Chapter 10
ICT-Based Traffic Safety Measures and Drivers' Responses

Junyi Zhang, Wonchul Kim, and Akimasa Fujiwara

Abstract With the rapid progress of information and communication technologies (ICT), measures and policies targeting specific individuals rather than the public have become possible. Focusing on traffic safety measures, this study examines the effects of in-vehicle traffic warning information (IVTWI) on reducing driving risk, which is defined based on changes of driving speed. An ordered response probit model is used to represent driving risk by explicitly reflecting the influence of short-term memory and long-term driving experience. Based on data collected from an on-site driving experiment targeting a signalized intersection with limited signal visibility in Hiroshima City, Japan, the model estimation results showed that driving risk could be reduced by providing IVTWI in that the utility of this information gradually decreased up to 20 s after it was provided. However, IVTWI remained effective for 7.5 s. It was found that in an interactive traffic situation, the decay of information utility was faster than in a free-driving situation. This indicates that the timing and human–machine interface of IVTWI provision should be considered based on the degree of traffic congestion. Regarding the influence of driving experience on drivers' short-term memory, the results showed that extensive driving experience improves drivers' memory of IVTWI.

Keywords Driving risk • Short-term memory • Traffic accident • Warning information

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10.1 Traffic Accidents, Human Errors and Roles of ICT-Based Measures

In the field of traffic safety, the motto “zero accidents and no injuries” would be the ideal target for happiness and health. To prevent traffic accidents, the design of interventions has traditionally used three major approaches known as “3E”; that is, Education, Enforcement and Engineering. Education is concerned with road users (i.e., drivers, pedestrians, or cyclists) and provides them with knowledge, skills and attitudes related to safe driving. Enforcement changes aggressive behavior by road users by imposing penalties if they do not comply with traffic rules. Engineering involves both vehicle and road engineering. It is also argued that encouragement should be listed as the fourth “E.” This concept refers to techniques of behavior management designed to elicit safer road user behavior through modifying its consequences. However, it is hard to achieve this “zero accidents and no injuries” ideal because various components interact in road traffic systems. It is widely agreed that road traffic systems are composed of humans, vehicles and roads as well as driving contexts (e.g., traffic volume, weather condition, and time of day). Thus, a traffic accident may be considered as a system failure. The relative contributions of the components to accidents were clearly analyzed in studies (Sabey 1980; Treat 1980) showing that road conditions caused 28–34 % of traffic accidents, human error caused 93–94 %, and vehicle factors caused 8–12 %.

According to the National Police Agency of Japan (NPA 2007), the number of traffic fatalities of primary parties due to “distracted driving” and “looking aside while driving” has decreased at a very slow pace in recent years. This is also true for the numbers due to “failure to confirm safety factors (e.g., failure to stop before the “Stop” sign)” and “improper steering/braking” (Fig. 10.1). To reduce the number of traffic accidents, it seems important to assist drivers by providing them with proper information.

To improve traffic safety, the Japanese Ministry of Land, Infrastructure and Transport (MLIT) has actively promoted the development and application of advanced technologies such as Advanced Cruise-Assist Highway Systems (AHS) (MLIT 2007). One of the key AHS technologies is the in-vehicle traffic warning information (IVTWI) system, whose effects on traffic safety are not yet clear. One of the main reasons for this is that driving behavior has not been satisfactorily represented in research literature. When information is provided to people, it may not be retained for long in their memory. Several studies have demonstrated that even immediately after passing a sign to which they clearly responded, most drivers cannot recall what the sign was (Martens 2000; Milosevic and Gajic 1986; Shinar and Drory 1983). Psychologists have addressed this forgetting phenomenon, using two principal theories: time-related forgetting (Baddeley 1997; 1983; Henderson 1999) and interference-related forgetting (Lewandowsky et al. 2004). The former indicates that the information stored in human memory decays over time, whereas the latter means that old information in memory is displaced by new information. A wide range of interfering factors may cause people to forget information while performing a task.

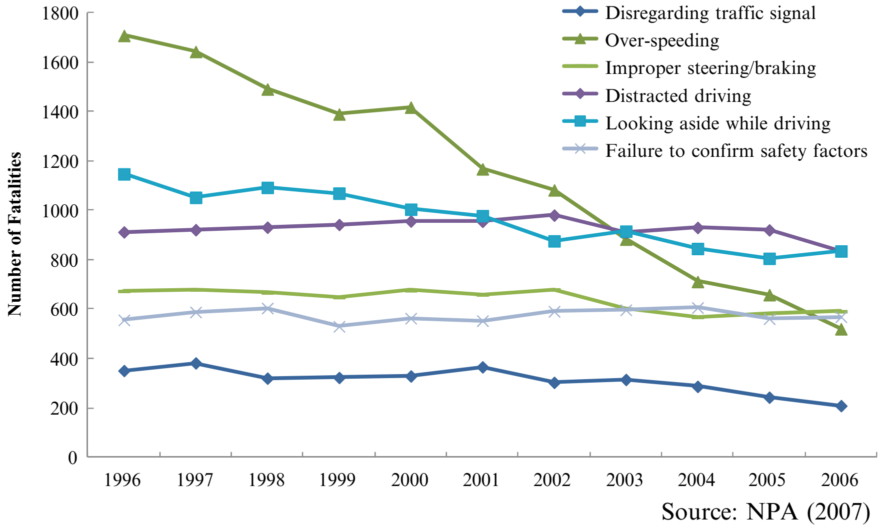

Fig. 10.1 Numbers of traffic fatalities of primary party by human errors. Source: NPA (2007)

The driver of a car receives information through multiple channels, such as driving environment, vehicles, and other drivers/passengers. However, it seems reasonable to suggest that if IVTWI could be provided at the right time and in the right format, the effects of interference might be minimized. For this reason, it is important to understand how drivers react to IVTWI while driving and how factors such as the timing and format of IVTWI provision influence this reaction. However, even the best existing analysis approaches adopt a dummy variable (i.e., one and zero) to indicate information provision while assuming that the effects of the information remain constant from the time it is provided. This is clearly unrealistic considering the forgetting phenomenon inherent in human short-term memory.

In this chapter, approaches to overcoming the limitations of existing studies are first developed, and drivers' responses to the IVTWI are examined by explicitly incorporating the influence of drivers' short-term memory, focusing on a signalized intersection with a limited signal visibility in Hiroshima City (see Fig. 10.2). The target intersection, named Hiranobashi-higashi intersection, is located on the national highway 'Route 2' in the central area of Hiroshima City, and it is close to a bridge and formed with a crest vertical alignment with the crest at 120 m from stopline. Drivers more than 190 meters from the stop line on this approach usually have difficulty seeing traffic conditions in front. This makes this intersection one of the most dangerous on the national highway. Although a prewarning traffic signal is installed on the median strip, it has been reported as ineffective because it is too close to the traffic signal. The poor visibility has frequently caused rear-end collisions. This type of traffic accident is typical of those observed on Route 2, which, being located in the delta area of Hiroshima City, includes many river bridges.

