PRACTICAL USE OF THE REAL TIME TRAFFIC ACCIDENT RISK PREDCITION ON HANSHIN EXPRESSWAY

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ABSTRACT

Hanshin Expressway Company Limited (HECL) operates an urban expressway network in Kansai region in Japan, and it prioritizes traffic safety as one of the most important missions. To fulfill this mission, the HECL developed a quantitative traffic accident risk prediction model using accident data, road structural characteristics, and weather condition information. This study discusses the ongoing effort to develop a real-time dynamic traffic accident risk information service for the drivers and the company's traffic control operation staff, toward practical real-time operation in the future.

Keywords: Traffic safety, Traffic accident risk prediction, Driver support

INTRODUCTION

The Objective of Study

Hanshin Expressway is the 259.1-kilometer long urban expressway network in Kansai region in Japan, operated by Hanshin Expressway Company Limited (HECL) (**Figure 1**). Its annual average daily traffic is approximately 720,000.

HECL provides accident risk information ("black spots") based on what is positively defined as actual accident data on the network. However, prediction of traffic accidents using accident data only has limited prospects, especially when the information service to be provided is desirably specific to such detailed contexts such as road section, time of the day, whether condition. In this study, an accident risk prediction model that takes advantage of data from various sources is presented as an extension of the existing system.

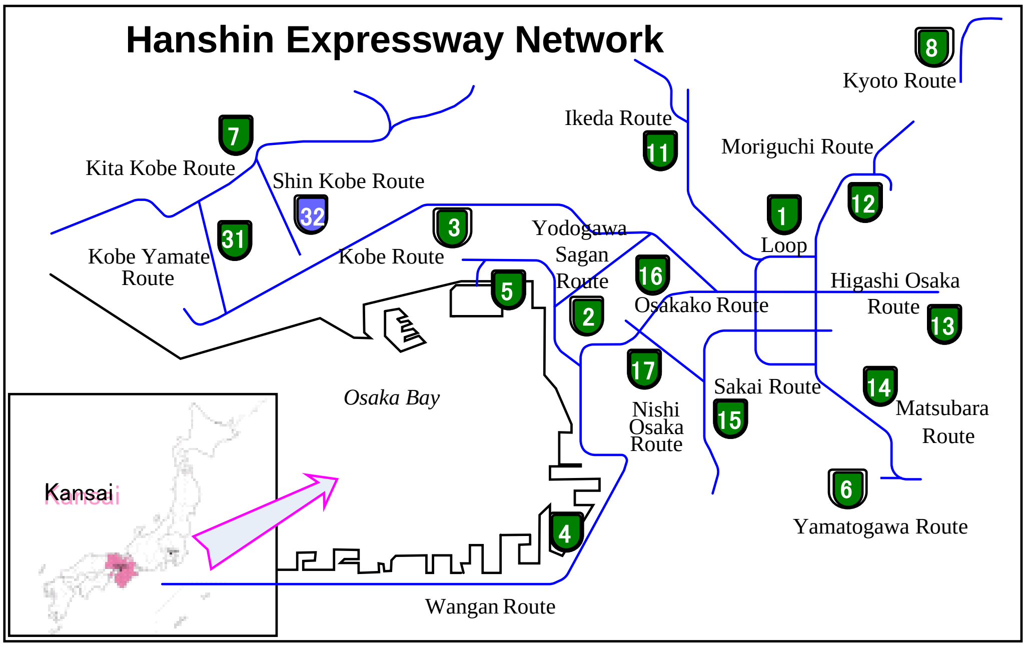

Figure 1. Hanshin Expressway Network

Literature Review

We review the literature relevant to the subject of this study. In 1978, what was then the Hanshin Expressway Public Corporation (prior to its privatization) quantitatively analyzed the probability of accidents of various kinds. The main findings of this analysis are, rear-ending collisions are more likely to occur under congested traffic flows; and, single-vehicle accidents are more likely to happen under free-flow traffic. These insights were used for evaluating the effect of traffic control measures on the expressway network [(1)].

Oguchi et al. evaluated the risk of traffic accidents on the Tomei Expressway near Ayase Bus Stop, for three types of traffic conditions, namely: free-flow, at-capacity, and congested flow. Their results indicated that the risk was higher under the at-capacity traffic level, which is in other words not congested but high-density traffic flows [(2)]. While effectively demonstrating that the levels of traffic volume influences the risk of accidents, the findings were limited in that they failed to take into consideration factors other than the traffic volumes.

