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Impacts of Driving Experience and In-Vehicle Traffic Safety Information on Traffic Stability Risk in Young Male Drivers: An Evaluation Incorporating Driver's Short-Term Memory

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Abstract: The simultaneous impacts of driving experience and use of in-vehicle traffic safety information on traffic safety was investigated in this study, focusing driving behavior of young male drivers. To evaluate this influence, the utility function of the information was first defined by incorporating the influence of driving experience based on the forgetting phenomenon in the short-term memory. By putting this utility function into a driving stability risk model which was built by an ordered response modeling approach based on drivers' speed choice, the level of traffic safety was measured. The estimated results show that driving experience is associated with better recall of the provided in-vehicle traffic safety information, showing that risk of driving could reduce by provision of the safety information. Data used for the analysis was collected through an on-site driving experiment using a probe vehicle, which was conducted at a signalized intersection approach with a limited traffic signal visibility on the national highway "route 2" in Hiroshima City, Japan in 2006.

Key Words: *driving experience, in-vehicle traffic safety information, driving stability risk, short-term memory*

1. INTRODUCTION

It is generally known that experienced drivers are able to take more appropriate responses than inexperienced drivers. This was clearly identified in the studies of Patten *et al*. (2006) for the peripheral target detection task inside a vehicle and Shinar *et al*. (1998) for road signs detection test. In that case, could driving experience also affect the traffic safety behavior of young male drivers? Young male drivers have peculiar driving behavior (Fuller, 2002), e.g., driving faster, decelerating and accelerating more abruptly, being less likely to come to a full stop at stop signs, and tailgating other cars, in comparison to middle aged (30-64 years old) and older (65+ years old) drivers (Porter and Whitton, 2002). The question is what the effects might be when their driving is supported by a traffic countermeasure, e.g., traffic safety warning information. This motivates us to implement a field driving experiment using a probe vehicle that focuses on the driving behavior of young male drivers (20-29 years old) with different driving experiences, providing in-vehicle traffic safety information (hereafter, IVTSI). The experiment was conducted on the national highway “route 2” in Hiroshima City, Japan in November 2006.

To evaluate the influences of driving experience and IVTSI provision on traffic safety, the ex-ante and ex-post analyses using a dummy variable have been used in existing studies. For example, a value of one is used to represent the case of providing safety information or the group of experienced drivers and other cases are denoted by a value of zero (e.g., the case of without information or the group of inexperienced drivers) as a general rule. However, this analysis methodology is insufficient in explaining the influence of these two factors because driver’s human factors are ignored. For example, concerning the impacts of IVTSI, a dummy variable taken one implicitly assumes that the utility (or value) of the IVTSI would be kept constant over time. In real driving situations, however, this might be not true because drivers actually forget the provided information as time passes and other interferences (or countless information) under capacity of short-term memory (STM) and driving experience. Note that, drivers can use the provided information as much as possible within the capacity of STM. In case of evaluating the impacts of IVTSI on traffic safety, it might be a reasonable hypothesis to state that the utility of IVTSI changes over time and this temporal change could be affected by driving experience. To the authors’ knowledge, the existing method is unable to represent such temporal-changes.

Therefore, this study attempts to properly evaluate the impacts of IVTSI on traffic safety by addressing driving experience based on the argument that the usability of the provided information would depend on both STM and driving experience. This requires understanding the mechanism of STM which is the centre of information processing while driving. As shown in Figure 1, for example, in case of a driving task, a driver usually receives several stimuli (e.g., safety information, traffic signs, and/or geometry) through receptors, perceive and identify what the stimuli are, and decide relevant or irrelevant responses within the capacity of the STM. During this procedure, the driver could forget the provided information over time, which is the so-called ‘forgetting phenomenon in STM’. As the assumption of the study, the forgetting phenomenon could be affected by driving experience.