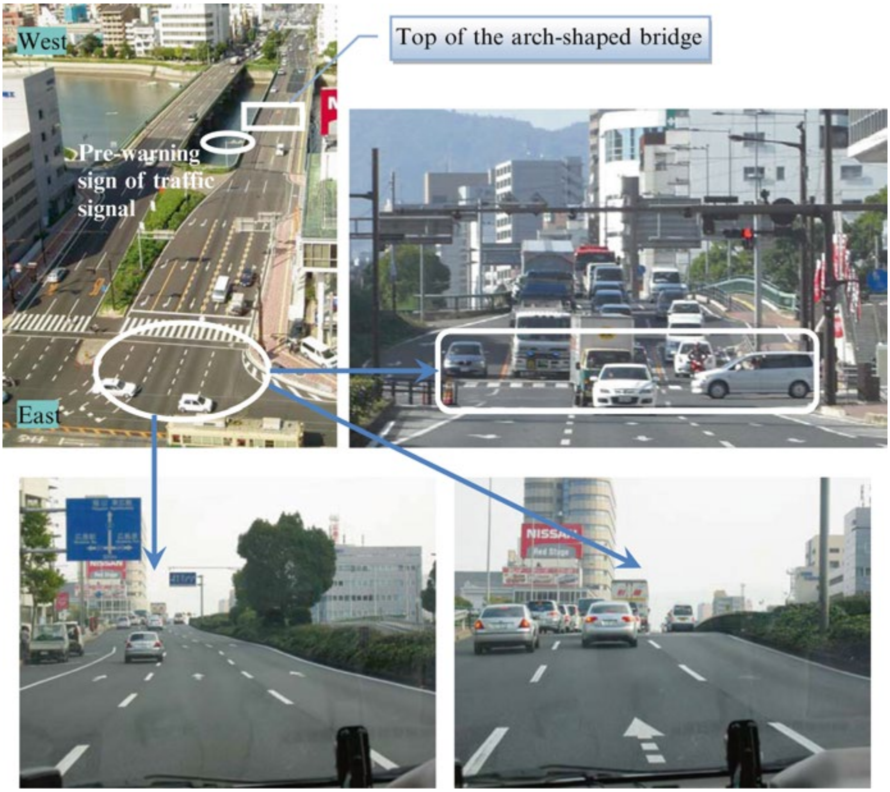

Fig. 10.2 Poor visibility nearby the Hiranobashi-Higashi intersection

10.2 Development of a Driving Risk Model

The common finding that an increase in speed deviation (i.e., the difference between a driver's speed and the average speed on a section of road) could increase the likelihood of an accident led us to adopt magnitude of speed deviation as an indicator of traffic safety. We therefore use the term *driving risk* to describe the level of road safety in terms of a driver's speed on a road section. In other words, greater homogeneity of speed increases safety (Lassarre 1986).

To define the level of *driving risk*, the unit of standard deviation is proposed because in most cases, it approximates the 85th percentile minus the average speed (TRB 1998, p. 42). Road segmentation is relevant when evaluating traffic safety. Two methods are generally suggested: the homogeneous-segment method (Kweon and Kockelman 2005) and the fixed-length method (Shankar et al. 1995). To control for geometric features rigorously, the former method has been the prevailing approach. In this approach, the roadway is first divided into sections according to the characteristics of vertical and horizontal alignment (e.g., horizontal curves and

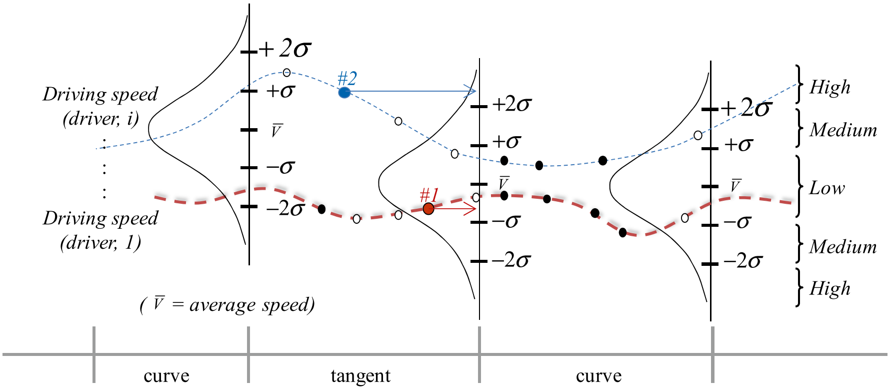

Fig. 10.3 Concept of driving risk measurement

radius and vertical grades), and the average speed and standard deviation are then computed for each section.

Figure 10.3 shows the concept of *driving risk*. The risk is reduced when individual driving speed falls within a range of one standard deviation on a road section; otherwise, it increases. For example, in the case of driver *i* (i.e., the dashed line in Fig. 10.3) traveling on the tangent of a roadway under study, the level of *driving risk* at points #1 and #2 can be evaluated as low and high, respectively.

By measuring the magnitude of speed deviation, it may be seen that the level of *driving risk* can be considered as a categorical variable showing that the danger of driving behavior will increase with larger values of y_n. To represent this variable, an ordered response probit (ORP) model is applicable. The ORP model can be constructed by defining the following latent variable. Here, sample *n* refers to the value of measured speed:

$$y_n = \begin{cases} 1, & if\ \Delta V_n \le \sigma & \rightarrow \text{Low driving risk} \\ 2, & if\ \sigma < \Delta V_n \le 2\sigma & \rightarrow \text{Medium driving risk} \\ 3, & if\ \Delta V_n > 2\sigma & \rightarrow \text{High driving risk} \end{cases} \tag{10.1}$$

$$\Delta V_n = \left|\bar{V} - V_n\right|$$

$$y_n^* = \beta' x_n + \varepsilon_n \tag{10.2}$$

where

y_n : level of *driving risk* of sample *n*,
V_n : driving speed of sample *n*,
$\bar{V}$: average speed on a road section under study,
ΔV_n: speed deviation between $\bar{V}$ and V_n,
σ : standard deviation,
y_n^* : latent variable capturing the *driving risk* of sample *n*,

x_n : vector of explanatory variables,
β : vector of parameters to be estimated, and
ε_n : error term assumed to follow a standard normal distribution.

10.3 Influence of Forgetting on Human Decisions

As Fuller and Santos (2002) stated, human memory can be divided into two parts: short-term and long-term memory. Long-term memory is more closely related to driving skills through habits formed by repetition over a long period of time (Shinar 2007). Drivers also use short-term memory in driving situations. Since short-term memory was first defined by Locke in the 17th century (Logie 1996), many researchers have found that its capacity is limited (Ebbinghaus 1885/2012; Miller 1956), that information in the short-term memory decreases over time (Lay 1986; Peterson and Peterson 1959) and that it will fade (or will be replaced) if another task is interposed (Cumming 1964). For example, Ogden (1995) mentioned that details of most features such as signs, signals, pavement markings, other vehicles, and pedestrians that a driver encounters on a trip, are merely "noted," and after use (if any) is made of the information, it fades from memory, without entering the long-term memory. This suggests that information stored in a driver's short-term memory declines because of the lapse of time and interference.

However, most existing studies of traffic warning information have introduced a dummy variable, with a value of one representing information provision and zero meaning no information is provided. The value of one implicitly suggests that the utility of the information provided to a driver remains constant. This would mean that the timing of information provision is irrelevant. However, the more time there is between information provision and the moment a driver needs to react to it, the more likely the information is to fade from the driver's memory. Because short-term memory is likely to lose information over time, the above "general rule" might be unrealistic. To measure the influence of traffic information properly, it is necessary to examine how the information provided decays in a driver's memory while he/she is driving. In real driving situations, sources of interference are manifold, and IVTWI provision should be timely. Therefore, IVTWI stored in short-term memory may fade rapidly because of various sources of interference during driving. Reflecting knowledge from previous studies in both transportation and other fields, especially psychology, this study assumes that the utility of IVTWI should be positive and that it will gradually decrease to zero, indicating that the information is completely forgotten or no longer useful. Thus, the following three assumptions related to the utility of IVTWI can be made.

(Assumption A) The utility of IVTWI is generated at the time of provision.
(Assumption B) The utility of IVTWI decreases over time after provision.
(Assumption C) The minimum utility of IVTWI is zero.

The forgetting curve in human memory was first generated by Ebbinghaus (1885/2012). Rubin and Wenzel (1996) recently examined the regularity of forgetting with a two-parameter function investigating the possibility of using one retention function to describe memory. They presented five functions—a linear, an exponential, a logarithmic, a power, and a hyperbolic function—to describe the regularity of forgetting. In the present study, the hyperbolic function is excluded because it has been found to be mostly useful for measuring animal memory (Harnett et al. 1984; Staddon 1983). The simplest form of function is the linear function. However, its drawback is that in an actual curve-fitting procedure, negative values of M (for large values of t) never occur. The exponential function has a simple form; its effectiveness has been confirmed in many short-term memory experiments, and consequently it has been widely applied to describe short-term memory (Peterson and Peterson 1959; Wickelgren 1970; Dosher and Ma 1998). The use of a logarithmic function was supported by early studies (e.g., Luh 1992; Woodworth 1938; Crovitz and Shiffman 1974). Like the linear function, the logarithmic function has the limitation that a negative value for the amount of memory U can be observed when t exceeds a certain value. Moreover, when $t = 0$, the logarithmic function cannot be defined. Finally, the power function was proposed and validated by Wickelgren (1974, 1975a, b), Wixted and Ebbesen (1991), and Sikström (2002); however, its most serious drawback is that it cannot be defined when time $t = 0$.

