IMPACTS OF PROVISION LOCATIONS OF IN-VEHCILE REAL-TIME TRAFFIC SAFETY WARNIGN IFORMATION AT A LIMITED SIGNAL VISIBILITY APPROACH*

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1. Introduction

From view point of road safety, provision of warning signs on road sides has been considered in practice as one of the precautionary countermeasures.[1)-3)] The performance of these countermeasures has been enhancing by technologies of Intelligent Transportation Systems (ITS). In this context, attempts are being made to improve road safety, named 'Smart 2-miles Hiroshima' that commenced in 2005 on the national highway "route 2" in Hiroshima City. A main target of this project was to analyze the influence of in-vehicle Real-time Traffic Safety Warning Information (RTSWI) on traffic safety, especially driving stability risk of drivers. Given this objective, a field driving experiment was implemented at "Higashi-hiranobashi," one of the signalized intersections along the route with a limited signal visibility approach, in November 2006.

Even though this field driving experiment was implemented, the actual effectiveness has not yet been satisfactorily investigated. This paper examines when to provide the in-vehicle RTSWI to improve the driving stability risk at a limited signal visibility approach by means of establishing an ordered probit model. Moreover, the driving stability risk is estimated by considering various categories of variables, such as traffic operation factors, geometry factors, environmental factors, and driver factors, assuming decrease in the utility of in-vehicle RTSWI over time, simultaneously.

2. Backgrounds

The driving stability risk can be measured by the magnitude of speed deviation (i.e., speed variance) between average speed and operating speed in normal driving condition. As a benchmark study, Solomon[4)] showed that the greater the deviation between average speed and a driver's speed, the more chance of involvement in a crash. Recently, Garber[5)] showed that crash rates increase with increasing speed variance for all road types, examining 36 roadway segments, urban and rural interstates, urban and rural arterials, and rural major collectors in Virginia. More recently, Garber[6)] again found that the crash rate increases as the standard deviation of speed increases for all flow rates. Hence, earlier studies report that traffic safety, i.e., the driving stability risk, is affected by the magnitude of speed deviation.

In order to apply these findings into practice related to evaluating road safety, we define that the driving stability risk will improve if the speed deviation falls within a range of one standard deviation, while it will worsen in any other case. A specification of this relationship is as follows:

$$\begin{aligned}&\text{Low risk: } \Delta V \le \pm\sigma\\&\text{Medium risk: } \Delta V \le \pm 2\sigma\\&\text{High risk: } \Delta V > \pm 2\sigma\end{aligned} \tag{1}$$

ΔV_n stands for difference between an average speed of a road section ($\bar{V}$) and an operating speed of each driver n (V_n) and

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σ represents the standard deviation. A given definition above, the driving stability risk can be transformed into ordered response variables according to the magnitude of speed deviation, for example, 1 for low, 2 for medium, and 3 for high driving stability risk, respectively. The use of an ordered probit model in this study enables analyzing the influences of qualitative and quantitative variables on the ordered response variable coincidently[7], assumed the random error follows a standard normal distribution. The ordered probit model is specified as follows:

$$y_i^* = \beta x_i + \varepsilon_i \,, \tag{2}$$

A latent variable y_i^*, i.e., the driving stability risk become a function of explanatory variables x_i with parameters β to be estimated and random error term ε_i. The observed and coded ordered variable is determined from the model as shown in (2) while the probabilities associated with the coded responses of an ordered probit model are calculated following (3).

$$\begin{aligned}
\Pr(y=1) &= \Pr(y_i^* \le \mu_1) = \Pr(\beta x_i + \varepsilon_i \le \mu_1) \\
&= \Pr(\varepsilon_i \le \mu_1 - \beta x_i) = \Phi(\mu_1 - \beta x_i) \\
\Pr(y=2) &= \Pr(\mu_1 < y_i^* \le \mu_2) \\
&= \Pr(\varepsilon_i \le \mu_2 - \beta x_i) - \Pr(\varepsilon_i \le \mu_1 - \beta x_i) \\
&= \Phi(\mu_2 - \beta x_i) - \Phi(\mu_1 - \beta x_i) \\
\Pr(y=3) &= \Pr(\mu_3 < y_i^*) = 1 - \Phi(\mu_3 - \beta x_i)
\end{aligned} \tag{3}$$