Golob et al. considered not only the levels of traffic volume but also road surface conditions, the brightness level of lighting, and combined data from vehicular sensors and accident information. Their analysis suggested that the contribution of these factors were different depending on the pattern of accidents. Also, this study did not take into consideration road structural factors [(3)].

More recently, Yoshii et al. analyzed the relationship between accident risks and traffic levels, road structural variables, as well as weather conditions, for each pattern of accidents on the Hanshin Expressway network. The results suggested that a dynamic accident prediction model could possibly be developed for practical implementation [4][5].

This study will extend the knowledge by proposing a dynamic accident risk prediction model for the Hanshin Expressway, based on the insights from previous studies.

TRAFFIC ACCIDENT ANALYSIS

The HECL recently started operating a new database of traffic accidents, including such variables as time, location, driver characteristics (e.g. age, gender, years of driving experience and frequency of the expressway usage), accident types (i.e. rear-ending collisions, single-vehicle accidents, and side-by-side collisions), traffic conditions (traffic volume, average speed, and presence/absence of congestion), road structural characteristics (linear/curve, direction, accident history and pavement types), the weather conditions (e.g. precipitation), and traffic control measures being implemented at the time of the accident's occurrence.

In this section, we attempt to clarify the relationship between the likelihood of traffic accidents and various factors, such as driver characteristics, road structural characteristics, and traffic conditions, all available from the accident database. For example, it is possible to visualize that there is apparent relationships between the linearity of road sections, the levels of traffic volume, the average traffic speed and likelihood of traffic accident, for each accident type (**Figure 2**, **3**). It may be also noticed that under the rainy weather, the rate of accident occurrence increases, particularly at curved sections (**Figure 4**).

Figure 5 compares the rate of rear-ending collisions and single-vehicle accidents occurrence depending on the time of the day: rear-ending collisions were more likely to happen during the day time, while single-vehicle accidents were more likely to occur during the night time.