Providing IVTWI through a navigation system may become ineffective when a driver cannot interpret the information quickly or take action in response. Furthermore, during and after IVTWI provision, drivers must process other information concurrently because of interference (e.g., information related to driving, vehicle controls and unrelated thoughts). Hence, forgetting commences soon after the IVTWI is provided.

Figure 10.4 illustrates a driving situation with IVTWI provision, considering event-related interference and with constant strength of information.[1] In this case, a driver receives the information from 8 to 20 s after a predefined reference time (0), meaning that the exposure to IVTWI is for 12 s. Traditionally, a dummy variable is adopted to distinguish between cases with and without information, using "1" to represent a case "with information" and "0" for one "without information." This assumes that before IVTWI exposure, the utility of information is zero, and that it reaches its maximum at the start of exposure and continues at the same level to infinity (Fig. 10.4). However, given the influence of short-term memory, this assumption is not realistic, and the utility function should be defined so that it decays over time.

The four forgetting functions mentioned above have been validated using only data from small-scale laboratory experiments conducted by psychologists. To apply them to the case of IVTWI, some modifications may be required. In addition, it is necessary to discover the most suitable form of the function for reflecting the influence of short-term memory on driving, as illustrated in Fig. 10.4. To do this, we modify the function as shown in Eqs. (10.3)–(10.6), by adding a dummy variable ρ and a new term t_0. The variable ρ is used to indicate the state of information provision, and it equals 1 "after information provision" and 0 "before information provision." The elapsed time

[1] For example, when a driver receives two types of information, voice and image, with same content, the retention time of the information might be different because the strength of information is different.

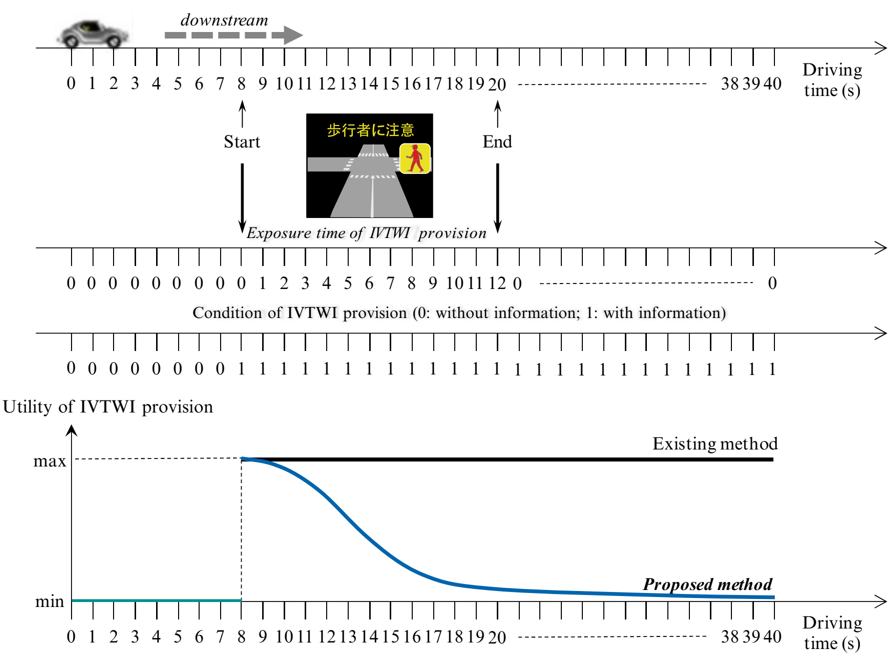

Fig. 10.4 Illustration of IVTWI provision and hypothetical utilities

t is further divided into two parts: driving time t and initial time of IVTWI exposure t_0, where t_0 is included in t:

$$U(t) = (-m \cdot (t - t_0) + b) \cdot \rho : \text{linear function} \tag{10.3}$$

$$U(t) = (b \cdot e^{-m \cdot (t - t_0)}) \cdot \rho : \text{exponential function} \tag{10.4}$$

$$U(t) = (b - m \cdot ln(t - t_0)) \cdot \rho : \text{logarithmic function} \tag{10.5}$$

$$U(t) = (b \cdot (t - t_0)^{-m}) \cdot \rho : \text{power function} \tag{10.6}$$

where

$U(t)$: utility of information usage (i.e., in psychology, the amount of memory),
m : forgetting rate,
b : intercept to represent strength of information, and
t : elapsed time.

Of the above four functions, the exponential function is the most appropriate form for describing the utility that a driver derives from using the IVTWI, reflecting the forgetting phenomenon in short-term memory shown in the above three assumptions (A, B and C). Having clarified the form of the function describing the utility of IVTWI, the effects of IVTWI on driving behavior will be evaluated. However, first the data used in this study are described briefly.

10.4 On-site Driving Experiment: In-vehicle Traffic Warning Information Provision

To examine the effects of IVTWI provision, we conducted an on-site driving experiment (also called a probe vehicle experiment) from November 21 (Tuesday) to 27 (Monday), 2006, targeting the signalized intersection shown in Fig. 10.1. Fourteen young drivers (one female and 13 male students from a local university) were recruited. All were in their early twenties (an average of 22.5 years of age with a standard deviation of 1.7 years), and 86 % had driven in the study area only once before, and 64 % had less than 3 years of driving experience. The experiment was conducted every day from 9:00 a.m. to 5:00 p.m., avoiding morning and evening peaks to remove bias due to external factors, such as excessive congestion or low speed. Table 10.1 shows the weather conditions during the experiment.

Four types of IVTWI were tested: static and dynamic voice-based information, and static and dynamic voice and image-based information (see Fig. 10.5), provided at one of two times (210 and 300 meters before the stop line). A "no information" scenario was also included. The information types and timings were combined and shown to drivers randomly. When stopping vehicles were detected in the surveillance area (i.e., between the crest and the stop line), the information "Attention, stopping vehicles ahead!" was announced via the navigation system (called dynamic information). If the surveillance area was free from stopping vehicles, the information "Attention, traffic signal ahead!" was provided (called static information). The static information did not mean that the signal had changed but was a simple warning to alert

Table 10.1 Weather conditions during the on-site driving experiment

Date	11/21	11/22	11/23	11/24	11/25	11/26	11/27
Day	Tue	Wed	Thu	Fri	Sat	Sun	Mon
Weather condition	Clouds, Rain	Sunny	Clouds	Sunny	Sunny	Rain	Clouds, Rain

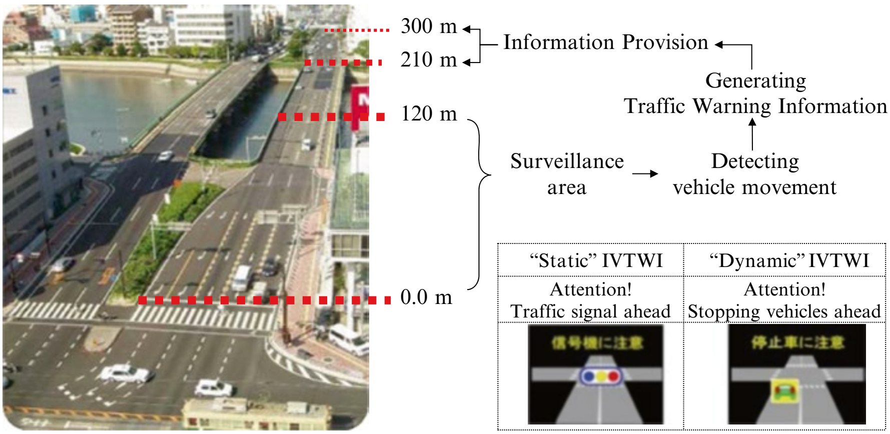

Fig. 10.5 Study area of the first on-site driving experiment

(i) Probe vehicle (ii) HUD image

Fig. 10.6 Apparatus used in the first on-site driving experiment. (i) Probe vehicle, (ii) HUD image

the driver to the signal. Stopping vehicles were detected in real time by an experimenter observing the intersection from the window of a room on the 11th floor of a high-rise building near the intersection, from which position vehicles could be clearly identified. The experimenter was in direct contact with another experimenter, who controlled the IVTWI provision from the rear seat of the probe vehicle. Once the IVTWI was triggered, the information was displayed until the driver crossed the stop line. Because exposure time changed with driving speed, the average exposure to the IVTWI was 21.38 s. Before the experiment, drivers were instructed to drive the probe vehicle along the designated route as usual. They knew that they would receive traffic information from the navigation system inside the vehicle, but they did not know when or what kind of information would be provided.