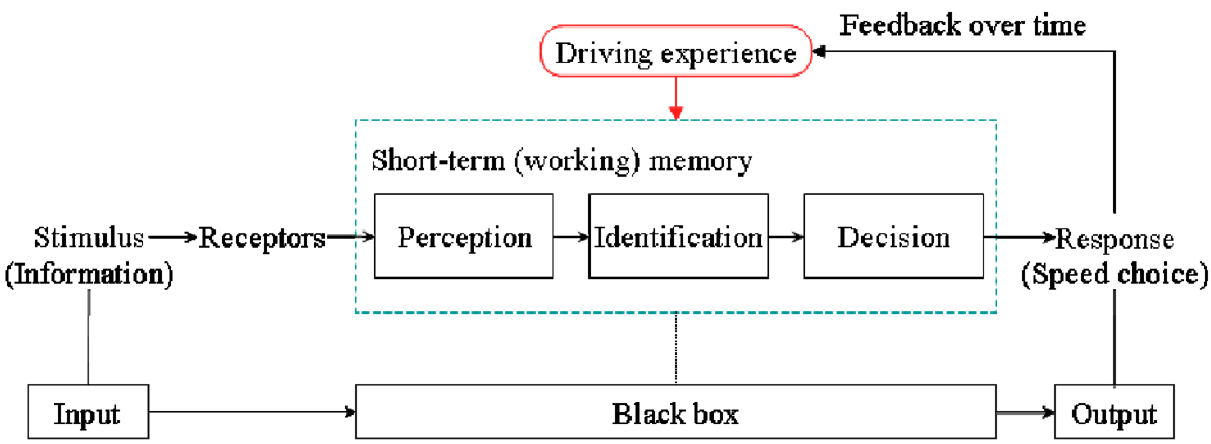

Figure 1 Driving information processing incorporating driving experience

Given the aforementioned assumptions, we will first formulate the utility function of the IVTSI based on the forgetting curve, assuming that the effectiveness of provided IVTSI decreases over time following the forgetting phenomenon in STM. Second, we will develop a new utility function of provided IVTSI by incorporating the influences of driving experience, which seems to work in long-term memory. The impacts of these forgetting in STM and driving experience on traffic safety will be evaluated by specifying a driving stability risk (DSR) model, based on driver's speed choice, in terms of an ordered response probit (ORP) model. In addition, other influential factors, e.g., traffic operating, road geometry, and driving environment, will be tested at the same time. The validity of the proposed method will be examined by scrutinizing the signs and significances of estimated parameters, comparing the results with those of the existing method which uses a dummy variable.

2. Methodology

2.1 Characteristics of Utility of Information Use

It has been known that the traffic safety information through a navigation system inside a vehicle gives either positive safety impacts (Iguchi *et al.*, 1997; Kume, 2000; Maltz and Shiner, 2004) or negative safety impacts (Tsimhoni *et al*, 2004; Blanco *et al*, 2006) on driving behavior in terms of traffic safety. These influences were in fact evaluated by simply using a dummy variable based on an assumption of invariant value of provided information over time. However, this is obviously not realistic in the real driving situation because drivers have the nature of forgetting property in the sense that all drivers cannot perfectly recall the provided signs after passing it even though they clearly respond to (Shinar and Drory, 1983; Milosevic and Gajic, 1986, Martens, 2000). That is to say, it might be worthless if the provided IVTSI faded from driver's memory and it thus might be reasonable to assume that the utility of provided IVTSI varies over time, depending on the capacity of driver's memory.

As cited by Shinar (2007), the driver's memory is composed of two distinct storage mechanisms, i.e., short-term memory (STM) and long-term memory (LTM). In driving situation, it is known that the STM is employed more frequently than LTM. Concerning the STM, Ogden (1995) and Shinar (2007) gave a well description about the characteristics of the STM: "the capacity of the STM is very limited. The information in the STM will be lost after 30s despite it is actively/repeatedly reinforced or by use in some other activity, as well as it cannot be recalled once it has faded. In addition, the information in the STM fades (or it replaced) if another task is interposed". These facts enable us to assume that the utility of IVTSI would be maximal at the onset of provision, decrease over time and disappear after 30s, and should be zero in case of no provision.

A driving task related to the characteristics of STM seems to be influenced by driving experience. For example, Shinar *et al.* (1998) studied the influences of driving experience on sign recognition while shifting gears, assuming that shifting gears would be less automatic for inexperienced drivers (all with less than two years of licensed driving experience) than for the experienced drivers (over 5 years of experience), and the former will therefore have less attention capacity to devote to the signs. The results showed that the inexperienced drivers in general detected fewer signs than the more experienced drivers when shifting gears. This gives some reason to believe that driving behavior would improve by driving experience.

2.2 Specification of Utility Function of Information Use

As mentioned above, one of the apparent features of STM is the forgetting phenomenon over time. To formulate this forgetting phenomenon into a regular function, many psychologists have made a lot of efforts for about one-hundred years. Ebbinghaus (1885/1964) is the first person who generated the forgetting curve and discovered the forgetting propensities (e.g., to be smooth and monotonous, decrease rapidly at first and then gradually level out). Following the same fashion of the Ebbinghaus's study, two functions, i.e., a power function and an exponential function, have been widely developed/applied in psychology field. Even though some studies of Crovitz and Shiffman (1974), Wixted and Ebbesen (1991), and Sikström (2002) support the use of the power function to explain the forgetting phenomenon in STM, the superiority of the exponential function was confirmed by Rubin and Wenzel (1996) and Dosher and Ma (1998).

For the purpose of formulating the utility function of IVTSI provision, we adopt the following descriptive model proposed by Dosher and Ma (1998) which was based on exponential function advised by Wickelgren (1970).

$$U(t) = \lambda e^{-\beta(t)} \tag{1}$$

where,

$U(t)$: forgetting curve at time t following exponential function,

λ : encoded strength for the entire list prior to forgetting, and

β : the forgetting rate

In case of providing IVTSI while driving, time (t) could be divided into two indicators: one is for driving time (t) and the other is for providing IVTSI. To represent these two indicators, the forgetting curve in the equation (1) is modified into equation (2) by adding a variable t_0.