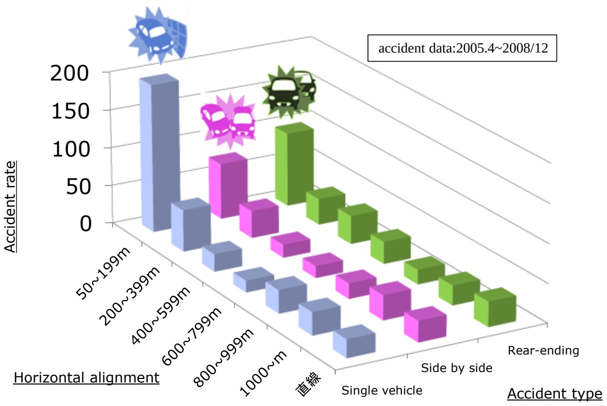

Figure 2. Relation to Liner

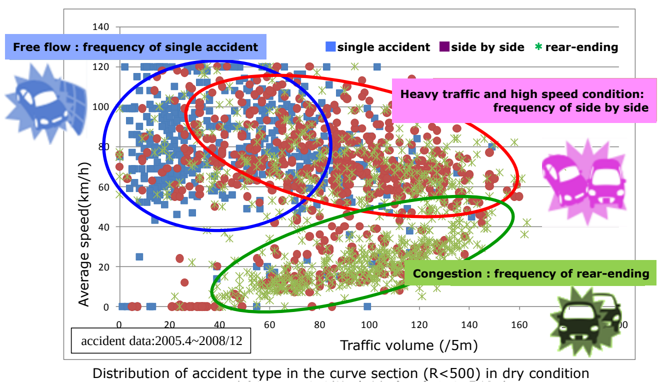

Figure 3. Relation to Traffic Environment

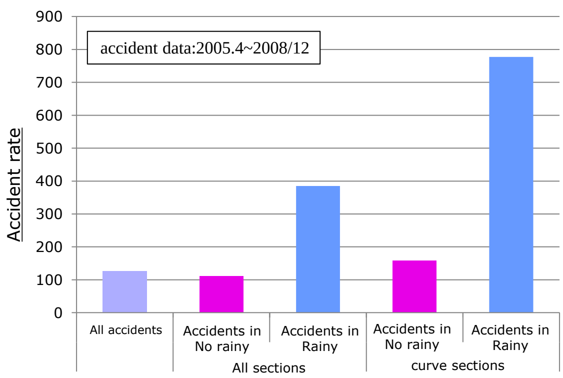

Figure 4. Relation to Weather

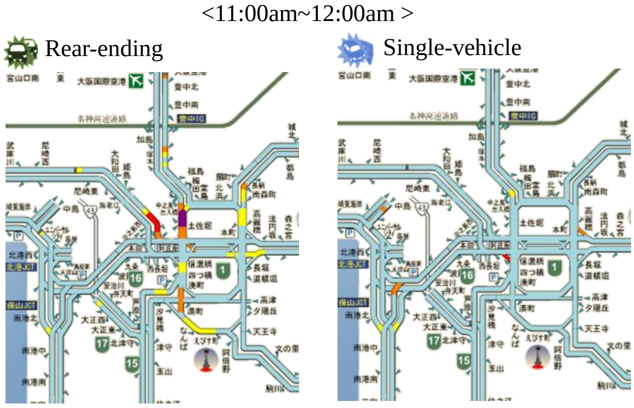

Figure 5. Accident Rate Map

Overall, we find from this analysis that the probability of traffic accidents is distinct, depending on static road environment factors as well as dynamic traffic condition factors. We can therefore propose a dynamic model of traffic accidents for each type, which is capable of predicting the risk of traffic accidents in a real-time manner.

THE ARCHITECTURE OF REAL TIME TRAFFIC ACCIDENT RISK MODEL

The Objective and User Services

The objective of accident risk information service is to intuitively assist in preventing traffic accidents by the drivers, and to reduce any losses from traffic accidents. In pursuing those objectives, two types of accident risk information service are provided: statistics of accidents in the past, and outputs from the dynamic risk prediction model. This section introduces the dynamic risk prediction model.

The information service is targeted to two main groups of users: the drivers of the expressway network, and the staff of the expressway company in the traffic control operation center, road patrol division, maintenance division, and disaster response division (**Figure 6**).

It is expected that the information service benefits drivers by raising the awareness that they are approaching a risky section, while assisting their selection of safer routes by providing accident information on their originally planned trip routes. The information service is also expected to benefit the operation staff in the traffic control center through informing high-accident risk sections and installing automatic focus function of the ITV-video cameras, which helps early detection of accidents and reducing accident response time.

The information service benefits road patrol vehicles through informing high-accident risk sections, which consequently helps in turn aid in developing resource allocation plans that shortens accident response time. The information service also assists the disaster response division with its accident risk statistics and measures to prevent secondary disasters, while benefiting the maintenance division with the information is planning physical preventive measures of traffic accidents. In short, the benefits of the model to be proposed in this study are multi-faceted.

Requirements of Information Service for Expressway Users

The first component of the information service to the expressway users is to raise the awareness that they are approaching an accident-prone zone. The proposed system generates accident risk index as well as locations (i.e. expressway sections or zones) with high-accident risks, based on the real time traffic condition data, weather information (precipitation), and road structural information. The information is provided to the expressway users through changeable road signboard, vehicle navigation system, and/or mobile application, contributing to preventing accidents by heightening awareness levels of drivers.

The second component of the information service to the expressway users is to provide information that assists their pre-trip route choices. Maps, route-specific and location-specific information with the real time accident risk information are provided to the expressway users via changeable road signboard, mobile application, and webpages. This service is expected to contribute to arrange safer trip plans.

Finally, the high-accident risk section information service is meant to assist the operations by the expressway staff. Maps, and other generated route information that are based on the real time accident risk information are provided via medium such as the web. They contribute to shorten the time to detect traffic accidents and the response. The ITV-automatic focusing finding identifies locations with high priorities in terms of their accident risks, and pre-set the focus of video cameras is to enable early accident detection, contributing to smoother accident response operations (**Table 1**).