Figure 10.6 shows the probe vehicle used for the on-site driving experiment. The probe vehicle in this study was developed by the National Institute for Land and Infrastructure Management in Japan. A Global Positioning System (GPS) sensor equipped in the probe vehicle automatically recorded the location, driving speed, acceleration and deceleration every 0.1 s. Other driving metrics, such as lateral acceleration, gap distance (distance from other vehicles), braking pressure and handling were measured using built-in sensors on the vehicle. Information was provided to drivers via the voice- and/or image-based human–machine interface (HMI). The IVTWI images were shown through a heads-up display (HUD) on the windshield, superimposing the information on the driver's view of the road environment.

10.5 Model Specification, Estimation, and Effects of Information Provision

10.5.1 Utility Function with Short-Term Memory

To clarify the effects of IVTWI provision and other factors on traffic safety, the *driving risk* model with an ORP structure (Eqs. (10.1) and (10.2)) was applied. For comparison, two types of ORP models were estimated. One model only had a

Table 10.2 Variables used for model estimation

Variables	Definition	Mean	S.D.
Traffic flow factors			
Speed change	The absolute value of the difference between speed at time t and that at t-1 (the time interval is 0.1s in this study) [km/h]	0.169	0.251
Gap distance	The distance between the rear end of preceded vehicle and the front end of the probe vehicle, divided by 1000 [m]	0.104	0.034
Geometry factors			
Signal visibility	The ability of a driver to identify traffic signal due to obstacles [0 = visible (over 190 m from the stop-line); 1 = invisible]	0.351	0.477
Vertical grade	The absolute value of vertical grade divided by 10 [%, positive sign = upgrade; negative sign = downgrade]	0.285	0.199
Environment factors			
Road surface	The condition of road surface when driving was performed on the subject road [0 = dry; 1 = wet]	0.432	0.495
Time slot	The time of day implementing the driving experiment during a day [0 = morning; 1 = afternoon]	0.491	0.500
Day slot	The day of recording the scene either weekday or weekend [0 = weekday; 1 = weekend (holiday)]	0.589	0.492
Driver factors			
Trial number	The number of driving trials on the subject road during a day divided by 10 [integer, positive sign]	0.300	0.135
Driving experience	The real driving experience (i.e., months) of each driver divided by 10 [integer, positive sign]	0.196	0.108
Provision of the in-vehicle traffic warning information (IVTWI)			
Provision of IVTWI	Whether the IVTWI is provide or not [0 = without information; 1 = with information]	0.659	0.474

dummy variable to indicate that IVTWI was provided, which was set to one if information was provided and zero otherwise. This model is called "the existing model." Another model, called "the proposed model," was constructed based on the exponential form in Eq. (10.4). In line with the studies by Dosher and Ma (1998) and Wickelgren (1970), the distribution of forgetting over time shown in Eq. (10.4) was modified for application to real driving situations, based on the assumption of a Gaussian distribution with mean 0 and standard deviation σ_t, where σ_t indicates the strength of the forgetting curve to be estimated:

$$U(t) = \begin{cases} \dfrac{1}{\sigma_t\sqrt{2\pi}}\exp\left(-\dfrac{(t-t_0)^2}{2\sigma_t^2}\right) & \text{if } t \geq t_0 \\ 0 & \text{if } t < t_0 \end{cases} \tag{10.7}$$

where the other notations are as described in Eq. (10.4).

To estimate the *driving risk* models, the independent variables shown in Table 10.2 are adopted, and five major types of factors are included: traffic flow factors, geometric factors, environmental factors, driver factors, and provision of IVTWI. The effectiveness of both the existing and proposed models is confirmed. It is also clear that the proposed model is superior to the existing model. For details, refer to Kim et al. (2010).

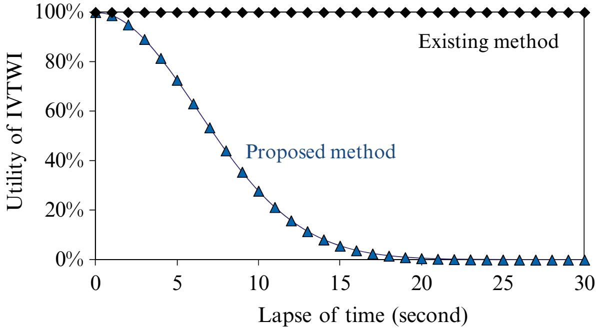

Fig. 10.7 Estimated utilities of IVTWI between the existing and proposed models

10.5.2 Effects of In-vehicle Traffic Warning Information Provision

The parameter for IVTWI provision has a positive value in the existing model, meaning that IVTWI provision increases *driving risk*. In the proposed model, however, the corresponding parameter has a negative value, suggesting that the provision of IVTWI is effective in reducing *driving risk*. Because the proposed model has a logical structure and is more accurate than the existing model, it appears most likely that *driving risk* could be reduced by providing IVTWI.

Figure 10.7 shows the estimated utility functions of IVTWI in the proposed model and the influence of IVTWI provision in the existing model. In the case of the existing model with a dummy variable, the influence of provision is constant over time. As stated above, this ignores the forgetting phenomenon. On the other hand, the estimated utility function of the proposed model can describe the three assumptions (A, B and C) related to the characteristics of short-term memory. Specifically, utility begins immediately when IVTWI is provided. The utility monotonically decreases for nearly 20 s, when it approximates the value of zero. This propensity for a decaying curve captures forgetting in the driver's short-term memory. In addition, Fig. 10.7 shows that the elapsed time (almost 7.5 s after provision) that corresponds to 50 % of utility of IVTWI (i.e., on the y-axis) is considerable because the uncertainty of the information provided becomes maximal at that point. Uncertainty about the IVTWI is maximized where the driver can visually confirm the traffic situation in the surveillance area; that is, 190 meters from the stop line. Based on the speed analysis of the collected data, within 7.5 s, a driver can move nearly 105 meters when traveling at an average speed of 50 km/h. In other words, to maximize the influence of IVTWI on driving behavior and traffic safety, information should be provided at least 295 m (= 190 m + 105 m) before the stop line to minimize loss.

