25th ITS World Congress, Copenhagen, Denmark, 17-21 September 2018

Paper ID：AP-TP1214

A Driver Navigation System Incorporating Traffic Accident Risks: Providing Drivers Low Accident Risk Directions

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Abstract

This study presents an initiative to reduce traffic accidents and associated economic risks by providing driving directions that account for traffic accident risks through a mobile application. This initiative was part of an expressway operator’s traffic safety management operation that utilized traffic accident risk information. This paper reports data required for developing such a framework, proposes a set of traffic accident risk models, analyzes findings from empirical estimation, and discusses a framework by which estimated traffic accident risk information can be incorporated into a driver navigation mobile application. We report findings from a social experiment in which the proposed framework was implemented, and discuss ongoing initiatives to experimentally operate the model on a private mobile application platform starting in December 2017.

Keywords:

Traffic Accident Risk, Traffic Management, Vehicle Navigation System

Introduction

Hanshin Expressway Company Limited (HEP) is committed to traffic safety as part of its management objectives. It has been implementing measures to encourage drivers to consider traffic safety when determining their travel routes and departure times. HEP offered SAFETY Drive Smart Choice, a web-based tool that provides accident risk information for given travel routes, and usage analyses found that drivers gave comparable considerations on accident risk indices to travel time, toll levels, and other factors[1), 2)].

An in-depth analysis of surveys to expressway users suggested that it might add value and relevance to their travel decision making if traffic information on arterials alternative to expressway lines in addition to information regarding traffic condition and expected travel times were to be provided. Expressway accident risk information can be useful when provided in relation to equivalent information on alternative non-expressway routes. Also, while accident risk indices might be informative in and of itself, travel time can be more important to consider, since a driver would not typically select a route with extreme additional travel time just to minimize expected accident risk. Furthermore, as Figure 1 shows, it has been found that traffic accident risk can be as high as eight times in congested flows as under free flow conditions[3), 4)]. For these reasons, accident risk information to be provided to expressway users should reflect real-time traffic, weather, and other driving conditions.

This study focuses on navigation (i.e., "GPS" service) as a means to inform drivers on traffic accident risks in making travel decisions. As research has found that large proportion of drivers follow driving directions shown on navigation systems, it is also reasonable to utilize navigation systems when providing accident risk information[5)]. Figure 2 conceptualizes reduction of accident risks through navigating vehicles to low accident risk routes. The objective of expressway traffic management is to reduce accident risks at the network level through shifting individual drivers' travel route decisions. This study therefore proposes an accident risk estimation model using accident and other relevant data for expressway and arterials in Hanshin region, which is integrated into driver navigation system that accounts for the accident risks for users of the expressway.

The remainder of the paper is structured as follows. The next section will present analytical framework: traffic accident risk model and description of data used for empirical estimation. Estimation results will then be summarized, followed by a discussion on integration of the traffic risk and driver navigation system. After presenting the framework developed in this study to achieve the objective of the study, the concluding section will discuss the way forward with expected challenges that the authors will need to address in further improving the models.