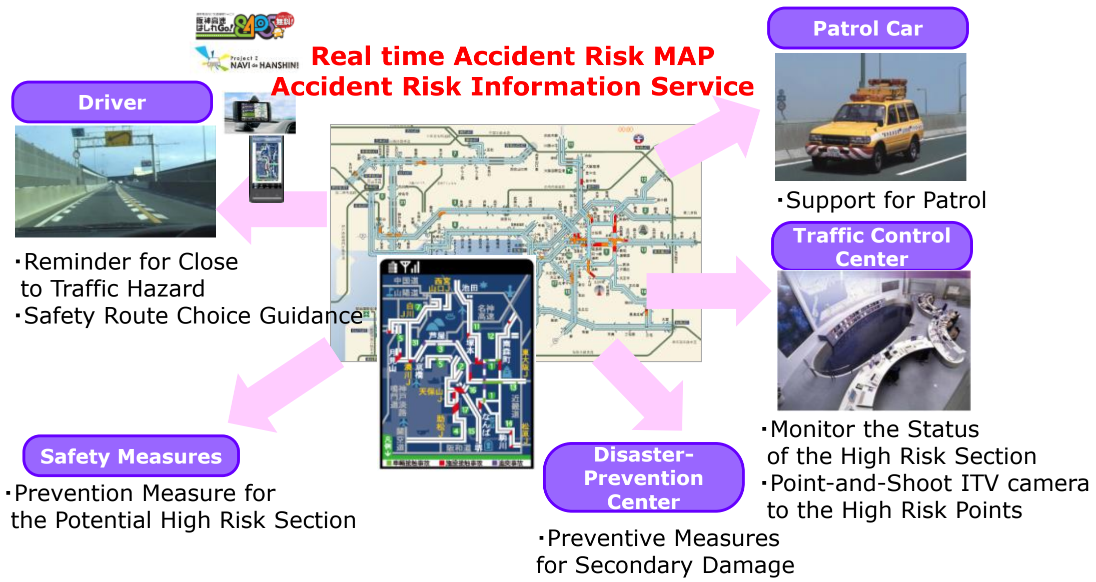

Figure 6. User Services

Table 1. User Requirements

Function	providing interval	providing point	contents of information	media				user				
				VMS	PDA (Car navi)	WEB	others	driver	TCC	patrol car	MS	DPC
Reminder for Proximity to Traffic Hazards	/5min	approaching point of the high risk section	Real time risk of an accident index, Information of the hazard place	○	○			○	○	○	○	○
Safety Route Choice Guidance	/5min	any point, traffic control center	Real time risk of an accident index (MAP, Information for Route Choice, Information of the hazard place)	○	○	○		○		○		○
Information of the High Risk Points	/5min	any point, traffic control center	Real time risk of an accident index (MAP, Information for Route Choice)			○	○		○	○	○	○
Point-and-Shoot ITV camera	/5min	traffic control center	autofocusing ITV camera				○		○			

VMS:variable message board system, PDA: personal degital assistant,
TCC:Traffic Control Center, MS:maintenance Section,
DPC: disaster-prevention center

ANALYSIS OF REAL TIME TRAFFIC ACCIDENT RISK PREDICTION MODEL

The Real Time Traffic Accident Risk Prediction Model

We hypothesize a Poisson distribution in modeling the occurrence of a traffic accident, such that the following mathematical model is defined for estimation (we omit formal model formulation for brevity):

$$\mu_i = \lambda_i \times t_i$$

μ_i : expected number of accidents

λ_i : traffic accident risk (accidents/vehicle-kilometers)

t_i : traveled distance (vehicle-kilometers)

i : explanatory variables of traffic accidents

$$Y_i \sim Po(\mu_i)$$

$$\ln(\mu_i) = \ln(\lambda_i t_i) = (\alpha + \sum \beta_j x_{ji}) + \ln(t_i)$$

$$\mu_i = \lambda_i t_i = \exp(\alpha + \sum \beta_j x_{ji}) t_i$$

x_j : the explanatory variables of traffic accidents, j=1,2,…

α, β : parameters to be empirically estimated

Model Analysis and Verification

This section shows the analytical framework of the model. The dependent variable is the number of accidents by their types for each lane. Parameters can be empirically estimated, for unit road-segment vehicle-kilometers traveled. **Table 2** summarizes the explanatory variables.

- The road network under study: Hanshin Expressway networks (approximately 260km)
- Study period: 4/1/2010～3/31/2013 (3 years)
- Unit of analysis: the section between traffic counter (approximately 500meters)
- Time interval: every 5 minutes

We employ the following verification procedures:

1. Logical consistency, based on the sensitivity and plausibility of the estimated model;
2. Accuracy, through comparing the model prediction and actual values.
3. Practicality, by checking the reproducibility of predicted high risk spots.

The third step of the above verification procedures is not carried out, as the objective of this study was merely to examine the possibility of the model for practical implementation (**Figure 7**).