The probability of changes in *driving risk* because of changes in IVTWI utility is also interesting. To address this concern, a sensitivity analysis was performed by controlling the variable of IVTWI provision, using a value of zero for discontinuous variables and average values for continuous variables. Figure 10.8 shows the impacts of

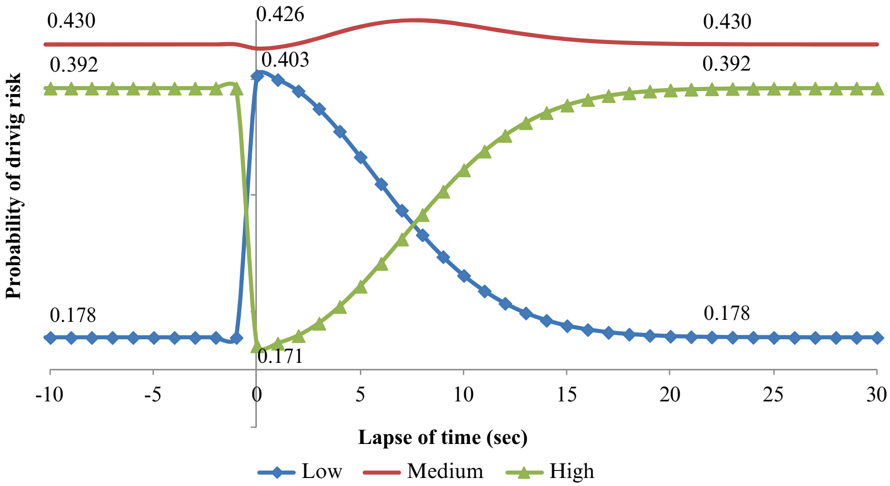

Fig. 10.8 Probability changes in driving risk with IVTWI provision over time

IVTWI provision on changes in probability of low, medium, and high *driving risk*. When no IVTWI was provided (i.e., negative values on the x-axis), the probabilities of low, medium, and high *driving risks* were 0.178, 0.430, and 0.392, respectively. At the instant that IVTWI was provided to drivers (i.e., 0 on the x-axis), these probabilities changed to 0.403 (126.40 % increase), 0.426 (0.93 % decrease), and 0.171 (56.38 % decrease), respectively. These probabilities vary for nearly 20 s, after which they return to the initial condition when no IVTWI was provided. This tendency reconfirms our assumption that the utility of IVTWI is reduced over time. In addition, Fig. 10.8 shows that the impacts of IVTWI provision changed from positive to negative at 7.5 s after provision, showing the same probabilities for low and high risk, and a maximum value for medium risk. After that, the medium risk began to decrease, the low risk continuously decreased, and the high risk further increased until the initial state of *driving risk* (i.e., the "without provision" condition) was reached again.

10.5.3 Comparison with Other Factors

Regarding other variables, it was found that increasing the values for gap distance and vertical grades on wet road surfaces decreases *driving risk*. This finding is consistent with several other studies (e.g., Saad 1996; Haglund and Åberg 2002; Andrey and Kanpper 2003). Other estimated parameters confirm our prior belief that the average *driving risk* has a negative relationship with variables such as speed change, signal visibility, time slot, trial number, and driving experience. For example, the effects of speed changes are similar to the road design consistency indicator used by Cafiso et al. (2005), which is that a larger change of speed

Table 10.3 Elasticity of continuous variables

Continuous variables	*Driving risk* Low	Medium	High
1 % increase in speed change	–0.080	0.005	0.088
1 % increase in gap distance	0.766	–0.048	–0.848
1 % increase in vertical grades	0.468	–0.030	–0.517
1 % increase in trial number	–0.888	0.056	0.982
1 % increase in driving experience	–0.365	0.023	0.404
1 % increase in utility of IVTWI	0.470	–0.030	–0.519

indicates reduced traffic safety. It is also revealed that *driving risk* increases on the road section with limited visibility. In addition, the effects of time slot, trial number, and driving experience on *driving risk* are consistent with earlier studies focusing on the relationship between the characteristics of young male drivers and traffic safety (Masten 2004; Corbett 2003; Yagil 1998; Maycock 1995; Leger 1994; Finn 1986). These studies indicated that *driving risk* could increase if male drivers in their early twenties with less than 2 years of driving experience drove in the afternoon in a one-day repeated driving scenario.

The relative magnitudes of the estimated coefficients are also of interest. Because *driving risk* is specified as a linear function of the explanatory variables, the relative magnitudes of the estimated coefficients of the discontinuous variables are, in most cases, a measure of the relative impacts of those variables on the average *driving risk*. For instance, the estimated coefficient of the discontinuous variable recording signal visibility (= 0.412) is about 2.03 times higher than that of time slot (= 0.203). This indicates that the increase in *driving risk* faced by an individual driving on a road section with limited signal visibility is about 2.03 times higher than that of driving in the afternoon, assuming that all other factors are equal. Most of the estimated coefficients of discontinuous variables can be compared in this way, and their relative influences on average *driving risk* can be ranked.

The comparison of continuous variables is also important. Table 10.3 presents the elasticity results of the variables, showing that all estimates (absolute values) are significantly less than one. This means that changes in any continuous variable lead to small changes in *driving risk*. For example, a 1 % increase in gap distance, vertical grade, or IVTWI utility results in a decreased probability of medium and high risk and an increased probability of low risk. Although the effect of an increased IVTWI utility is smaller than that of increased gap distance, it is of the same magnitude as the effect of increased vertical grade. The results show that provision of IVTWI is effective in reducing *driving risk*.

10.5.4 Effective Ways to Provide the In-vehicle Traffic Warning Information

According to the experimental scenarios, four types of IVTWI were tested; i.e., static and dynamic voice-based information, and static and dynamic voice and image-based information at two different timings of provision (i.e., the different locations of information provision). To assess the effects of these four IVTWI formats on *driving risk* at different locations, we additionally estimated five *driving risk* models. The first model is used to evaluate the influence of location of IVTWI provision (210 m and 300 m from the stop line) on *driving risk*. The other four models are used to evaluate the influences of various information formats (i.e., static or dynamic, voice, or voice and image) at both locations. The first model shows that provision of IVTWI at 300 m from the stop line contributed more to reducing *driving risk* than at 210 m. This suggests that earlier provision of information allows drivers more time to make a safe driving decision before approaching the road section with limited visibility. Furthermore, the other four models demonstrate that drivers preferred the voice-based provision 210 m from the stop line. In contrast, at 300 m, drivers preferred the IVTWI with voice and image. Concerning information type, dynamic information was preferred to static information at both locations.

10.6 Effects of Information Under Heterogeneous Driving Situations

10.6.1 Driving Behavior Under Different Driving Situations

For safety, drivers have to take appropriate action in response to different situations in which the phenomenon of forgetting may arise. Two types of driving situations can be distinguished: the interactive and free-driving situations. In the former situation, a driver must follow another vehicle(s), and in the latter, he/she can drive at his/her own speed. In the free-driving situation, the driver can choose a speed without interference by other vehicles. In contrast, in the interactive-driving situation, the driver must pay sufficient attention at least to the vehicle in front. In this sense, the driver is required to perform more complicated tasks in the interactive situation than in the free-driving situation. Accordingly, under these two heterogeneous situations, it is expected that the roles and effects of IVTWI provision will differ. Because a driver's short-term memory is limited, an additional task while driving may significantly weaken the effects of IVTWI, and such deteriorated effects of information could be more noticeable in the interactive-driving situation than in the free-driving situation. The above psychological explanation suggests that the effects of the information depend on the traffic situation. To evaluate the effects of information on traffic safety properly, the forgetting phenomenon in drivers' short-term memory, especially in heterogeneous traffic situations, must be taken into account.

10.6.2 Data Processing for Analysis

The same data collected in the previous section are used here. Following data retrieval, the 4,836 samples collected are divided into 1,746 samples for the interactive-driving situation and 3,090 for the free-driving situation. Note that a sample means the value for driving speed detected by the probe vehicle every 0.1 s. Because the detection points vary according to speed, different numbers of samples were obtained for each run. If driving speeds were always exactly 60 km/h, for example, the sample size should be 4,320 (= 24 runs × 180 detection points (= 300 m ÷ 16.67 m/s ÷ 0.1 s) along the whole road). However, because driving speed varied across road sections and between runs, the sample size for this study is 4,836. During the on-site driving experiment, two traffic operation factors (speed change and gap distance), two geometry factors (signal visibility and vertical grade), and three environmental factors (road surface, time slot, and day) were observed.