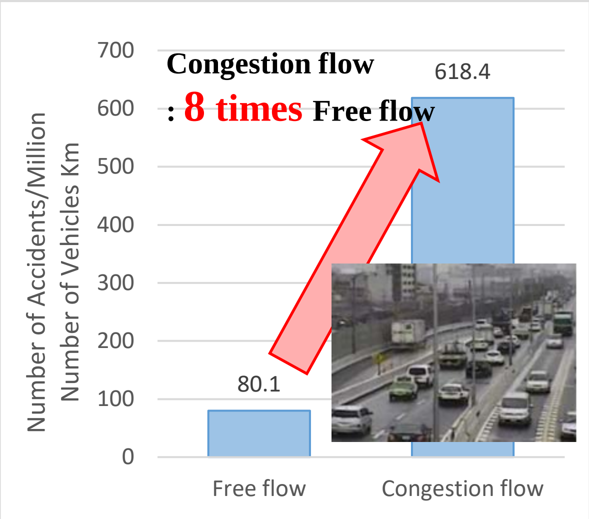

Figure 1 - Comparison of Traffic Accident Risk by Traffic Conditions

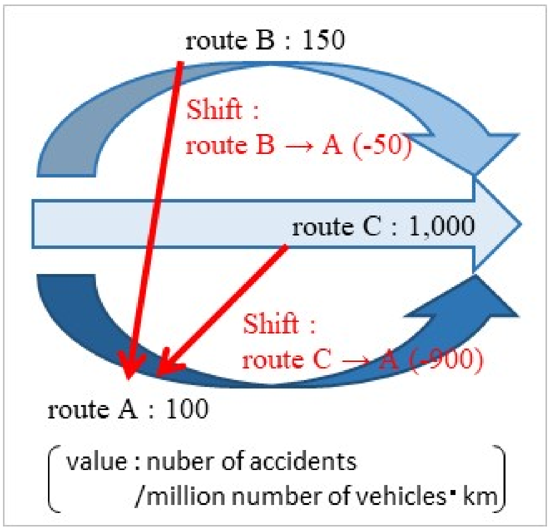

Figure 2 - Traffic Accident Risk Reduction Conceptual Scheme

Analytical Framework

Model Formulation

In this study, we assume the number of traffic accident on a given road network section follows Poisson distribution, i.e., Y～Poisson(μ)[6), 7)]. The probability Y_i that an accident occurs on section i in a given time is modeled as:

$$\mathrm{P}(Y_i) = \frac{e^{-\mu_i}\mu_i^{Y_i}}{Y_i!}$$

where μ_i is expected number of traffic accidents. This is then estimated using Poisson regression model:

$$\mu_i = \lambda_i t_i$$

where,

λ_i: number of accidents per vehicle-kilometer on section i

t_i: traffic volume (vehicle-kilometer) on section i.

Further, we model traffic accident risk on section i as follows:

$$\lambda_i = exp\left(a + \sum_n b_{ni}x_{ni}\right)$$

x_{ni}: explanatory variables that represent factors that cause traffic accidents on section i

a: constant to be estimated

b_{ni}: parameters of variables to be empirically estimated.

Table 1 lists explanatory variables of the proposed model.

Data

Table 2 summarizes data used for empirical estimation. Data on the number of traffic accidents (by accident category) was matched with information on road structure, traffic, and weather condition. Categories of traffic accident data includes:

- **Days of the week**: weekday, Sunday and holiday, and weekend
- **Time of day**: every 3 hours
- **Weather**: snow, precipitation, and no snow/precipitation
- **Traffic**: congestion and free flow

Table 1 - Lists Explanatory Variables of the Proposed Model

Type	Explanatory Variable
Dynamic	Day of week: weekday, Sunday or holiday, weekend Day time / Night time Time of day: 6-9am, 9am-12pm, 12pm-3pm, 3-6pm, 6pm-6am Traffic condition: Congestion, free flow Precipitation: presence, absence
Static	Roadside situation: DID(Densely Inhabited District), urban area, others
Static Factors (Expressways)	Presence of Toll booths Presence of entrance Presence of expressway entrance Presence of expressway exit Presence of curves with radius larger than 300m, less than 300m
Static Factors (Surface Arterials)	Right of way width of 5m or more, less than 5pm 70% or more with sidewalks, less than 70% Density of intersections with traffic signals 10 intersections/km or more, less than 10 intersections/km Density of intersections with no traffic signals, 10 intersections/km or more, less than 10 intersections/km Density of intersections, 10 intersections/km or more, less than 10 intersections/km Proportion of traffic signals' time in blue: over 30%, less than 30% Proportion of traffic signals' time in blue: over 70%, less than 70% Crossing with railways

Table2 - The Summarized Data

Type	Unit	Source
Traffic Accident	3 hour interval by road network section	Road Traffic Census Traffic Accident Statistics by Accident Categories (ITARDA)
Road Structure	Road network section	2010 National Road Traffic Census (MLIT)
Traffic Condition	1 hour interval by road network section	National Road Traffic Census Traffic Volume Data (MLIT)
Weather	1 hour interval by observation station	Precipitation Intensity Data by Observation Station (Japan Meteorological Agency)

Estimation Results

The model was estimated for different road types, inter-city expressway, intra-city expressway, and local arterial, since explanatory variables (e.g., road structure) and available data are drastically different among these road types. Table 3 reports estimation results. The likelihood ratio of the urban expressway model was 0.28, which we believe is reasonable, and estimated coefficients of explanatory variables were all statistically significant. The signs of estimated coefficients were as we had expected. The local arterial model also demonstrated reasonable statistical significance of estimated coefficients as well as their signs, and, albeit lower than expected likelihood ratio of 0.13, it is reasonable to employ this model as part of the analysis.