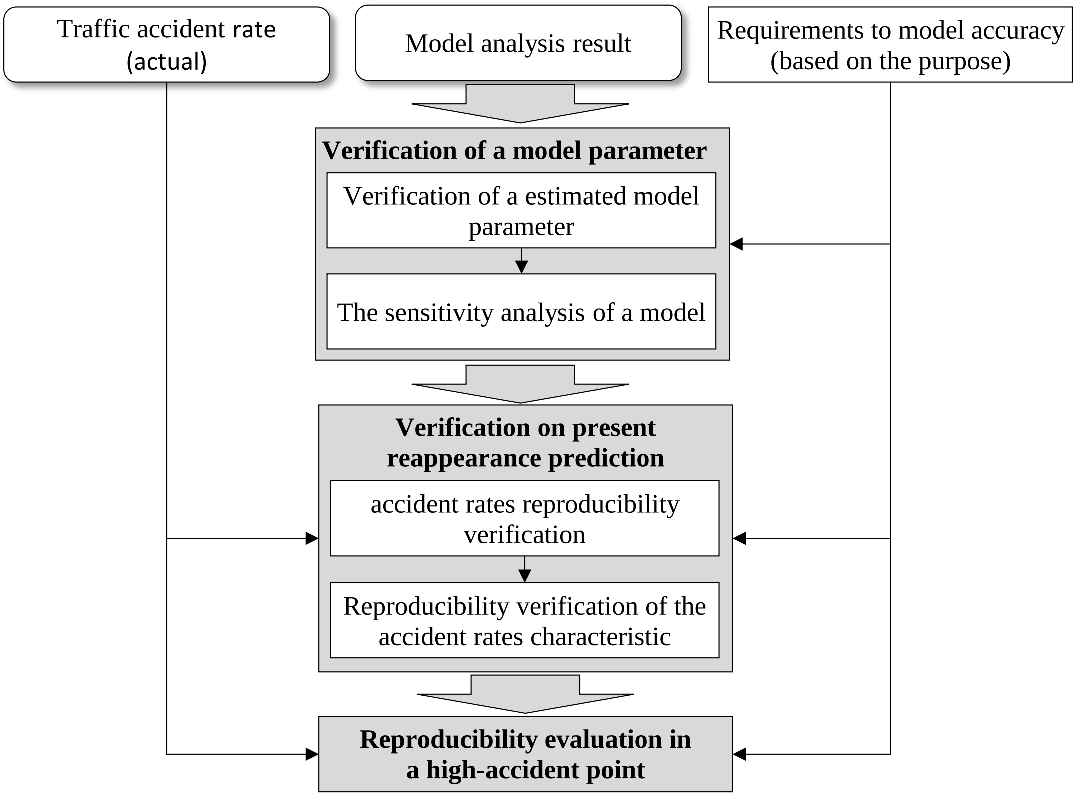

Figure 7. The Process of Model Validation

Table 2. Explanatory Variable

Classification	Explanatory Variables	Category
Traffic Situation	Traffic Situation	1.Free Flow, low volume 2. Free Flow, mid volume 3. Free Flow, high volume 4.Mixing Flow, mid volume 5. .Mixing Flow, high volume 6.Congestion, 7. Heavy Congestion, 8. low-velocity
Road Design	Plane Curve	0.Straight(≧1,000m), 1. shelving curve(1,000m>≧500m), 2.curve(500m>≧250m), 3. sharp curve (250m>)
	Vertical Sope_Up	0.Flat(5.0%>), 1.Uphill(≧5.0%)
	Vertical Slope_Down	0.Flat(>-5.0%), 1. Downhill (≧-5.0%)
	Junction interflow/ split flow	0. straight, 1. interflow/ split flow
	Junction interflow	0. straight, 1. interflow
	Junction split flow	0. straight, 1. split flow
	Toll gate_ main road	0. straight, 1. Toll gate
Weather	predipitation	0.NA, 1.Low rain(20mm/10min>), 2.Heavy rain(≧20mm/10min)
Calendar	Days of the week	0.Weekday, 1.Weekend, 2.Holiday

Table 3. Results of Model Analysis (Example: Rear-Ending Collision)

