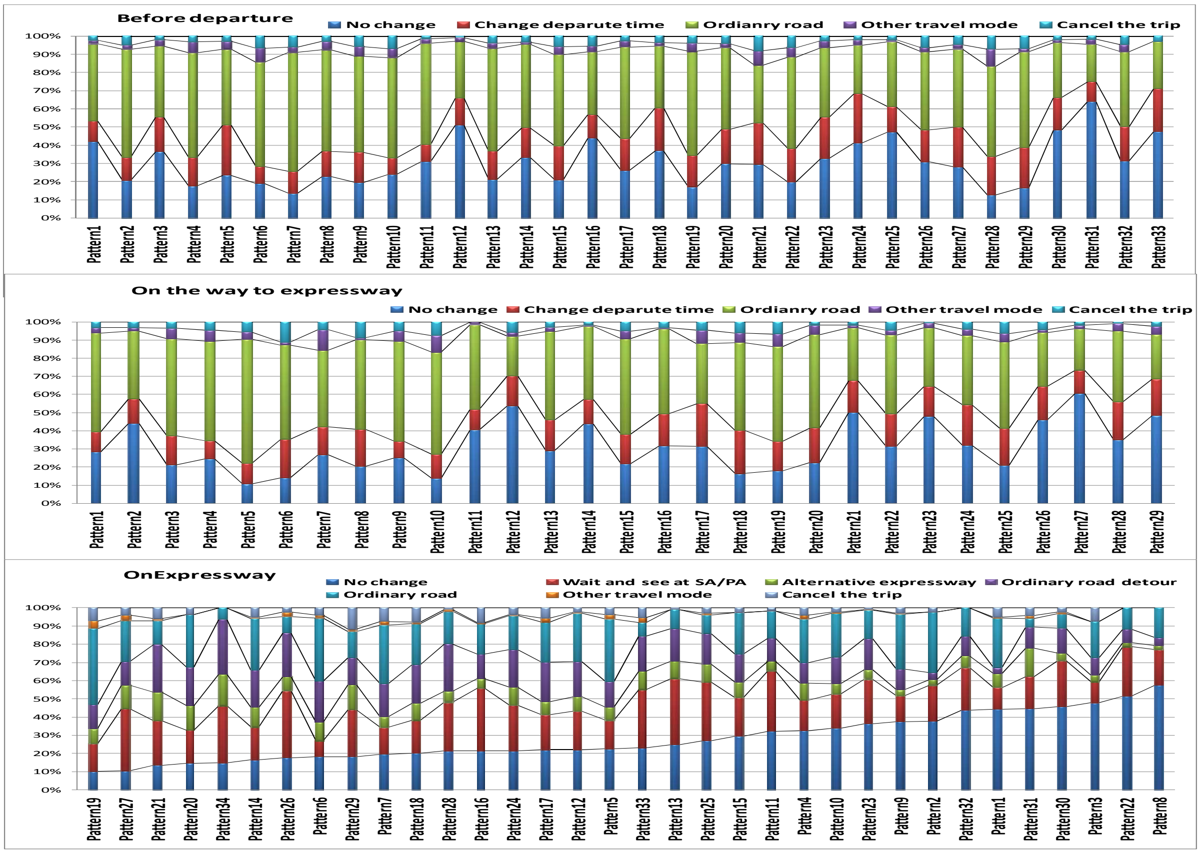

Figure 1. Adaptation patterns for three decision scenes

Table 1. Influencing factors for different types of adaptation behavior

Before Departure Pattern

Pattern#	Distance to Site	Clearance Time	No fatal accident	Queue decrease	Fatal accident	clearing away %
1	<=17.4	<=20				
2	<=17.4	(20,28]	0			
3	<=17.4	(20,28]	1			
4	<=17.4	(28,48]	0			
5	<=17.4	(28,48]	1			
6	<=17.4	(48,68]				
7	<=17.4	(68,72]	0			
8	<=17.4	(68,72]	1			
9	<=17.4	>72		0		
10	<=17.4	>72		1		
11	(17.4,34.8]	<=28		0		
12	(17.4,34.8]	<=28		1		
13	(17.4,34.8]	(28,84]	0			
14	(17.4,34.8]	(28,84]	1			
15	(17.4,34.8]	>84				
16	(17.4,34.8]	<=20				
17	(17.4,34.8]	(20,68]		0		
18	(17.4,34.8]	(20,68]		1		
19	(17.4,34.8]	(68,84]		0		
20	(17.4,34.8]	(68,84]		1		
21	(17.4,34.8]	(84,106]				
22	(17.4,34.8]	>106				
23	(69.3,140]			0	0	
24	(69.3,140]			1	0	
25	(69.3,140]	<=28			1	
26	(69.3,140]	(28,72]			1	
27	(69.3,140]	(72,106]			1	
28	(69.3,140]	(106,142]			1	
29	(69.3,140]	>142			1	
30	>140				0	0.6
31	>140				0	0.8
32	>140			0	1	
33	>140			1	1	

Way to Expressway Pattern

Pattern#	Distance to Site	Clearance Time	No fatal accident	Queue decrease	Fatal accident	clearing away %
1	<=17.4	<=28	0			
2	<=17.4	<=28	1			
3	<=17.4	(28,48]				
4	<=17.4	(48,84]			0	
5	<=17.4	(48,84]			1	
6	<=6	(84,106]				
7	(6,10.5]	(84,106]				
8	(10.5,17.4]	(84,106]				
9	<=6	>106				
10	(6,17.4]	>106				
11	(17.4,34.8]	<=20				
12	(34.8,69.3]	<=20				
13	(17.4,69.3]	(20,42]				0.6
14	(17.4,69.3]	(20,42]				0.8
15	(17.4,69.3]	(42,84]	0			
16	(17.4,69.3]	(42,84]	1			
17	(17.4,69.3]	(84,106]			0	
18	(17.4,69.3]	(84,106]			1	
19	(17.4,69.3]	>106		0		
20	(17.4,69.3]	>106		1		
21	(69.3,140]	<=42				
22	(69.3,140]	(42,68]				0.6
23	(69.3,140]	(42,68]				0.8
24	(69.3,140]	>68			0	
25	(69.3,140]	>68			1	
26	>140				0	0.6
27	>140				0	0.8
28	>140				1	0.6
29	>140				1	0.8

On Expressway Pattern