Table 4 summarizes performance of the empirical model by comparing predictions with actual accident statistics. The correlation coefficient was 0.6 which was reasonably high, and RMSPE of the accident risk was 30% for expressways and 45% for local arterials. We believe our models demonstrate acceptable levels of predictive power.

Figure 3 shows estimated accident risks plotted against road network sections. It appears that the accident risk of inter-urban expressways was projected to be the lowest, then intra-urban expressways, and local arterials demonstrated the highest accident risks of all road types.

Table 3 - Empirical Estimation Results by Model Type

Urban Expressway

Explanatory Variable	Estimate	Std.Error	z value	Pr(>|z|)	
(Intercept)	-17.6475	0.1369	-128.93	< 2e-16	***
Precipitation	0.39377	0.0549	7.171	7.42E-13	***
Weekday	0.59871	0.06	9.988	< 2e-16	***
Weekend	0.43691	0.0783	5.582	2.38E-08	***
Period time 6h〜9h	0.61521	0.0636	9.669	< 2e-16	***
Period time 9h〜12h	0.62764	0.0632	9.926	< 2e-16	***
Period time 12h〜15h	0.3461	0.0689	5.025	5.03E-07	***
Period time 15h〜18h	0.77072	0.0616	12.519	< 2e-16	***
Curve radius ≦300m	0.25921	0.0418	6.195	5.84E-10	***
Roadside situation：DID	0.58361	0.1224	4.77	1.84E-06	***
Congestion	0.59997	0.049	12.246	< 2e-16	***
Dummy: Frequent section of traffic accidents	1.09693	0.0472	23.233	< 2e-16	***
AIC	9686.4				
likelihood ratio	0.2752858 (df=1)				

Signif. codes: '***' 0.001, '**' 0.01, '*' 0.05

Surface Road

Explanatory variable	Estimate	Std.Error	z value	Pr(>|z|)	
(Intercept)	-15.4379	0.0318	-484.91	< 2e-16	***
Precipitation	0.22213	0.0143	15.551	< 2e-16	***
Weekday	0.52519	0.0145	36.356	< 2e-16	***
Weekend	0.41676	0.0188	22.117	< 2e-16	***
Period time 6h〜9h	-0.08478	0.0134	-6.339	2.31E-10	***
Period time 9h〜12h	-0.13172	0.0135	-9.743	< 2e-16	***
Period time 12h〜15h	-0.09094	0.0135	-6.734	1.65E-11	***
Roadway width ≧5m	-0.27066	0.0129	-20.921	< 2e-16	***
Density of intersection ≧10/Km	0.37116	0.0103	35.882	< 2e-16	***
Green ratio on traffic right ≧70%	-0.27721	0.0233	-11.883	< 2e-16	***
Roadside situation：DID	0.89069	0.0291	30.571	< 2e-16	***
Roadside situation：urban area	0.65739	0.0359	18.303	< 2e-16	***
Congestion	0.29161	0.0232	12.572	< 2e-16	***
Dummy : Frequent section of traffic accidents	0.63145	0.0103	61.351	< 2e-16	***
AIC	79150				
likelihood ratio	0.136435 (df=1)				

Table 4 - Predictive Power of Empirical Models

model	N	number of traffic accidents	Traffic accident rate	
		RMSE	RMSE	RMSPE
Inter-urban expressway model	6,420	0.74	158.46	29.29
Urban expressway model	12,210	0.76	307.62	32.18
Surface road model	116,760	1.36	1120.8	45.59