Values of thresholds (μ_j) are endogenously given by estimation. $P(K)$ and $\Phi(\,)$ represent the probability of individual driver respond and the standard normal cumulative distribution, respectively. Interpretation of the model parameters can be expressed as that positive signs indicate increase of the driving stability risk due to increasing values of the associated variables, and vice versa. The model parameters and the thresholds values are estimated by using the maximum likelihood estimation as in:

$$L = \sum_{j=1}^{J} \sum_{y_1 = j} \log(\Phi(\mu_j - \beta x_i) - \Phi(\mu_{j-1} - \beta x_i)) \tag{4}$$

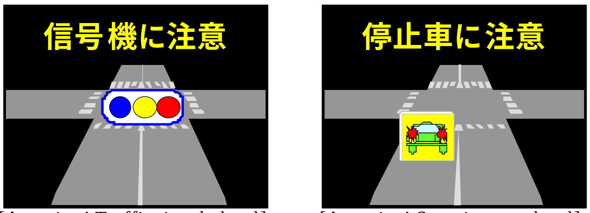
3. Data Collection

In order to determine the influence of the in-vehicle RTSWI on the driving stability risk, a field driving experiment was performed from November 21st (Tuesday) to 27th (Monday) in 2006 at Hiranobashi-higashi intersection approach with a limited signal visibility, Hiroshima City. Drivers further than 190m away from the stop line on this approach cannot see the signal indication because the crest (at 120m from the stop line) of vertical alignment obstructs their vision. This is the main reason for considering this signalized intersection as the most dangerous intersection on the national highway “route 2” in Hiroshima City.

Fourteen young drivers (13 male and 1 female in twenties), having at least one year driving experience, participated in the field experiment. A driving task was conducted from 9 a.m. to 5 p.m., avoiding both morning and evening peak times, to exclude severe traffic jam.

To assist a safe driving in our driving experiment, two contents (i.e., static and dynamic) and two strategies (i.e., “only voice” and “voice & image”) of the in-vehicle RTSWI were provided to drivers at 210m or 300m from the stop line. For example, when a driver approached the intersection, one of the driving scenarios was randomly provided to the driver through a Head-Up Display (HUD) on the windshield. This random provision method was selected for considering traffic situation when a driver approaches the subject road section. The either static or dynamic content of the RTSWI informed the driver about fixed objects (e.g. Attention! traffic signal ahead) and moving objects (e.g. Attention! stopping car ahead) (Fig.1). As for one exception, the dynamic RTSWI was not provided when stopping vehicles were detected within 120m from the stop line even though the driver was approaching at 210 or 300m from the stop line. Here, the concept of Minimum Stopping Sight Distance[8] (MSSD) let considering of a provision location to become at 210m from the stop line because about 90m distance of MSSD (2.5s perception reaction time, 0.35 coefficient of friction (wet pavement) is required to make a safe stop for drivers having 60km/h (the 85th operating speed) if an event suddenly occurs at 120m (the crest) from the stop line. Related to this sense, an assumption can be arisen that a provision of the in-vehicle RTSWI at 300m would lead drivers to be safer than that of at 210m from the stop line.

An probe vehicle was used for data collection, mounted with a Global Positioning System (GPS) for recording the driving history by 0.1s, a Human Machine Interface (HMI) to provide the voice (or voice & image) RTSWI content to drivers, and cameras on dashboard for taping the driver's face and the driving scene. The images of the RTSWI were shown through the HUD on the windshield to enhance the driver's vision (Fig.2). All obtained data, i.e., speed, longitudinal de-/acceleration, lateral de-/acceleration, braking pressure, lateral de-/acceleration pressure, handling pressure and even video images can be dealt with corresponding to each location on digital map.



[Attention! Traffic signal ahead]
(i) Static RTSW

[Attention! Stopping car ahead]
(ii) Dynamic RTSW

Figure 1: Voice & Image information of RTSW

Figure 2: An image of HUD

4. A Model Build

(1) Overview

An ordered probit model was estimated to identify provision location of the in-vehicle RTSWI on the driving stability risk at a signalized intersection approach with a limited signal visibility. A total 1245 observation related to non-stop behavior in interacting vehicle condition was used to estimate the model. Moreover, various influential factors, such as traffic operation factors, geometry factors, environmental factors, and driver factors were used for a model build. Table 1 shows the definition of the employed variables, their mean value and standard deviation.