Pattern#	Distance to Site	Clearance Time	No fatal accident	Queue decrease	Fatal accident	Time accuracy	clearing away %
1	<=6	<=20					
2	(6,10.5]	<=20					
3	(10.5,17.4]	<=20					
4	<=17.4	(20,68]		1			
5	<=17.4	(20,68]		0			
6	<=17.4	>68		1			
7	<=17.4	>68		0			
8	(17.4,69.3]	<=20		1			
9	(17.4,69.3]	<=20		0			
10	(17.4,69.3]	(20,42]	0				
11	(17.4,69.3]	(20,42]	1				
12	(17.4,69.3]	(42,48]	0				
13	(17.4,69.3]	(42,48]	1				
14	(17.4,69.3]	(48,72]	0				
15	(17.4,69.3]	(48,72]	1				
16	(17.4,69.3]	(72,106]		1			
17	(17.4,69.3]	(72,106]		0			
18	(17.4,69.3]	>106					<=4.8
19	(17.4,69.3]	>106					(4.8,7.7]
20	(17.4,69.3]	>106					(7.7,12]
21	(17.4,69.3]	>106					>12
22	(69.3,140]	<=42		1			
23	(69.3,140]	<=42		0			
24	(69.3,140]	(42,106]				0.6	
25	(69.3,140]	(42,106]				0.8	
26	(69.3,140]	(106,136]			0		
27	(69.3,140]	(106,136]			1		
28	(69.3,94.5]	>136					
29	(94.5,140]	>136					
30	>140	<=106			0		
31	>140	>106			0		
32	>140	<=68			1		
33	>140	(68,136]			1		
34	>140	>136			1		

Note: "clearing away % " represents "the probability of clearing away the traffic congestion at a certain clearance time;

provision, a data mining approach called Exhaustive CHAID (Chi-squared Automatic Interaction Detector) approach (Biggs et al, 1991) is adopted. It uses the given data to automatically build a series of "if-then" rules (in the form of decision tree) that can find the best split for each predictor variable to give the strongest association with target variable. Decision trees are charts that illustrate decision rules. They begin with one root (parent) node that contains all of the observations in the sample. The process is then applied recursively to subgroups to define sub-subgroups, and so on, until the tree is converged based on certain stopping criteria. Before applying the Exhaustive CHAID approach, univariate variance analyses were conducted to reduce the number of predictor variables.