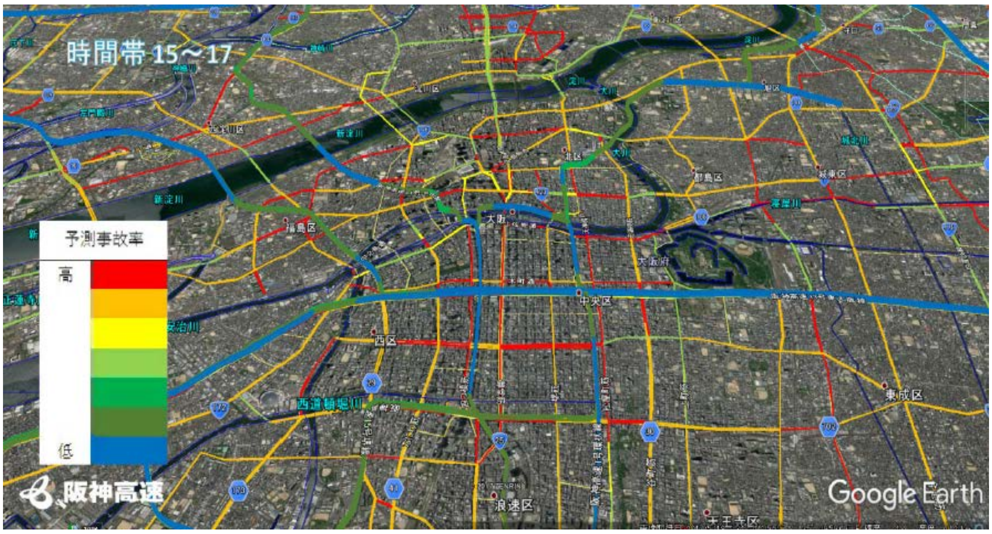

Figure 3 - Traffic Accident Risk Map, Osaka City

Providing Traffic Accident Risk Information to Drivers

Framework to Provide Low Accident Risk Driving Directions

In this study, a social experiment was conducted to inquire whether integrating traffic accident risk in driving directions would reduce individual and network-wide traffic accident risks. As part of the framework of the analysis the study team utilized “Drive Supporter,” a mobile application developed by NAVITIME (a private software developer) to incorporate the traffic accident risk model discussed in the previous section.

An existing driver navigation system (i.e., Drive Supporter) was chosen so as to achieve broad and sustainable use of the outcome of this project. Also, in this framework low accident risk driving directions would be reflected as “recommended direction” to appear on top of alternative routes when direction is searched for a destination. This is because of the objective of this study to promote the use of low accident risk direction and enhance its effect, and since it is known that drivers show high propensity of selecting the research result that appears at the top.

Framework to Incorporate Low Accident Risk Route Information into Driving Directions

In this experiment, low traffic accident risk route information was incorporated into route search algorithm of the mobile application. Drivers are known to consider travel time and expressway tolls, if appropriate, in making travel decisions using the application. In addition to this, the framework herein will account for traffic accident risk in searching for alternative driving directions. In the literature, considerable proportion of drivers consider traffic accident risks in making travel route decisions, and it is reasonable to add accident risk as an index when navigation application searches for alternative driving directions[1), 2)] .

The present study proposes a traffic accident risk index as part of network link cost as follows:

$$C_{it} = w_T T_{it} + w_F F_{it} + w_r M_{it}$$

where

C_{it}: travel cost of link i during time period t in JPN Yen

T_{it}: monetized travel time during time period t on link i in JPN Yen

F_{it}: expressway toll during time period t on link i in JPN Yen

M_{it}: risk of traffic accident loss during time period t on link i in JPN Yen

w: weight assigned to each index.

Traffic accident loss risk is then modeled as the risk of causing an accident (i.e., the number of accidents a particular vehicle is involved as the primary party) multiplied by monetary loss per accident:

$$M_{it} = L \times R_{it}$$
$$R_{it} = \mu_{it} \times d_i$$

where,

R_{it}: Risk to be involved in a traffic accident during time period t on link i in number of accidents

μ_{it}: Risk of traffic accident occurrence during time period t on link i in number of accidents per vehicle-kilometer

d_i: Length of link i in kilometer

L: Monetary loss of a traffic accident in JPN Yen, which is determined following statistics reported by Government of Japan Cabinet Office[8)].

Framework to Estimate Accident Risk During Driver Navigation

The traffic accident risk prediction model discussed above was then incorporated into Drive Supporter, a driver navigation mobile application. The following objectives were pursued in developing the framework:

- Endogenous accident risk information generation
- Limited burden on navigation system
- Ease of system adjustment, operation, and maintenance

In pursuit of these objectives, we implemented the following measures:

- Reduce the number of models by integrating local arterial and regional arterial networks as a single “surface road network” model
- Drop explanatory variables that were hard to acquire and maintain
- Simplify explanatory variables

Table 5 reports estimation results, and Table 6 shows a comparison of predictions and actual statistics. Correlation coefficient between predictions and actual statistics and RMSE statistics did not change considerably, hence we accepted the improved models.