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

where,

ν^2 : unknown parameter, and

t_0 : the timing of providing IVTSI

As argued previously, the forgetting in STM would be affected by driving experience, equation (2) is further re-written as follows:

$$U(t) = \begin{cases} [\dfrac{1}{\nu\sqrt{2\pi}} exp(-\dfrac{1}{2}\dfrac{(t-t_0)^2}{\nu^2}) + exp(\gamma(x_{DS}))] & if\ t \geq t_0 \\ 0 & if\ t < t_0 \end{cases} \tag{3}$$

where,

x_{DS} : driving experience, and

γ : unknown parameter

3. DATA COLLECTION

3.1 Study Area

To evaluate the influence of the IVTSI on traffic safety at a signalized intersection approach with a limited traffic signal visibility (see the left side of Figure 2), a probe vehicle experiment was conducted in the central area of Hiroshima City, Japan from November 21 (Tuesday) through 27 (Monday) in 2006. The intersection named Hiranobashi-higashi intersection is the target study area which has an approach of a bridge structure with a crest vertical alignment being a crest at 120m from a stop line. Due to such vertical structure of road section, drivers outside 190m from the stop line usually face some difficulties to visually recognize traffic signal indications in front. Such poor visibility makes this intersection being one of the most dangerous signalized intersections on the national highway ‘route 2’ in Hiroshima City, especially since 2004.

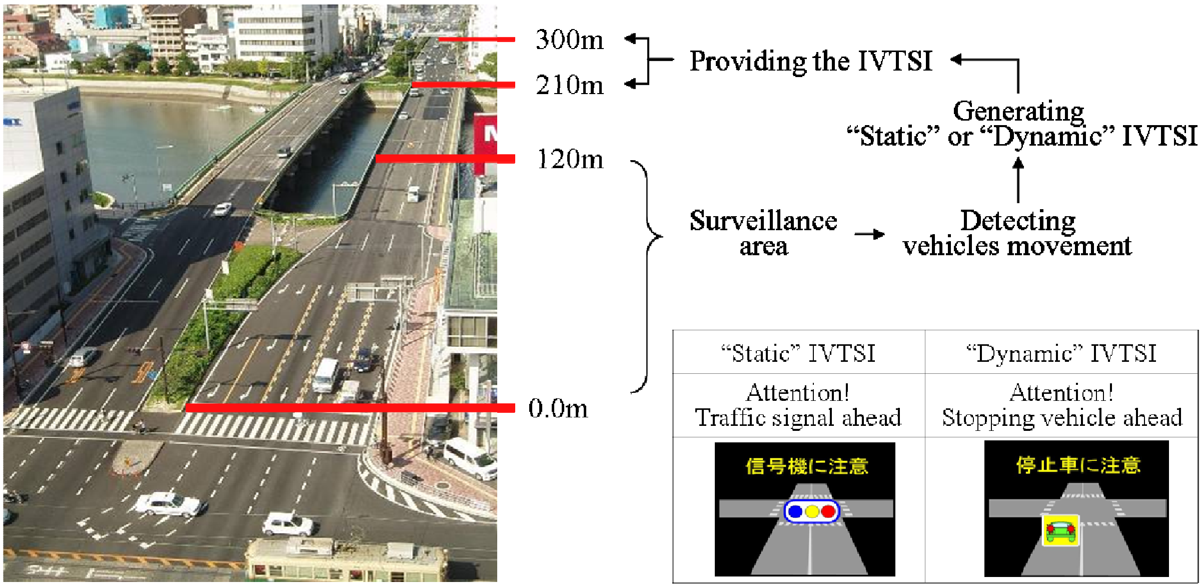

Figure 2 Procedure of IVTSI provision at an on-site driving experiment site

3.2 Experiment Scenario

In the probe vehicle experiment, 14 young drivers (i.e., 13 male, 1 female) participated. The experiment was conducted from 9:00 a.m. to 5:00 p.m., avoiding morning and evening peaks to get rid of the expected external factors, such as, too dense, too low speed, and controlled right of way. Before the start of the experiment, the drivers were asked to drive the probe vehicle along the “route 2” as usual. They knew that they would get some traffic information through a navigation system inside the vehicle, but did not know the exact timing and type of the information. In other words, they did not know the experiment scenarios. To eliminate sampling bias, data of the female driver was neglected in the analysis. All of the young male drivers were 20-29 years old and had between 5-50 months driving experience.

The IVTSI was composed of four types of information, i.e., static and dynamic voice-based information, and static and dynamic voice & image-based information. These four types of information were provided to the drivers depending on the traffic flow condition of the surveillance area, i.e., the area with a limited traffic signal visibility which measured from the stop line to the crest (see Figure 2). Concretely speaking, in case that there were some stopping vehicles in the surveillance area, the dynamic information “Attention, stopping vehicles ahead!" was announced. If there were no stopping vehicles, the static information "Attention, traffic signal ahead!" was provided. The average exposure time of the IVTSI provision was 21.9 seconds, which implied that the IVTSI was released from the location where drivers received the information to the location where they could visually recognize the traffic flow condition in the surveillance area.