10.6.3 Heterogeneous Effects of Information Provision

1. Specification of Driving Risk Models
   The purpose of this part of the analysis is to investigate how to provide the IVTWI. Specifically, timing, information type (static or dynamic), and human–machine interface (voice or voice and image) will be examined. The utility function reflecting the influence of forgetting is defined in Eq. (10.7), as in the previous section. Two *driving risk* models are estimated: Model 1 and Model 2. Model 1 is used to evaluate the influence of provision timing (i.e., provision locations: 210 m and 300 m from the stop line) on *driving risk*. Model 2 is used to evaluate the impacts of information type (static or dynamic) and human–machine interface (voice or voice and image) at two locations where it is provided. In addition to these information-related variables, variables related to traffic operation, road environment and geometry, and driver characteristics are simultaneously introduced into the *driving risk* models. The samples from the case of no information were excluded.
2. Heterogeneous Effects of IVTWI Provision in Different Driving Situations
   This study assumes that the safety impacts of IVTWI provision may vary over time in the two heterogeneous driving situations. Figure 10.9 confirms this assumption. Specifically, the estimated utility functions approach zero (0.001) at about 17 s in the interactive-driving situation and 20 s in the free-driving situation after providing IVTWI. This indicates that the decay of utility of IVTWI in the interactive-driving situation is faster than that in the free-driving situation. This may be because drivers must perceive and react to more sources of information simultaneously in an interactive-driving situation than in a free-driving situation.

   Regarding the safety impact of IVTWI provision timing, it is shown that drivers prefer to receive IVTWI at 300 m from the stop line rather than at 210 m, which is observed in both heterogeneous traffic situations. This emphasizes that for effective reduction of *driving risk*, the IVTWI should be provided before drivers approach the crest (at 120 m from the stop line) so that they can take proper evasive action.

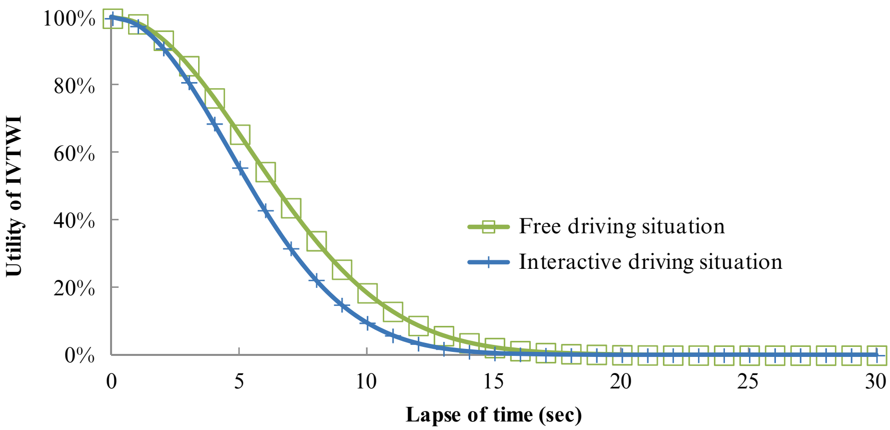

Fig. 10.9 Estimated IVTWI utility functions in heterogeneous traffic situations

The information and human–machine interface types of IVTWI have different effects on *driving risk* according to provision timing. In the interactive-driving situation, dynamic voice-based information is preferred by drivers at 210 m from the stop line, and dynamic voice and image-based information is preferred at 300 m. In contrast, in the free-driving situation, static voice and image-based information is preferred at both 210 m and 300 m.

To examine the safety impacts of IVTWI provision methods in detail (i.e., provision timing, and types of information and human–machine interface) on *driving risk*, a sensitivity analysis was conducted. For this analysis, the concept of "Standard *Driving Risk* Model (SDRM)" is used to represent a standard driving condition, where all variables have their average values. Note that the average value of the IVTWI utility was endogenously estimated from the empirical data.

Figure 10.10 shows that the probability change of *driving risk* is affected by the method of information provision in the two traffic situations. Figure 10.10 (i) shows the probability change of *driving risk* in the interactive-driving situation. In the case without information, the *driving risk* probabilities for low, medium, and high risk are 0.127, 0.634, and 0.239, respectively. These probabilities change to 0.260 (low), 0.626 (medium), and 0.114 (high) when IVTWI is provided. Such changes are also affected by the timing of information provision. For example, when the IVTWI is provided at 210 m, the probabilities become 0.186 (low), 0.471 (medium), and 0.343 (high), and change to 0.251 (low), 0.483 (medium), and 0.266 (high) when the information is provided at 300 m from the stop line. In addition, the *driving risk* probabilities change with the information and human–machine interface types. For example, when the dynamic voice-based information is provided at 210 m, the probabilities change to 0.146 (low), 0.597 (medium), and 0.257 (high), and to 0.144 (low), 0.596 (medium), and 0.261 (high) when dynamic voice and image-based information is provided at 300 m. Similarly, these changes of *driving risk* are seen in the free-driving situation,

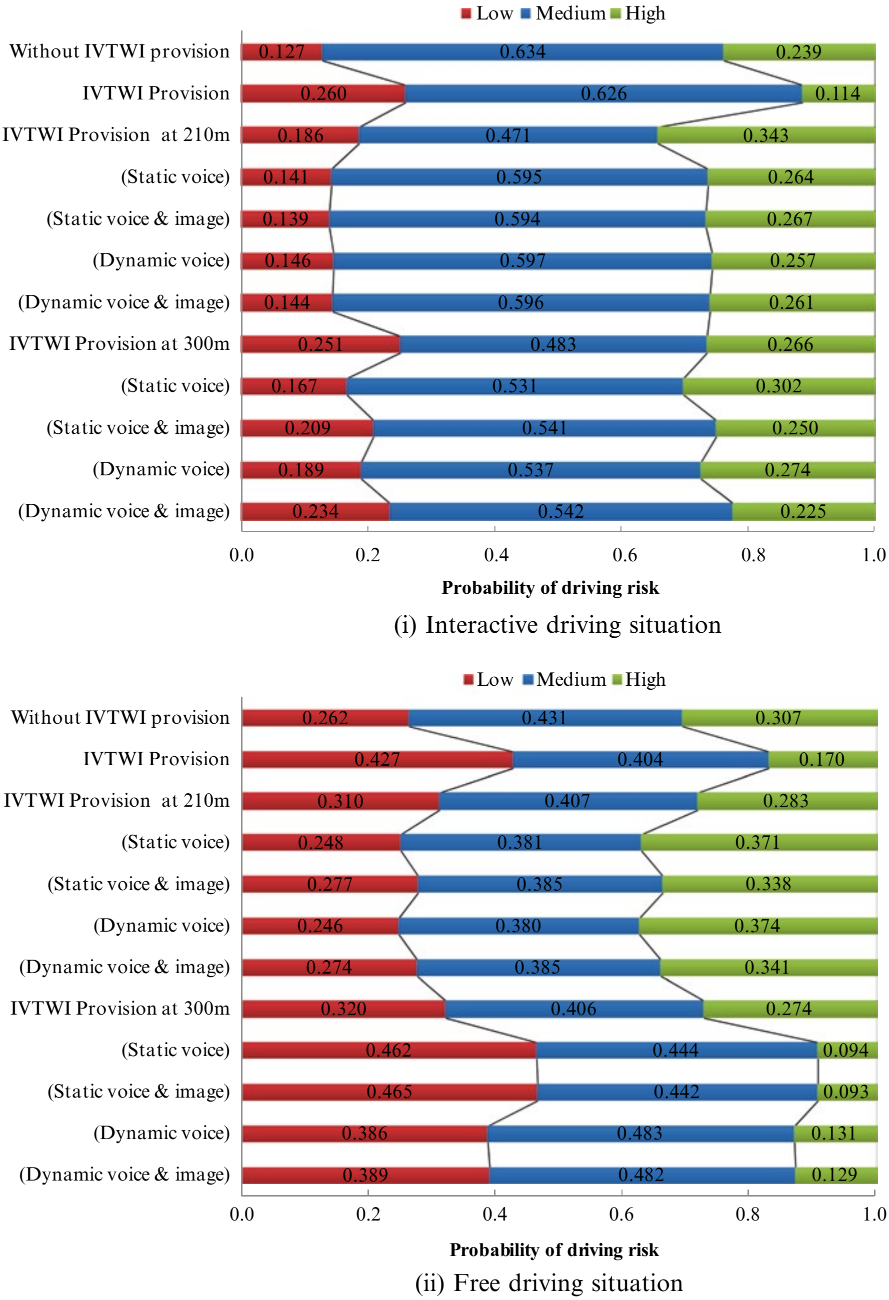

Fig. 10.10 Probability change in driving risk (SDRM condition). (i) Interactive driving situation. (ii) Free driving situation