Table 5 - Estimation Results of Models for Driver Navigation

Urban Expressway

Explanatory Variable	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-17.5917	0.1368	-128.642	< 2e-16	***
Precipitation	0.3902	0.0549	7.1060	1.2E-12	***
Weekday	0.5984	0.0600	9.9830	< 2e-16	***
Weekend	0.4368	0.0783	5.5810	2.39E-08	***
Period time 6h〜9h	0.5637	0.0637	8.8540	< 2e-16	***
Period time 9h〜12h	0.5655	0.0633	8.9410	< 2e-16	***
Period time 12h〜15h	0.2894	0.0689	4.2000	0.0000267	***
Period time 15h〜18h	0.7359	0.0616	11.9530	< 2e-16	***
Curve radius <300m	0.1239	0.0409	3.0270	0.00247	**
Roadside situation：DID	0.8070	0.1217	6.6330	3.29E-11	***
Congestion	1.0542	0.0436	24.1820	< 2e-16	***
AIC	10,235				
likelihood ratio	0.2339538 (df=1)				

Signif. codes: '***' 0.001, '**' 0.01, '*' 0.05

Surface Road

Explanatory Variable	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-15.1996	0.0214	-711.35	<2e-16	***
Precipitation	0.1594	0.0123	13.0100	<2e-16	***
Weekday	0.5291	0.0122	43.4700	<2e-16	***
Weekend	0.4387	0.0158	27.7800	<2e-16	***
Period time 6h〜9h	-0.1217	0.0112	-10.8400	<2e-16	***
Period time 9h〜12h	-0.1499	0.0113	-13.2500	<2e-16	***
Period time 12h〜15h	-0.1296	0.0114	-11.3800	<2e-16	***
Density of intersection ≧10/Km	0.4175	0.0087	48.1800	<2e-16	***
Roadside situation：DID	1.0849	0.0188	57.7500	<2e-16	***
Roadside situation：urban area	0.6785	0.0246	27.5600	<2e-16	***
Congestion	0.1990	0.0119	16.7700	<2e-16	***
Over four-lane	-0.1599	0.0093	-17.2600	<2e-16	***
AIC	130,691				
likelihood ratio	0.09312612 (df=1)				

Table 6 - Predictive Accuracy of Models for Driver Navigation

model	N	number of traffic accidents	Traffic accident rate	
		RMSE	RMSE	RMSPE
Inter-urban expressway model	6,420	0.75	158.43	27.16
Urban expressway model	12,210	0.84	307.97	30.89
Surface road model	116,760	1.45	1121.21	51.42

Conclusion

Reducing traffic accidents and associated economic loss is of critical importance to policy makers and expressway operators. In this study the study team, as part of traffic safety management operation, proposed a traffic accident risk model and incorporated the model into a driver navigation system available from a private mobile application developer. This study discussed various considerations that need to be accounted for in developing such a system.

The study team continues the effort to integrate the traffic accident risk estimation and the framework to generate low accident risk driving directions. NAVITIME JAPAN Co., Ltd started providing low accident risk driving directions to the public on December 20, 2017 (Wed) through a publicly released mobile application, “Drive Supporter (Figure 4, available domestically).”

The service has already begun demonstrating its effectiveness in influencing drivers’ behaviors and lowering system-wide accident risks. The aggregate number of searches for low-accident risk driving directions reached 153,700 during a two-week period between February 7 – 20, 2018 (with origins and destinations within Hanshin metropolitan region). We estimate that 14,602 searches (9.5% of all searches) resulted in drivers’ choosing routes different from directions that would not consider accident risks. Figure 5 summarizes the nature of these changes: when considering accident risks, a large proportion of drivers chose routes involving expressways rather than arterials. We estimate that accident loss risk has dropped by 3.6% whereas total travel time decreased by 0.8% across the metropolitan region, as a result of the low accident driving navigation service that has now become available to drivers.

The study will need to address a number of foreseen challenges, mostly in terms of scale and continuity. With respect to scale, it will be necessary to expand the use of the system from merely a single driving navigation mobile application to more media and platforms. Regarding continuity, the study will need to further enhance the models to continuously update traffic accident data with appropriate levels of operational and maintenance costs. These improvements will be essential in expanding the use of the models for more services.

Figure 4 - The Displayed Screen of Low Accident Risk Driving Directions on Navigation Mobile

Figure 5 - The Route Changes when Considering Accident Risks

Acknowledgments

This paper is based primarily on activity by A Study Group of Traffic Management utilizing Accident Risk Information on Hanshin Urban Ares, especially we wish to thank members of A study Group for many helpful advice.

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