3.3 Apparatus

The probe vehicle, developed by the National Institute for Land and Infrastructure Management (MLIT), Japan, was used in the on-site driving experiment. Information related to vehicle movement across the roadway over time and space can be automatically measured. A Global Positioning System (GPS) sensor equipped in the probe vehicle automatically records the location information every 0.1 seconds including driving speed, acceleration and deceleration. Other driving histories, such as, lateral acceleration, gap distance, and pressure of braking and handling, were measured by the built-in sensors. Especially image processing equipments were installed, for example, a Human Machine Interface (HMI) to provide the IVTSI to drivers, and cameras on dashboard and ceiling to record a driver's face in a dangerous driving scene. The images of the IVTSI were projected through a Head-Up Display (HUD) on the windshield to superimpose on the driver's view of the road in front (Figure 3).

(i) A probe vehicle (ii) HUD image

Figure 3 A probe vehicle and HUD image

3.4 Obtained Data

Driving histories of each driver, such as operating speed, acceleration/deceleration, lateral acceleration/deceleration, a gap distance between a leading vehicle and the probe vehicle, acceleration pressure, and brake pressure were recorded per 0.1s. For seven days of an on-site driving experiment, 72 runs were conducted. Only 24 runs were valid cases for a non-stop driving behavior (i.e., drivers crossed the intersection without stopping): 4 cases of no information provision, 12 cases and 8 cases with information at 210m and at 300m from the stop line were valid, respectively. While driving, the traffic operation and safety information provision factors were automatically recorded by the recording system and stored into a hard disk of probe vehicle. Other factors (i.e., road geometry, driving environment, and driver factors) were measured by investigators during the study. More details about obtained data are presented in the Table 1.

4. MODEL ESTIMATION AND DISCUSSION

4.1 A Driving Stability Risk Model

In case of no traffic accident records, speed could be used to evaluate traffic safety level. This argument is supported by the axiomatic relationship between speed deviation and traffic safety. The well-known U-shaped curve by Solomon (1964) shows that the greater the deviation between the average speed and driving speeds the more chance of involvement in a crash. Cirillo (1968) also found similar results. Over a decade later, Lave (1985) studied the relationship between speed dispersion (the difference between the 85th percentile and average traffic speed) and crash occurrence rates by using the data from 48 U.S. states, and found that the more speed dispersion the higher crash rates in most road types. More recently, Garber *et al.* (2000) found that the crash rate increases with an increasing standard deviation of speed for all flow rates in Virginia. Based on these contexts, we define a term of driving stability risk to represent the level of traffic safety based on the relationship between driving speeds and the average speed at a road section. In other words, it is assumed that the DSR increases with increasing speed deviation and that this relationship further varies non-linearly with the magnitude of standard deviation. To estimate the proposed DSR model, the roadway in Figure 2 is first divided into sections of 5m (i.e., length of the probe vehicle), which can be regarded as the minimum road section unaffected by road geometry factors, especially a vertical alignment, because an inclined angle at any location in the vehicle is constant.

To measure the values of the DSR at all divided road sections (60 road sections under study), the above-described relationship between drivers' operating speeds and average speed can be formulated to the following equation (4). Each average speed and its standard deviation at every 5m road section across the whole roadway are represented as $\overline{V}$ and σ, respectively.

$$y_n = \begin{cases} \Delta V_n \le \sigma & \rightarrow \text{Low driving stability risk} \\ \sigma < \Delta V_n \le 2\sigma & \rightarrow \text{Medium driving stability risk} \\ \Delta V_n > 2\sigma & \rightarrow \text{High driving stability risk} \end{cases} \tag{4}$$

where,

- y_n : observed level of the DSR of sample *n* at a road section,
- V_n : driving speed of sample *n* at a road section,
- $\overline{V}$: average speed of a road section under study,
- ΔV_n : speed deviation between $\overline{V}_s$ and $V_{n,s}$ at a road section, and
- σ : standard deviation at a road section.

One can see that the observed DSR level is a categorized variable and the larger value of y_n the more dangerous driving behavior. To represent such categorized variable, an ordered response probit (ORP) model is appropriate. The ORP modeling approach is first defined as the following latent variable.

$$y_n^* = \beta x_n + \varepsilon_n \tag{5}$$

where,

- y_n^* : latent variable capturing the driving stability risk of sample *n*,
- x_n : vector of explanatory variables at a road section,
- β : vector of parameters to be estimated, and
- ε_n : random error term at a road section.

where the error term is assumed to follow a standard normal distribution. Based on the above-defined latent variable y_n^*, the observed DSR variable y_n can be expressed as follows:

$$y_n = \begin{cases} 1 & \text{if } -\infty \le \varepsilon_n \le -\beta x_n & (\text{Low driving stability risk}) \\ 2 & \text{if } -\beta x_n < \varepsilon_n \le \mu_2 - \beta x_n & (\text{Medium driving stability risk}) \\ 3 & \text{if } \mu_2 - \beta x_n < \varepsilon_n \le \infty & (\text{High driving stability risk}) \end{cases} \tag{6}$$

where μ_j (j=1, 2) indicates the threshold to identify the categorized DSR level. The probability associated with each DSR category can be specified as follows:

$$\begin{aligned} Pr(y_n = 1) &= \int_{-\infty}^{-\beta x_n} \phi(\varepsilon_n) d\varepsilon_n = \phi(-\beta x_n) - \phi(-\infty) = \Phi(-\beta x_n) \\ Pr(y_n = 2) &= \int_{-\beta x_n}^{\mu_2 - \beta x_n} \phi(\varepsilon_n) d\varepsilon_n = \Phi(\mu_2 - \beta x_n) - \Phi(-\beta x_n) \\ Pr(y_n = 3) &= \int_{\mu_2 - \beta x_n}^{\infty} \phi(\varepsilon_n) d\varepsilon_n = \phi(\infty) - \phi(\mu_2 - \beta x_n) = 1 - \Phi(\mu_2 - \beta x_n) \end{aligned} \tag{7}$$

where, $\phi(\ )$ and $\Phi(\ )$ stand for the standard normal probability density function and the standard normal cumulative distribution function, respectively. Note that $\mu_1 = 0$ and $\mu_3 = \infty$ are usually assumed for ease of interpretation without loss of generality (of course, any real value can be assumed). This means that only μ_2 will be estimated in the present study.

Equation (7) can be estimated using maximum likelihood estimation method based on the following log-likelihood function, where δ_n^k is a dummy variable with a value of "1" if y_n belongs to category k, otherwise "0." Positive sign of parameter (β) means that the DSR will increase with the value of the corresponding variable, and vice versa.

$$L = \sum_{n=1}^{N} \sum_{k=1}^{3} \delta_n^k \, ln\big(P_n(y_n = k)\big) \tag{8}$$

4.2 Model Estimation

4.2.1 Explanatory variables

As explained above, the DSR model is constructed based on driving behavior, i.e., speed choice behavior. Because speed choice behavior is influenced by many factors, this should be taken into account in the analysis. For this reason, various explanatory variables (e.g., factors related to traffic operation, road geometry, driving environment, driver, and safety information provision) should be simultaneously taken into account in the model estimation, in order to properly estimate the DSR model.

The definitions of each explanatory variable used in this study are shown in the Table 1. Although traffic volume and number of lanes are well known traffic operation factors that influence traffic safety, the speed change and the gap distance recorded by 0.1 seconds were used instead because the modeling approach was focused on microscopic analysis. For the road geometry factors, two variables (i.e., signal visibility and vertical grades) are presented.

According to the driving environment factors, half of the driving experiment was implemented in the afternoon (= 0.491 of mean value). More than half of the driving was conducted on dry road surface (=0.432 of mean value) in weekdays (=0.589). Drivers traversed the study area more than three times and they had 19.6 months of driving experience on average. The information about provision of IVTSI shows that cases with information provision (=0.659 of mean value) are more used in this analysis compared to cases without provision and the utility of IVTSI should be estimated.

Table 1 Explanatory variables used for model estimation

Variables	Definition	mean	S.D.
Traffic operation factors			
Speed change	The absolute value of the speed difference between current and 0.1s past [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
Road geometry factors			
Signal visibility	The ability of drivers to whether or not see the traffic signal indication due to obstacles [0 = visibility (190m from the stop-line); 1 = limited]	0.351	0.477
Vertical grades	The absolute value of vertical grades divided by 10 [%, positive sign = upgrades; negative sign = downgrades]	0.285	0.199
Driving 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 per month of each driver divided by 10 [integer, positive sign]	0.196	0.108
Provision of In-Vehicle Traffic Safety Information (IVTSI)			
Provision of the IVTSI	Provision of the IVTSI [0 = without; 1 = provision]	0.659	0.474
Utility of the IVTSI	The utility of the IVTSI	-	-

- Not relevant; S.D: Standard Deviation

4.2.2 Statistical validity of model estimation

For the purpose of comparison, three types of DSR models were estimated, respectively. One DSR model only introduced a dummy variable to represent the status of IVTSI provision, where the dummy is set to one for the case of with information provision and zero for the case of without provision, which is called “the existing model.” Other models are called “the proposed model I and II” because the proposed utility function of IVTSI is employed. The difference between the proposed model I and II is that the former incorporates only the forgetting phenomenon in STM which was specified by equation (2) and the latter incorporates both the forgetting phenomenon and the influence of driving experience which was specified by equation (3).

The estimation results of the three models are shown in Table 2. Parameters were estimated by the maximum likelihood method using the Time Series Processor (TSP) software (Hall, 1997). To compare the goodness-of-fit of the three models, the adjusted McFadden's Rho-squared ($\bar{\rho}^2$) and Akaike's Information criterion (AIC) are applied (Long, 1997). Observing the results, it is found that the values of $\bar{\rho}^2$ and AIC are improved by 8.2% (= (0.252-0.233)/0.233) and 1.6% (= (1.848-1.879)/1.879) in the proposed model I compared to those of the existing model. These indicators are further improved in the proposed model II, showing that $\bar{\rho}^2$ increases 33.0% (= (0.310-0.233)/0.233) and AIC 7.1% (= (1.746-1.879)/1.879) compared to the existing model.