Rear-Ending Collision			4-Lane Road		3-Lane Road		2-Lane Road		1-Lane Road	
Explanatory Variables			Estimate	Pr(>|z|)	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)	Estimate	Pr(>|z|)
Constant Values			3.1387	< 2e-16 ***	2.1522	< 2e-16 ***	2.5952	< 2e-16 ***	2.4299	6.7E-08 ***
Traffic Situation	1. Free Flow, low volume									
	2. Free Flow, medium volume									
	3. Free Flow, high volume						0.3106	1.15E-07 ***		
	4. Mixed Flow, medium volume		2.6316	< 2e-16 ***	1.7535	< 2e-16 ***	2.0571	< 2e-16 ***		
	5. Mixed Flow, high volume		1.1614	< 2e-16 ***	1.9064	< 2e-16 ***	1.4368	< 2e-16 ***		
	6. Congestion		3.7294	< 2e-16 ***	3.5591	< 2e-16 ***	3.0348	< 2e-16 ***		
	7. Heavy Congestion		3.2241	< 2e-16 ***	3.6817	< 2e-16 ***	3.3078	< 2e-16 ***		
	8. low-velocity		3.1982	6.79E-16 ***	4.8097	< 2e-16 ***	4.183	< 2e-16 ***	3.8758	3E-09 ***
Road Design	Plane Curve	1. shelving curve								
		2. curve			0.6075	5.91E-09 ***				
		3. sharp curve	0.5082	1.26E-08 ***	0.4565	0.00014 ***	0.2111	1.79E-09 ***		
	Uphill(≧5.0%)				0.9931	1.79E-05 ***	0.2638	0.04169 *		
	Downhill (≧-5.0%)						0.6501	5.33E-15 ***		
	Junction interflow/split flow				0.6315	4.13E-07 ***	0.3225	6.2E-07 ***	2.7431	0.0121 *
	Junction interflow						0.1908	8.10E-08 ***		
	Junction split flow						0.3297	< 2e-16 ***	2.2066	2.91E-05 ***
	Toll gate_ main road				1.6613	< 2e-16 ***	1.1418	< 2e-16 ***		
Weather	Low rain		1.2956	< 2e-16 ***	1.1713	< 2e-16 ***	0.6368	< 2e-16 ***		
	Heavy rain		1.965	1.30E-13 ***			0.536	2.16E-03 **		
Calendar	Weekend		0.4983	3.63E-06 ***	0.3159	0.00568 **	0.2116	8.08E-08 ***		
	Holiday		0.2933	0.0385 *	0.2862	0.01561 *	0.1691	2.60E-05 ***		
n			400		1125		2253		401	
Likelihood Ratio : σ^2			0.506		0.511		0.730		0.370	

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1

The Results of Model Analyses

Table 3 shows an example of the model analysis results. The explanatory variables include in the model (i.e., traffic conditions, precipitation, and road structural characteristics) has parameters with statistical significance. The overall explanatory power of the model is also considerably high. The results therefore suggest no significant problem with this model.

We then reproduce accident risks of representative expressway sections using the estimated model. The results indicate that when the average traffic velocity is low under congested traffic conditions, the number of rear-ending collisions increases. As the traffic volume increases, side-by-side collisions and rear-ending collisions increase. Also, the estimated accident risk shows reasonable changes with respect to the traffic condition variables (**Figure 8**).

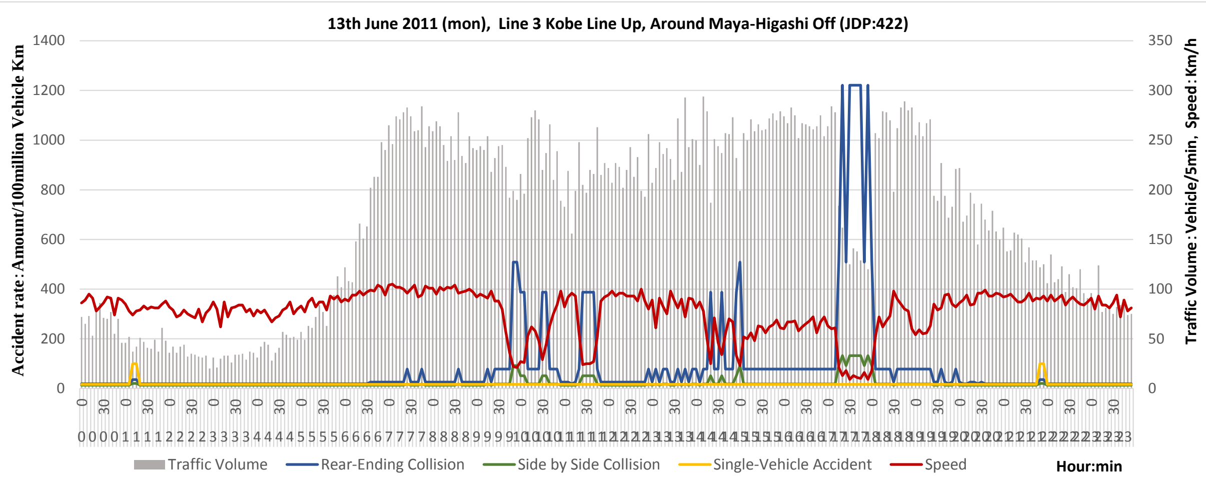

Figure 8. An Example of An Accident Rates

Verification: Comparing Predictions against Actual Values

This section summarizes the first step of verification by comparing the model predictions against actual accident statistics, focusing on the three-year study period from April 1, 2010 to March 31, 2013. The analysis demonstrates that the correlation between the likelihoods of accidents by accident types for each time interval and the actual accident statistics are considerably high for all lanes and for all days of the week. The estimation accuracy is reasonable, as the RMSE is not large relative to the average.