The above analyses derives 33 adaptation patterns for the "before departure" scene, 29 patterns for the "on the way to expressway" and 34 patterns for the "on expressway" scene (see Figure 1, where all the patterns are ordered based on the distance to accident site). The influencing attributes and levels are shown in Table 1. Significant influencing factors identified are "distance to site", "clearance time", "no fatal accident", "queue decreasing trend" and "fatal accident" for the scenes of "before departure" and "on the way to expressway". As for "on expressway" scene, one additional factor of "queue length" was further found. The first and most important influencing factor is the "distance to site" information, followed by the "clearance time" information; however, when the "distance to site" exceeds 140 km, in the scenes of "before departure" and "on the way to expressway", the "clearance time" information becomes insignificant, instead, the "fatal accident" information comes out. In contrast, in the "on expressway" scene, the "clearance time" information is still influential, but less than the "fatal accident" information. Detailed discussion for each scene is given below.

4.1 Findings of the Scene "Before Departure"

Alternatives of "**a)** *no change*" and "**c)** *ordinary road*" are the two top adaptation actions among the given five alternatives, followed by "**b)** *change departure time*". The share of "**a)** *no change*" alternative ranges from 12.8% (Pattern 28) to 64.4% (Pattern 31), that of "**c)** *ordinary road*" from 20.8% (Pattern 31) to 65.6% (Pattern 7), and that of "**b)** *change departure time*" from 9.0% (Pattern 10) to 27.9% (Pattern 5).

The "no fatal accident" information is influential when the "distance to site" is less than 34.8 km (occupying 24.9% of the total SP responses), the "fatal accident" information is only relevant when the "distance to site" is larger than 69.3 km (32.0% of responses), and only about 6.1% of responses are sensitive to the probability of clearing away the traffic congestion at a certain clearance time. For the "queue changing trend" information, only the decreasing trend information is influential and totally 42.3% of responses are sensitive to this information.

Among the 33 patterns, 13 patterns (occupying about 45.9% of responses) show that the share of giving up the use of expressway, including "**c)** *ordinary road*", "**d)** *other travel mode*", and "**e)** *cancel the trip*", is higher than 60%. It is observed that a large range of clearance time value could discourage the use of expressway, the "no fatal accident" information especially works when the clearance time is less than 84 min and the "queue decreasing trend" information does for the case with longer clearance time. More than 70% of "give up the use of expressway" decisions are identified in Pattern 6 and Pattern 7, which is only influenced by the distance to site less than 17.4 km and the clearance time of (48 min, 68 min] in Pattern 6 and (68 min, 78 min] in Pattern 7, respectively.

Focusing on the "keep the use of expressway" adaptation behavior, including "**a)** *no change*" and "**b)** *change departure time*, seven patterns show that the corresponding share is higher than 60% (i.e., more drivers wants to keep the use of expressway). When the distance to site is shorter than 140 km, the dominating influential factors are the clearance time with relatively smaller value and the "queue decreasing trend" information. In most of the 33 patterns, the share of "**a)** *no change*" is higher than that of "**b)** *change departure time*.

4.2 Findings of the Scene "On the Way to Expressway"

For this scene, 29 patterns are identified. Same as the above scene, the top three adaptation actions are "**a)** *no change*", "**c)** *ordinary road*" and "**b)** *change departure time*". Here, only the major differences from the above "before departure" scene are emphasized.

First, pattern 15 occupies 13.0% of the total SP responses, which is considerably higher than any other patterns. And the variance of the shares of other patterns is quite smaller.

Second, "distance to site" is observed to be influential at different levels of decision trees, implying that it is more important in the scene of "on the way to expressway" than in the "before departure" scene. This might be because drivers have already been driving on the road, and therefore become more sensitive to the information of distance to accident location. Another important information factor is the probability of clearing away the traffic congestion at a certain clearance time with respect to seven patterns; in contrast, in the "before departure" scene, only two patterns are influenced by this probability.