Table 2 Model estimation results

Independent Variables	The existing model		The proposed model I		The proposed model II	
	Estimate	t-statistic	Estimate	t-statistic	Estimate	t-statistic
Constant	0.913**	10.982	0.838**	10.018	1.875**	21.445
Speed change	0.400**	4.381	0.410**	4.475	0.359**	4.022
Gap distance	–7.443**	–14.514	–6.384**	–11.928	–7.936**	–14.878
Signal visibility	0.323**	8.305	0.412**	10.808	0.457**	11.595
Vertical grades	–1.173**	–13.176	–1.424**	–15.517	–1.584**	–17.000
Road surface	–1.110**	–26.888	–1.050**	–24.769	–0.639**	–14.922
Time slot	0.250**	4.846	0.203**	3.911	0.321**	6.743
Trial number	1.902**	9.596	2.570**	14.649	1.605**	8.950
Driving experience	1.328**	8.005	1.613**	9.773	-	-
Provision of IVTSI	0.096	2.004	-	-	-	-
Utility of the IVTSI	-	-	–10.626**	–10.699	–11.387**	–15.765
μ	1.167**	51.568	1.196**	51.423	1.279**	51.092
ν^2	-	-	39.092**	8.349	44.965**	7.582
γ	-	-	-	-	–25.627**	–39.043
Observations	4836		4836		4836	
Initial log-likelihood	–5924.732		–5971.105		–6113.117	
Final log-likelihood	–4533.361		–4456.993		–4208.739	
$\bar{\rho}^2$	0.233		0.252		0.310	
AIC	1.879		1.848		1.746	

- Not relevant; ** Significant at 1% confidence level; * Significant at 5% level.

4.2.3 Influences of IVTSI provision on traffic safety

The estimated parameter of IVTSI provision in the existing model has a positive sign (=0.096), indicating that the probability of DSR would increase by IVTSI provision. However, in the proposed models, estimated parameters of the utility of IVTSI have negative signs (-10.626 in the proposed model I and -11.387 in the proposed model II), suggesting that the IVTSI provision is effective to reduce the risk of driving stability.

The estimated utility functions of IVTSI provision in the existing model and proposed models are described in Figure 4. Note that a value of "0" on the x-axis represents the time of IVTSI provision. In the existing model using a dummy variable, the influence of providing IVTSI is kept constant as a maximum value over time. This obviously violates the forgetting phenomenon in STM. In contrast, the estimated utility functions from the proposed models demonstrate that (1) the maximum utility of IVTSI begins at the onset of provision, (2) the utility of IVTSI monotonously decreases up to nearly 20s, and then (3) it approximates to a value of “0” which represents a minimum utility. This indicates that the driving stability risk would be lowest at the time of IVTSI provision and it would increase with lapse of time, because the utility of IVTSI fades over time.

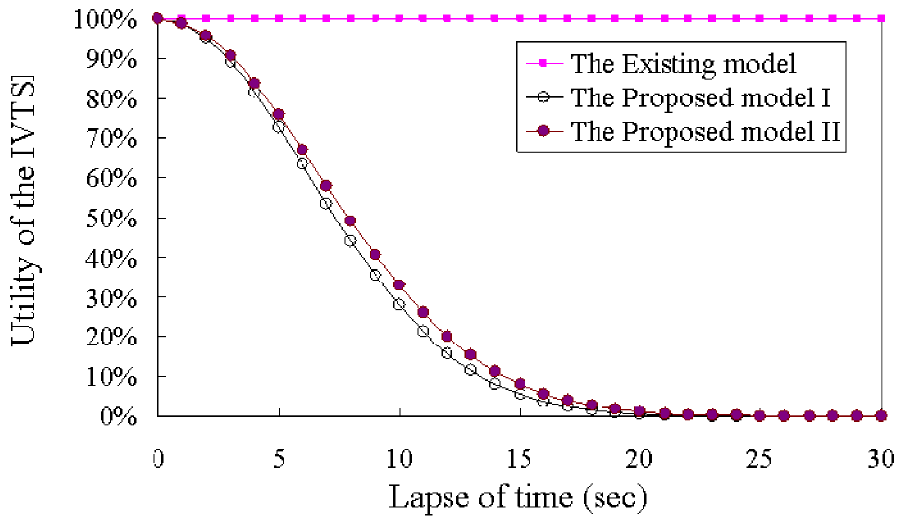

Figure 4 Estimated utility functions of the IVTSI in the existing and proposed models

4.2.4 Impacts of driving experience on traffic safety

Concerning the influences of driving experience on the utility of IVTSI provision, Figure 4 shows that the two utility curves of the proposed models have similar shapes and approach to zero at almost the same point in time. Interestingly, the gradient of estimated utility curve in the proposed model II is less steep than that of the proposed model I although the difference is moderate. This means that the speed of information decay in STM of inexperienced drivers is faster than that of experienced drivers. In other words, experienced drivers could memorize the provided IVTSI for longer time compared to inexperienced drivers.

The estimated results in Table 2 confirm again above findings in the sense that the absolute value of the parameter (-11.378) of the utility of IVTSI in the proposed model II is greater than that (-10.626) of the proposed model I. This implies that providing IVTSI could be effective to reduce the DSR 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).