It should be pointed out, as **Table 4** shows, that single-vehicle accidents (collisions against road facilities) shows relatively lower correlation coefficients than other accident types, and the RMSE is relatively large. Similar results are obtained when analyzing the correlation between the road-section accident likelihood by time interval and the actual accident statistics: as **Figure 9** shows, observations are generally plotted proximate to the X=Y line. Again, the single-vehicle accidents show lower correlation.

Figure 10 visualizes the section of accident predictions and the actual statistics on the expressway network map by rank. Despite few instances of differences primarily on routes with lower travel demand, the predictions are overall consistent with the actual accident statistics. This result suggests that the prediction model can be further improved to address the upward bias for expressway sections with low travel demand and low numbers of traffic accidents.

Overall, we can conclude argue that the accident risk prediction model analyzed in this study can be viable for practical implementation, while some adjustment should be made at the operation level.

Table 4. Correlativity of The Accident Rates Between A Predicted And Actual Value

		N	Rear-Ending Collision			Side by Side Collision			Single-Vehicle Accident		
			Average	R	RMSE	Average	R	RMSE	Average	R	RMSE
Number of Lanes	Sum total	24,600	33.2	0.931	21.4	20.0	0.846	21.2	47.2	0.667	62.8
	4 Lanes	336	73.1	0.747	46.2	119.3	0.963	18.3	43.7	0.588	59.1
	3 Lanes	3,432	22.2	0.826	19.4	20.9	0.931	17.5	33.2	0.679	36.9
	2 Lanes	20,208	34.4	0.944	20.2	17.3	0.720	21.1	46.5	0.645	64.8
	1 Lane	576	35.9	0.836	41.8	50.7	0.932	40.0	161.9	0.746	104.7
Days-of-the-week type	Weekday	24,600	28.5	0.927	23.2	17.0	0.802	24.8	35.1	0.676	54.1
	Weekend	24,600	28.5	0.841	37.3	17.1	0.653	35.5	49.1	0.619	94.6
	Holiday	24,600	22.2	0.838	25.7	14.1	0.831	19.2	47.7	0.570	84.0

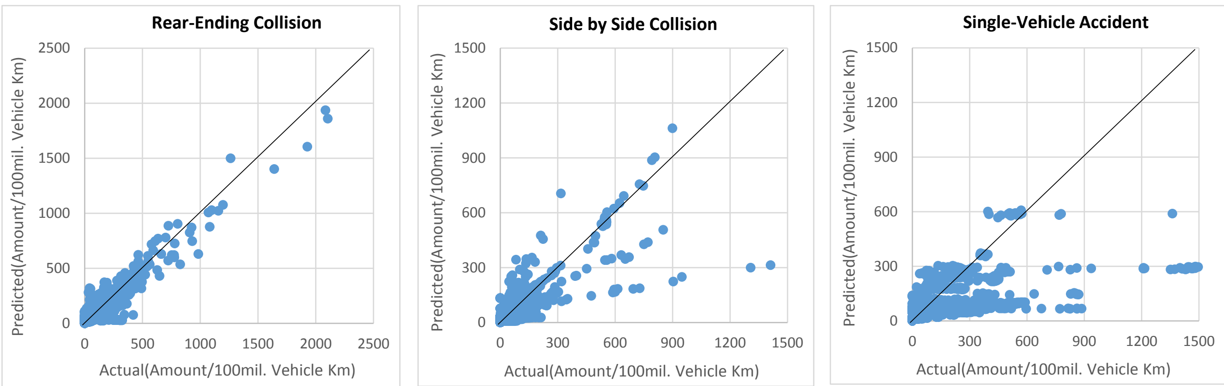

Figure 9. The Correlation Diagram of The Accident Rates Predicted And Actual Value