Table 1: Variables used for model build and estimated results

Variables: definition	Mean	S.D	Estimate	t-statistic
Constant	-	-	2.181	8.966†
Speed difference: The absolute value of the difference between current speed and past speed [km/h]	0.139	0.152	0.862	3.262†
Gap distance: Distance between the preceded vehicle and the probe vehicle divided by 1000 [m]	0.063	0.025	–26.200	–13.986†
Signal visibility: Whether or not see the signal indication [0 = visible (190m from the stop line); 1 = limited]	0.224	0.417	1.422	8.696†
Vertical grades: The absolute value of vertical grades divided by 10 [%]	0.327	0.203	–3.405	–17.458†
Road surface: The condition of road surface when driving was performed [0 = dry; 1 = wet]	0.471	0.499	–1.730	–10.542†
Time slot: The time of day implementing the driving experiment during a day [0 = morning; 1 = afternoon]	0.511	0.500	0.961	5.985†
Day slot: The day of recording the scene either weekday or weekend [0 = weekday; 1 = weekend (holiday)]	0.675	0.468	2.949	20.775†
Trial number: The number of driving trials on the subject road divided by 10 [integer, positive sign]	0.305	0.131	–1.347	–2.823†
Driving experience: The real driving experience of each driver divided by 10 [integer, positive sign]	0.210	0.131	2.319	5.235†
Provision location: Location of providing the in-vehicle RTSWI from the stop line [0 = 200m; 1 = 300m]	-	-	–29.626	–10.359†
μ	-	-	2.009	27.900†
Observations			1245	
Log-likelihood with zero coefficients [LL(0)]			–2241.532	
Log-likelihood for estimated model [LL(β)]			–797.969	
Adjusted R-squared [$\bar{\rho}^2$]			0.638	

† Significant at 1% confidence level. - not relevant.

(2) Estimated results

Maximum likelihood estimates of the structural parameters β and estimated asymptotic t -statistics were calculated by using the Eicker-White estimator in TSP software are presented in Table 1. The estimated result, i.e., adjusted R-squared ($\bar{\rho}^2$ =0.638) indicates that applying the ordered probit model is an appropriate methodology for analyzing the relationship between various influential factors and driving stability risk. According to equation (2), estimates that are greater than zero imply that increases in the associated variables incline to lead to an increased driving stability risk. Thus, the estimates reported in Table 1 confirm our prior beliefs that the average risk of driving stability decreases with the values of the continuous variables, gap distance, vertical grades, provision of the in-vehicle RTSWI at 300m from the stop line, and trial number, showing its relative importance in order. It is again worth noting that the driving stability risk might be reduced by means of provision of the in-vehicle RTSWI at 300m from the stop-line to drivers. The estimated dummy variable coefficients confirm our prior beliefs that the average risk of the driving stability risk increases when a driver is traveling on a limited signal visibility road section in weekend afternoon.

The relative magnitudes of the estimated coefficients are also of interest. Because the driving stability risk is specified as a linear function of the explanatory variables, the relative magnitudes of the estimated dummy variable coefficients are, in most cases, a measure of the relative impacts of these variables on the average risk of the driving stability. For instance, the estimated coefficient of the dummy variable recording the day of driving (=2.949) is about 1.07 times higher than that of signal visibility (=1.422), which means that the increase in driving stability risk faced by an individual driving in weekend is about 1.07 times higher than that of in a section with limited signal visibility, all other things being equal. Other estimated dummy variable coefficients can be compared in this way.

5. Conclusion and Discussion

Providing the in-vehicle RTSWI is considered as valuable task for improving road safety. Nevertheless, it is problematic when to provide the in-vehicle RTSWI to drivers because there is a strong relationship between the in-vehicle RTSWI and driver decision making process. Moreover, this phenomenon becomes serious in road section with a limited signal visibility.

As shown the results in this paper, limited signal visibility negatively affects the driving stability, i.e., road safety. Differently, this paper find out that the driving stability risk would be improved as increase of a value of gap distance, provision of in-vehicle RTSWI, and trial number. Concerning dummy variables, it shows that the driving stability risk depends much more strongly on the traffic environment factor (weekend) than on the geometry factor (signal visibility). Precisely, this paper reveals that providing the in-vehicle RTSWI at 300m from the stop-line (almost 2 times of a MSSD at a given road section) is more effective than that at 200m (same to a MSSD). These results mean that the driving stability risk will be improved by means of software method as like controlling the gap distance by providing the in-vehicle RTSWI at 300m from the stop line.

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