4.2.5 Influence of other variables on traffic safety

Relating other variables affecting the risk of driving stability, Table 2 shows that the estimated parameters in the existing model and proposed models have the same signs. Based on our prior beliefs, traffic safety could increase with increasing values of gap distance and vertical grades on road sections with wet surface condition. As might be expected, these results confirm findings in existing studies. For example, the Traffic Conflict Technique (TCT) developed by

Hydén (1987) was based the assumption that the likelihood occurring traffic accidents increases with shorter gap distance between vehicles. Haglund and Åberg (2002) found that the likelihood of speeding in flat road sections is higher than that of inclined road sections. The positive influences of wet road surface on traffic safety was confirmed by Andrey and Knapper (2003) who found that drivers pay more attention to their speed control under wet road surface condition.

On the other hand, the results in Table 2 indicate that the DSR could increases with larger speed change and increased trial number at road sections with a limited visibility in the afternoon. The negative influence of larger speed change on traffic safety is consistent with the study by Lamm *et al*. (2002). Concerning the limited visibility, traffic safety (i.e., the DSR) might be jeopardized due to increased expectancy violation. In addition, the DSR would be increased due to repeated driving (i.e., increased trial number) which can cause some fatigue in the afternoon.

5. CONCLUSIONS

In case that drivers receive driving–related information, their decisions and responses are affected by the capacity of memory and driving experience. As evidence, one can find situations in which drivers cannot exactly remember the provided information while driving (the so-called forgetting phenomenon in short-term memory). Commonly, this phenomenon occurs not only in experienced drivers but also in inexperienced drivers. However, the interaction of these two factors (i.e., the forgetting phenomenon and driving experience) has not been satisfactorily investigated in existing studies.

To support the deficiencies of the existing method, this paper has presented a methodology to take such human factors (i.e., the forgetting phenomenon and driving experience) into account in analysis of traffic safety and to evaluate the influences of IVTSI provision on traffic safety. For the analysis, an on-site driving experiment was implemented at a signalized intersection approach with a limited traffic signal visibility in Hiroshima City, Japan. In the driving experiment, 14 young drivers (i.e., 13 males, 1 female) participated who were 20-29 years old and had 5-50 months driving experiences. In this analysis only male drivers' data were used to eliminate sampling bias. Data related to drivers' behavior were collected by a probe vehicle. Four types of in-vehicle traffic safety information (IVTSI), i.e., static and dynamic voice-based information, and static and dynamic voice & image-based information, were provided to drivers depending on the traffic flow condition of the surveillance area, which measured from the stop line to the crest.

To examine these human factors in terms of traffic safety, first the utility function of IVTSI was developed by the exponential functional form based on an assumption that the utility of the IVTSI would be maximum at the onset of provision, decreasing over time, and disappearing after 30s, and that the utility should be zero in case of no provision. This proposed utility function of IVTSI was further improved by introducing a factor that represents driving experience, to describe the interaction impacts of the forgetting phenomenon and driving experience on traffic safety. Second, to evaluate the level of traffic safety based on driver behavior, a speed choice based driving stability risk (DSR) model was proposed. Because the level of driving risk was grouped by a categorical variable, an ordered response probit modeling approach was applied to construct the DSR model. The developed DSR model was used for evaluating the influence of IVTSI incorporating driver's STM and driving experience on traffic safety. Finally, by incorporating the newly defined utility function of IVTSI into the DSR model, the interaction influences of the forgetting phenomenon in the STM and driving experience on traffic safety were evaluated.

From the empirical data analysis, it was found that the proposed utility of IVTSI was well described by the exponential function form. Estimation results confirmed that traffic safety could be improved by providing the IVTSI and experienced drivers could better memorize the information than inexperienced drivers. The results also show the influences of other external factors on traffic safety. It was confirmed that traffic safety could increase when a driver drives with larger gap distance to the proceeding vehicles on inclined road sections with wet surface condition. This might be because drivers feel more comfortable with larger gap distance to a leading vehicle and the likelihood of speeding might be reduced on graded road section on a rainy day. On the other hand, the DSR will increase with increasing values of speed change and increasing trial number on a limited visibility road section. Reasons for this might be that too frequent controlling ac/deceleration could make unstable driving status, the fatigue could increase with number of repeated driving per day, and the expectancy violation could increase on road sections with limited visibility.

Even though the influences of driving experience were analyzed in this study by incorporating the forgetting phenomenon in short-term memory on traffic safety and the results show the superiority of the proposed model in comparison to the existing method, some limitations exist as the on-road driving experiment addressed particular circumstances in terms of participants (e.g. age and gender) and target area due to the limited budget. Nevertheless, it is expected that the proposed method under study could be applicable in other studies that examine the traffic safety impacts of countermeasures (e.g. traffic safety information).

REFERENCES

Andrey, J., and Kanpeer, C. K. (eds.) (2003) Weather and Transportation in Canada. Department of Geography Publication Series. No. 55, University of Waterloo.

Blanco, M., Biever, W. J., Gallagher, J. P., and Dingus, T. A. (2006) The Impact of Secondary Task Cognitive Processing Demand on Driving Performance. **Accident Analysis and Prevention, Vol. 38, No. 5**, pp. 895-906.