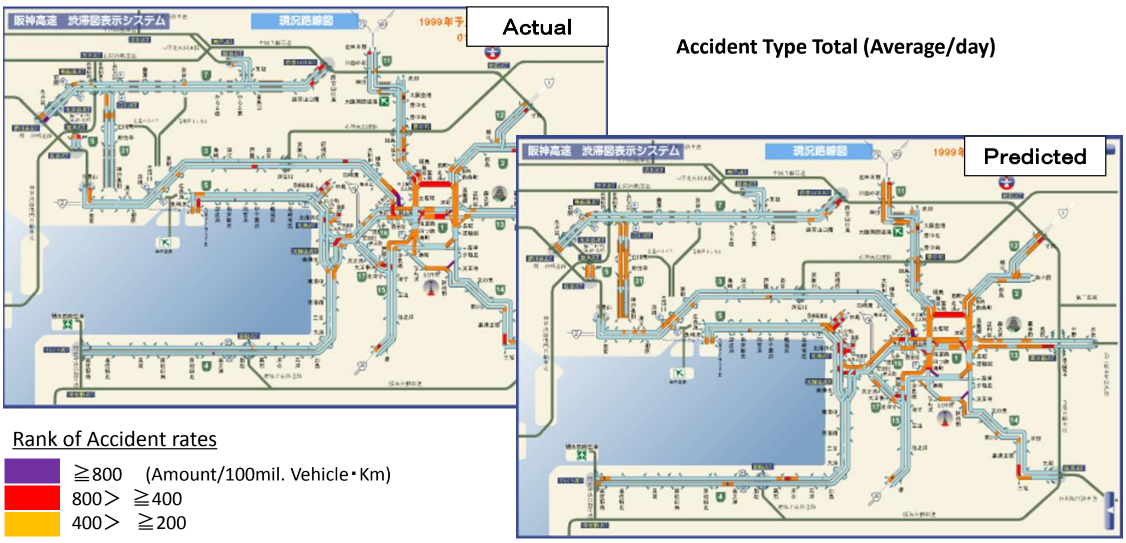

Figure 10. Comparison of An Average Accident Rates Predicted And An Actual Value

CHALLENGES FOR PRACTICAL IMPLEMENTATION

Consideration for Accident Risk Information Provision for Drivers

Provided the practicality of the accident prediction model which is proved in the previous section, the remaining challenge is not only to improve the accuracy of prediction model but also to modify the methodologies of providing actual accident risk information to drivers. It is necessary to develop a new media and the accident risk information service. After a plausible system framework is developed, the important next step is to analyze whether the drivers would show the expected responses, given their recognition of the provided information, their attitudes, and behavioral adoption in response to the accident risk information to be provided to them.

For instance, it may be desirable to conduct a region-wide social experiment to provide the accident risk information to drivers via an existing medium, “NAVI de HANSHIN” (6). A future extension of this experiment may be to use private information medium with wider subscribes.

It should be pointed out that ex ante / ex post evaluation of the accident risk information provision is an indispensable perspective in evaluating the alternative strategies to provide risk information. It is then be necessary to consider the framework and strategy for evaluating the alternatives (**Table 5**).

Table 5. The Subject Concerning Provides to Drivers

Challenging Issues	Contents
1.Provide of Media and Information	･Set up the present media strategically with focus a prospective media
	･Examination of the accident risk-related information according to a media
2.Verification about Driver's perception, behavior to provided information	･Formulation of a verification plan according to the action to expect
	･Implementation of the verification (the perception of information, change of behavior)
	･Practical use verification (evaluate the attitude of a system and a driver, and an execution intention and the behavior modification of a driver)
3.Evaluation of the impact of the accident risk information service	･The ex-ante evaluation
	･The ex-post evaluation

TOWARDS THE DEVELOPMENT OF A USEFUL SYSTEM

This study proposes a dynamic and real-time traffic accident prediction model that accounts for traffic conditions, road structural characteristics and weather condition. The model shows reasonable performance, with clearly defined objectives, user serviceability, and output requirements. The implication of the proposed framework is substantial, as the demand for dynamic accident risk information provision is rapidly increasing in recent years. Based on the results, we examine further challenges pertaining to media and contents of the information service, toward possible real-time operation in the future.

We intend to continue and enhance this research as follows. First, it is necessary to construct a more practical operational model, especially through improving the model prediction accuracy at accident-prone network sections. Also, drivers' recognition, attitudinal responses, and behavioral shifts in response to the provided accident risk information showed to be evaluated, by developing a system to provide the accident risk information to them.

Furthermore, we continue our effort to develop an implementable prototype accident risk information provision system.

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