depending on the information and human–machine interface types under different timings of provision. Figure 10.10 (ii) shows that *driving risk* probabilities in the case without information are 0.262 (low), 0.431 (medium), and 0.307 (high). These values change to 0.427 (low), 0.404 (medium), and 0.170 (high) when the IVTWI is provided. Regarding the impacts of provision location, the same tendency in probability changes is observed in the interactive-driving situation. For example, when the IVTWI is provided at 300 m, the improvement in *driving risk* is greater than that at 210 m in the sense that the probabilities change from 0.310 (low), 0.407 (medium), and 0.283 (high) to 0.320 (low), 0.406 (medium), and 0.274 (high), respectively. These probabilities also vary with information and human–machine interface types. For example, static voice and image-based information is preferred when information is provided at 210 m and 300 m, because the *driving risk* probabilities change from 0.277 (low), 0.385 (medium), and 0.338 (high) to 0.465 (low), 0.442 (medium), and 0.093 (high), respectively.

10.7 Influence of Driving Experience on Information Provision

Experienced drivers are generally expected to take more appropriate action than inexperienced drivers. This expectation has been justified in the studies by Patten et al. (2006) for a peripheral target detection task inside a vehicle and by Shinar et al. (1998) for a test of road sign detection. However, it is questionable whether driving experience has a positive influence on traffic safety for young male drivers (20–29 years old). This is because they have distinctive driving behavior, such as driving faster, decelerating and accelerating more abruptly, being less likely to come to a full stop at stop signs, and being more likely to tailgate other cars than middle-aged (30–64 years old) and older (65+ years old) drivers (Porter and Whitton 2002).

To assess the influence of information provision and driving experience, ex ante and ex post analysis using a dummy variable has been used in previous studies without consideration of human factors, especially drivers' memory. Because traffic safety depends a great deal on drivers themselves, it is essential to account for memory when evaluating traffic safety. Drivers can use as much of the information provided as possible within the capacity of short-term memory. Thus, it is a reasonable hypothesis that the utility of IVTWI changes over time and is affected by driving experience. Therefore, this study will examine this point, particularly by addressing human factors on the basis that the usability of the information provided depends on drivers' short-term memory as well as driving experience.

As shown in Fig. 10.11, in a driving exercise, drivers usually receive several stimuli (e.g., IVTWI and traffic signs) through receptors, perceive and identify these stimuli, and decide on responses within the capacity of their short-term memory. Moreover, this mechanism works according to the forgetting phenomenon, implying that drivers cannot remember all the given information over time. This property of short-term memory is also affected by driving experience.

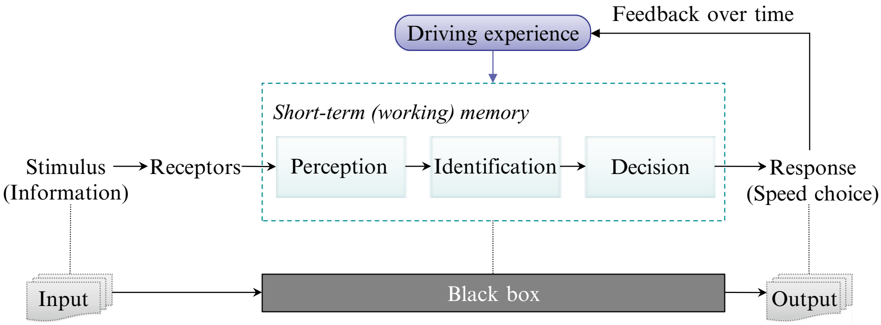

Fig. 10.11 Information process incorporating driving experience

10.7.1 Improving Utility Function and Model Estimation

As argued previously, time-related forgetting in the short-term memory is affected by driving experience. By adding a term for driving experience (DE) to Eq. (10.7), the utility of IVTWI incorporating driving experience can be expressed as follows, where the other notations are the same as described in Eq. (10.7):

$$U(t) = \begin{cases} [\frac{1}{v\sqrt{2\pi}}\exp(-\frac{1}{2}\frac{(t-t_0)^2}{v^2}) + \exp(\gamma(x_{DE}))] & \text{if } t \geq t_0 \\ 0 & \text{if } t < t_0 \end{cases} \tag{10.8}$$

where x_{DE} indicates driving experience, and γ is an unknown parameter to be estimated.

To estimate the *driving risk* model based on the ORP modeling approach, explanatory variables shown in Table 10.2 are adopted. Here we only focus on examining the effects of traffic information on driving experience. For comparison, three ORP models are estimated. One ORP model only has a dummy variable to evaluate the effects of IVTWI, which is set to one for the case of information provision and zero for the case of no information. This is called "the existing model." The other two models employ the utility function of IVTWI to reflect the influence of drivers' short-term memory. These are called "the proposed models." The difference between proposed models I and II is that Model I does not incorporate the influence of driving experience (i.e., $exp(\gamma(x_{DE}))$ is excluded from Eq. (10.8)), while model II does ($exp(\gamma(x_{DE}))$ is included). For detailed estimation results, refer to Kim et al. (2009).

10.7.2 Invariant Effects of Information Provision

The existing model estimates the parameter of IVTWI provision to be positive and statistically significant. This means that IVTWI provision increases *driving risk*.

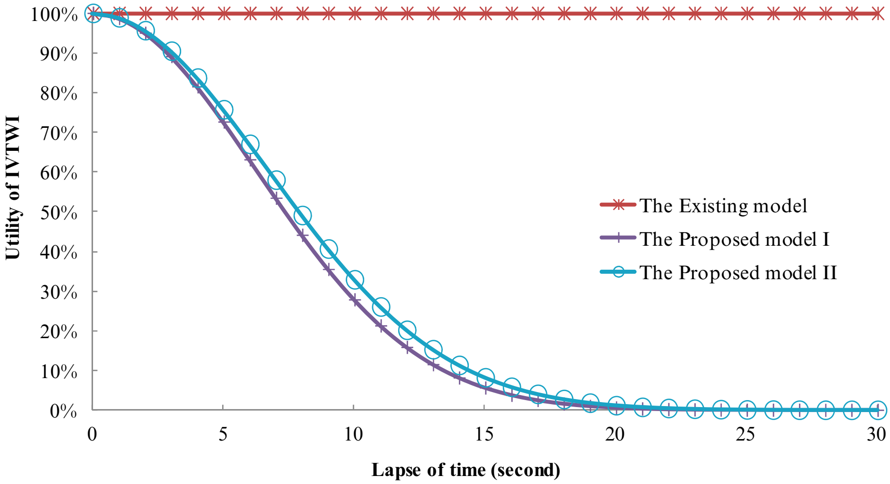

Fig. 10.12 Estimated utility functions of IVTWI in the existing and proposed models

However, in the two proposed models, it is observed that the parameters of the utility of IVTWI are negative, suggesting that IVTWI provision is effective in reducing *driving risk*. Because the proposed models showed greater accuracy than the existing model, it is believed that *driving risk* will be reduced by the provision of IVTWI.

Figure 10.12 compares the estimated utility functions of IVTWI from both the existing and proposed models. In the existing model, the use of a dummy variable implies that the influence of providing IVTWI remains constant over time. This obviously disregards the forgetting phenomenon in drivers' short-term memory. In contrast, the estimated utility functions from the proposed models demonstrate that (1) the maximum utility of IVTWI begins at the onset of provision, (2) the utility of IVTWI gradually decreases for nearly 20 s, and then (3) it approximates a value of zero, which represents minimum utility.