Cirillo, J. A. (1968) Interstate System Crash Research; Study II, Interim Report II, Public Roads 35 (3), pp. 71-76.

Corvits, H. F., and Schiffman, H. (1974) Frequency of Episodic Memories as a Function of Their Age. **Bulletin of the Psychonomics Society, 4**, pp. 517-518.

Dosher, B. A., and Ma, J. J. (1998) Output Loss or Rehearsal Loop? Output-Time versus Pronunciation-Time Limits in Immediate Recall for Forgetting-Matched Materials", **Journal of Experimental Psychology: Learning, Memory, and Cognition, Vol. 24, No. 2**, pp. 316-335.

Ebbinghaus, H. (1964). **Memory: A Contribution to Experimental Psychology** (H. A. Ruger & C. E. Bussenius, trans.). New York: Dover (Original work published 1885).

Fuller, R., and Santos, J. A. **Human Factors for Highway Engineering**. Pergamon. p.243.

Garber, N. J., and Ehrhart, A. A. (2000) Effect of Speed, Flow, and Geometric Characteristics on Crash Frequency for Two-lane Highways. **Transportation Research Record, No. 1717**, pp. 76-83.

Haglund, M., and Åberg, L. (2002) Stability in Driver's Speed Choice, **Transportation Research F. No. 5**, pp. 177-188.

Hall, B. H. (1997) **Time Series Processor (TSP) Version 4.4**. Clint Cummins.

Hydén. C. (1987) **The Development of a Method for Traffic Safety Evaluation: The Swedish Traffic Conflicts Technique**. Doctoral Dissertation, Lund University, Sweden.

Iguchi, M., Nakayama, K., and Miyazaki, T. (1997) Promotion Plan of the Development of Advanced Safety Vehicle (ASV). In proceedings of the 4th world congress on ITS, Berlin (CD-ROM).

Kume, M. (2000) Development and Promotion of Advanced Safety Vehicle. Proceedings of the 7th World Congress on ITS, Nov. 6~9, Turin (CD-ROM).

Lamm, R., Psarianos, B., and Cafiso, S. (2002) Safety Evaluation Process of Two-Lane Roads. A 10-Year Review. **Transportation Research Record, No. 1796**, pp. 51-59.

Long, J. S. (1997) **Regression Models for Categorical and Limited Dependent Variables**. Sage Publications.

Maltz, M., and Shinar, D. (2004) Imperfect In-vehicle Collision Avoidance Warning Systems Can Aid Drivers. **Human Factors, Vol. 46.** pp. 357-366.

Martens, M. H. (2000) Assessing Road Sign Perception: A Methodological Review. **Transportation Human Factors, Vol. 2, No. 4**, pp. 347-357.

Milosevic, S., and Gajic, R. (1986) Presentation factors and driver characteristics affecting road-sign registration. **Ergonomics, Vol. 29, No. 6**, pp. 807-815.

Ogden, K. W. (1995) **Safer Roads: A Guide to Road Safety Engineering**. Avebury Technical.

Patten, C. J. D., Kircher, A., Ostlund, J., Nilsson, L., and Svenson, O. (2006) Driver Experience and Cognitive Workload in Different Traffic Environments. **Accident Analysis and Prevention, Vol. 38, No. 5**, pp. 887-894.

Porter, M., and Whitton, M. J. (2002) Assessment of Driving With the Global Positioning System and Video Technology in Young, Middle-Aged, and Older Drivers. **The Journals of Gerontology Series A: Biological Sciences and Medical Sciences. Vol. 57A, No. 9**, pp. 578-582.

Rubin, D. C., and Wenzel, A. E. (1996) One Hundred Years of Forgetting: A Quantitative Description of Retention. **Psychological Review, Vol. 103, No. 4**, pp. 734-760.

Shinar. D. (2007) **Traffic Safety and Human Behavior**. ELSEVIER.

Shinar, D., and Drory, A. (1983) Sign Registration in daytime and nighttime driving. **Human Factors, Vol. 25, No. 1**, pp. 117-122.

Shinar, D., Meir, M., and Ben-Shoham, I. (1998) How automatic is manual gear shifting? **Human Factors, Vol. 40, No. 4**, pp. 647-654.

Sikström, S. (2002) Forgetting Curves: Implications for Connectionist Models, **Cognitive Psychology, 45**, pp. 95-152.

Solomon, D. (1964) Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle. FHWA. U.S. Department of Transportation, Washington, D.C., 1964 (reprinted in April 1974).

Tsimhoni, O., Smith, D., and Green, P. (2004) Address Entry While Driving: Speech Recognition versus a Touch-Screen Keyboard. **Human Factors, Vol. 46, No. 4**, pp. 600-610.

Wickelgren, W. A. (1970) Time, Interference, and Rate of Presentation in Short-term Recognition memory for Items", **Journal of Mathematical Psychology, Vol. 7**, pp. 219-235.

Wixted, J. T., and Ebbesen, E. B. (1991) On the form of Forgetting. **Psychological Science, 2**, pp. 409-415.