Third, those who especially prefer to give up the use of expressway (the share in the relevant pattern is higher than 70%) are found in Pattern 5 and Pattern 10. Pattern 10 identified the same contributing factors with the "before departure" scene, which are presented by short distance to accident site (6 km ~ 17.4 km) and longer clearance time (>106 min). Pattern 5 also shows that the short distance to accident site (<=17.4 km) is influential to the SP responses, but the differences from Pattern 10 are that the middle-valued clearance time (48 min ~ 84 min) and the information of revealing the occurrence of fatal accidents play more important role.

4.3 Findings of the Scene "On Expressway"

For this scene, 34 patterns are identified, which involve complicated adaptation patterns. The "**a)** *no change*" option shows higher share in shorter and longer distance to accident site. The relatively larger share of respondents replied that they want to wait and see at SA/PA in most of the 34 patterns. When the distance to accident site is relatively shorter, respondents prefer the "**e)** *ordinary road*" option. The "**d)** *ordinary road detour*" adaptation action is mainly observed in case that the distance to accident site is relatively longer. What's understandable is that there are much fewer respondents (on average 25%) that give up the use of expressway than in the above two scenes (the respective average share is 52%).

Concerning the "**a)** *no change*" alternative, the share ranges from 10.2% (Pattern 19) to 57.6% (Pattern 8). For those who most prefer "**a)** *no change*" (Patterns 8 and 22), the influential factors include the distance to accident site is influential, ranging from "between 17.4 km and 69.3 km" in Pattern 8 and "between 69.3 km and 140 km" in Pattern 22, the clearance time (less than 20 min in Pattern 8 and less than 42 min in Pattern 22), and the queue decreasing trend. For those who least prefer "**a)** *no change*" (Patterns 19 and 27), the influencing range of distance to accident site is similar to Patterns 8 and 22. The differences are, 1) the clearance time is relatively longer (longer than 106 min in Pattern 19 and between 106 min and 136 min in Pattern 27), and 2) the queue length (between 4.8 km and 7.7 km) is influential in Pattern 19 and the existence of fatal accident in Pattern 27.

Focusing on the "give up the use of expressway" behavior, more than 40% share is identified in Pattern 19 (51.3%), Pattern 5 (40.4%), Pattern 6 (40.3%), and Pattern 7 (41.6%). Since there is not obvious difference of the share in Pattern 5 to Pattern 7, the comparison of influential factors in these three patterns reveals that queue decreasing trend information cannot contribute to the change of choosing "give up the use of expressway" option.

Considering of the queue length factor, decision patterns being significantly influenced in this scene are Pattern 18 ~ Pattern 21, which are affected by the whole range of values of queue length.

5. CONCLUSIONS

Emphasizing the role of individualized dynamic traffic information in assisting drivers' decisions, this study quantitatively evaluates the effects of such information on drivers' adaptation behavior to the occurrence of traffic accidents in the context of expressway based on an SP survey. One of the good features of the SP survey is that it was designed to reflect the influence of each respondent's different driving experience and preference for travel information on the SP responses. The SP survey collected 30,000 SP responses in total. To the authors' best knowledge, no study in literature has been collecting such large-scale SP survey data, especially with individualized values of SP attributes. Another feature is that several new types of traffic information are examined, including the queue changing trend and clearance time information as well as the location to the accident site. Furthermore, to clarify drivers' heterogeneous adaptation patterns, a data mining technique called Exhaustive CHAID approach is adopted and derived about 30 patterns for three decision scenes, i.e., before departure, on the way to expressway and on expressway. Influential information contents are considerably different across the adaptation patterns, confirming the importance of individualized dynamic traffic information. Fortunately, these days, more and more individualized ICT devices (car navigation system, iPad, mobile phone with GPS function and other applications, etc.) are becoming more and more popular for not only young generation, but also other generations. It is expected that such progress of ICT technologies can not only assist drivers to make much smarter choices, but also provides various opportunities for transport policy makers to solve various transport issues, including traffic accident and congestion. Future studies should focus on how to develop better dynamic traffic information systems with careful consideration of individual drivers' heterogeneous preference and risk attitude. Such systems should be properly evaluated before the actual introduction to the real world.

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