10.7.3 Prolonged Effects of Information Provision

When driving experience is included as an independent factor in short-term memory, it is found in the existing model and proposed model I that *driving risk* increases with the driving experience of a young male driver. However, the effects of driving experience on *driving risk* in the estimation results of proposed model II are different.

Focusing on the impacts of driving experience on the utility of IVTWI, Fig. 10.12 shows that the two utility curves of the proposed models have similar shapes and approach zero at almost the same point in time. Interestingly, the gradient of the estimated utility curve in proposed model II is less than that of proposed model I, but the difference is moderate. This means that drivers with more driving experience (i.e., experienced drivers) can remember the IVTWI provided for a longer time than inexperienced drivers. In other words, the decay of information in the short-term memory of inexperienced drivers is faster than in that of experienced drivers. From this result, we may infer that the likelihood of information loss by inexperienced drivers is higher than that by experienced drivers.

The estimated results also confirm this phenomenon because the absolute value of the parameter (−11.378) of the utility of IVTWI in proposed model II is greater than (−10.626) in proposed model I. This implies that providing IVTWI is more effective in reducing the *driving risk* of experienced drivers, compared with inexperienced drivers. This finding is consistent with the outcomes (e.g., increased driving control in experienced drivers) of earlier studies by Patten et al. (2006) and Shinar et al. (1998).

10.8 Conclusions

In a study of IVTWI, the timing of its provision and the human–machine interface (voice or voice and image), the time-varying utility of IVTWI was conceptualized to reflect explicitly the forgetting phenomenon that is typical of short-term memory. In a numerical analysis, it was found that an exponential function is the most appropriate form to describe this phenomenon. The effectiveness of the proposed approach—that is, incorporating the time-varying utility function into the ordered *driving risk* model—was confirmed by comparing the results with those from existing evaluation methods that simply rely on a dummy variable (0 = without information; 1 = with information).

Based on data collected from an on-site driving experiment conducted at a dangerous signalized intersection with limited signal visibility in Hiroshima City, Japan, the model estimation results showed that *driving risk* can be reduced by providing IVTWI, in that IVTWI utility gradually decreased for 20 s after the information was provided. However, the effectiveness of IVTWI utility was likely to remain for 7.5 s after provision. Reflecting the temporal change property in its utility, the effects of IVTWI provision on *driving risk* were further evaluated by comparing the results in two heterogeneous (i.e., interactive-driving and free-driving) traffic situations and incorporating the influence of long-term driving experience. It was found that in the interactive-driving situation, the decay of information provision was faster than in the free-driving situation. This indicates that the timing and human–machine interface of IVTWI provision should be considered according to the level of traffic congestion. Regarding the influence of driving experience on drivers' short-term memory, the results showed that greater driving experience enables drivers to memorize IVTWI better. Based on the results of this study, Table 10.4 summarizes the most effective format in which to provide IVTWI according to location and traffic situations. The overall summary is presented in Table 10.5.

Table 10.4 IVTWI provision ways considering provision location and traffic situation

Traffic congestion level	IVTWI provision at 210 m	IVTWI provision at 300 m
Not considered	Dynamic voice	Dynamic voice & image
Interacting traffic flow (less than 110 m of gap distance)	Dynamic voice & image	Dynamic voice & image
Free traffic flow (more than 110 m of gap distance)	Static voice & image	Static & voice

Table 10.5 Summary of a driving risk model with short-term memory

Driving risk model	Ordered-response probit model based on speed choice behavior
Applied human factors	The time-related forgetting phenomenon of short-term memory in various traffic situations, normal, interacting and free traffic flow, and with influence of driving experience
Used data	An on-site driving experiment
Subject	Young drivers (64 % are with less 3 year driving experience)
Site feature	Urban signalized intersection approach with a limited visibility
Countermeasure	Providing in-vehicle traffic safety warning information
Observed drivers' behavior	Non-stop speed choice behavior
Observed results	– Exponential function is the best for describing the time-based forgetting phenomenon – Goodness-of-fit the proposed model (utility of IVTWI applied) is better than that of the existing model (a dummy variable used) – IVTWI utility gradually decreased up to 20 s after providing the information under the experiment scenario – Effectiveness of IVTWI utility is likely to be kept for 7.5 s after provision under study – IVTWI provision could reduce the *driving risk* – Effects of IVTWI provision vary with driving situations – More driving experience enables drivers to better memorize the provided IVTWI – *Driving risk* decreases with increasing gap distance and vertical grades under wet road condition and decreases with increasing speed change, trial number, and driving experience in the afternoon when the visibility is limited
Limitations	– The effects of driving repetitions in on-site experiment have not been considered

10.9 Future Challenges

How can the level of traffic safety be assessed when there is a lack of traffic accident data? Under such circumstances, how can the effects of new countermeasures for traffic safety still be evaluated? What are the impacts of human factors on traffic safety? What alternative approaches could solve these issues? Such questions are common in the traffic safety field, but no convincing solutions have yet been suggested. In an effort to answer such questions, this chapter has attempted to clarify the effects of providing in-vehicle traffic warning information on traffic safety based on *driving risk* models with driving decision mechanisms, especially the influence of drivers' short-term memory and driving experience. Having shown the effectiveness of the proposed models and demonstrated the potential usefulness of in-vehicle traffic warning information, the limitations of the present study should be recognized. Some suggestions for future research are made with respect to three aspects: data collection, driver behavior modeling and application of human factors.

1. Data Collection
   By means of on-site observation, valid and reliable data can be collected; however, it may not be possible to capture the perceived risk of each driver. If drivers drive several times on the same roadway, the risks perceived by the driver may vary because the driver could become familiar with the road, vehicle and driving environment. This driving phenomenon has not been measured and reflected in the analysis. Measuring changes in perceived risk may be difficult but not impossible. As one measurement technique, for example, it is suggested that researchers monitor drivers' eye movements and capture time of fixation on the same stretch of road, which could then be compared over repeated visits. For this purpose, data collection is recommended on a road section before its opening to the public use or in a virtual reality driving simulator, because in actual driving situations, drivers respond to various contingent events that may complicate the measurement of changing perceived risk. Obviously, on-site driving experiments should be conducted with a variety of driver types, not just younger drivers, on different types of roads.
2. Driver Behavior Modeling
   Driver characteristics related to traffic safety may differ across individuals, because they differ regarding aspects such as experience, motives, trends, and lifestyles. In this sense, the versatile characteristics of subjects should be considered in order to avoid the ecological fallacy, even if only small numbers of drivers participate in the experiments. However, this point has not been considered in developing *driving risk* models. To address the issue of ecological fallacy effectively, the proposed *driving risk* models may be improved by applying fixed/random-effects modeling techniques. Another limitation related to driver behavior modeling relates to the change of driver behavior according to longitudinal and latitudinal span: the former represents driver behavior changes over locations (or time spans) and the latter indicates that driver behavior varies according to the number of traversals of the roadway. For a comprehensive understanding of dynamic changes in driver behavior, chronological analyses (e.g., time-series models and lag-distributed models) and/or Heckman's modeling practices are recommended.
3. Human Factors
   To evaluate the human factors in the influence of IVTWI on traffic safety, this study focused only on time-related forgetting in short-term memory based on the assumption that the strength of IVTWI scenarios—static and dynamic voice-based information, and static and dynamic voice and image-based information—would be the same.

This could limit the practicality of the findings of this research, because the assumption cannot entirely be supported regarding the forgetting features of memory simultaneously affected by various factors such as interference, experience, or strength of information. Nevertheless, overcoming this limitation may be outside the scope of traffic safety engineering. Rather, it may be a task for psychologists in the field of traffic safety. It is therefore recommended that researchers from related disciplines should be involved in interdisciplinary joint research. In addition, to consider the precise characteristics of information processing in traffic safety research, drivers' visual attention and perceived risk status should be elucidated, because information processing begins with visual attention and subjectively perceived risk. For this purpose, it is suggested that researchers capture visual attention using eye cameras and perceived risk through techniques such as questionnaires, group interviews and direct observation of driving behavior.

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