APPLICABILITY OF A KOREA HIGHWAY SAFETY EVALUATION MODEL COMPARED TO THE CRASH PREDICTION MODULE OF IHSDM

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ABSTRACT

Roadway safety is crucial because traffic accidents create huge social and economic losses. For more effective and accurate roadway diagnosis, various studies are being conducted. Interactive Highway Safety Design Model(IHSDM), SafetyAnalyst, and MicroBENCOST are developed systems based through efforts. Notably, Crash Prediction, Policy Review, and Design Consistency modules in IHSDM not only evaluate safety of highway designed but also predict the number of accidents on existing and new roads and support experts' roadway safety evaluation efforts. In Korea as well, researches on the development of Korean highway safety evaluation models (KHSEM) including development of AMF were conducted. Thus, models for intersections and roadway segments were built. The predictability of the KHSEM and the applicability of IHSDM CPM in Korean highways were evaluated by applying them to the same segments.

IHSDM CPM reflects more roadway geometric elements, while KHSEM focuses more on environmental elements of roadway by reflecting Korea's rural highway characteristics; for example, an examination of accident data on segments of two different National highways that passes Jeollabuk-do (Jeonbuk) and Gyeonggi-do indicated that accidents were more caused by roadside environment factors. Thus, compared with the IHSDM CPM, the prediction by the KRSDM proved to be closer to actual accidents, while the IHSDM CPM indicated no particular risks in the target segment with a general roadway geometrics. This suggests that the IHSDM CPM is more universal, but that the KRSDM is more effective in predicting accidents in Korean roads.

Key words : IHSDM, KHSEM, Safety Assessment, Applicability , Crash Analysis

INTRODUCTION

In designing roadways, the first priority is placed on the efficiency of roadway travel and roadway safety. Risks of roadway accidents always exist although roadways are built on using a highway design manual. Although various roadway design criteria are based on research results in diverse fields, and notably, researches into the relations between roadway geometric, risks of accidents, and inefficiency of roadway operation, certain designed highways do not necessarily guarantee safety, because over 90% of traffic accidents occur due to human elements, and because individual geometric elements of roadway interact with one another, creating unexpected risks of accidents. Thus, systems need to be developed to analyze such risks and improve the design. One of such typical examples is the US-developed Interactive Highway Safety Design Model (IHSDM)'s Crash Prediction Module (CPM). Notably, IHSDM assumes the existence of risks of roadway accidents, and evaluates the safety of roadway designed using the prescribed roadway design criteria, design consistency, and an analysis of actual accident data. Such safety evaluation programs produce supporting features for experts' assessment, and support decision-making by calculating safety benefits in association with the number of expected accidents predicted according to alternative measures.

In this study, to examine whether the evaluation models in IHSDM are suitable for Korean situations in association with the existing safety diagnosis system or not, the applicability of IHSDM CPM was investigated with the results from KHSEM.

LITERATURE REVIEW

Interactive Highway Safety Design Model

IHSDM is a roadway design safety evaluation program developed by Federal Highway Administration (FHWA), and consist of six modules including accident prediction modules: design consistency module (DCM), policy review module (PRM), traffic analysis module (TAM), driver/vehicle module (DVM), intersection review module (IRM)) and crash prediction module (CPM). Of these modules, CPM, based on the base model and Accident Modification Factor(AMF), was examined herein.(FHWA., 2006)

IHSDM's CPM evaluates the safety of the target segments in a rural two-lane highway. If an array of relevant data, such as roadway geometric (horizontal alignment, and vertical alignment), cross section components (lane width, shoulder width, and roadway type), traffic operating elements (climbing roadway and lane for passing ahead), traffic volume, and posted speed, are input into the program, the module presents the target segment's total estimated accident frequency and accident rate, and the homogenous segment's accident frequency and accident rate, thereby evaluating the segment's safety.

The CPM evaluates the existing roadways by using the existing accident history. This process corrects and closely forecasts the location with frequent accidents, the severity of accidents, and the frequency of accidents. Also, a Calibration factor (C_r) can use for reflecting regional features.

$$N_{rs} = (ADT_n)(L)(365)(10^{-6})\exp(-0.4865)\,C_r AMF_{1....9} = N_{br} C_r AMF_{1....9} \quad (1)$$

N_{rs} = total expected accidents on the target road segment (crashes/year)
N_{br} = total expected accidents based on the base model
C_r = calibration factor
AMF $_{1...9}$ = Accident Modification Factor
ADT_n = Traffic volume during the target period (veh/day)
L = road segment length (mile)

Studies to Evaluate Highway Safety Using IHSDM

Since the accident evaluation modules, which are supposed to quantify safety benefits, would produce great impact depending on their accuracy, CPM, MicroBENCOST, and Transportation Association of Canada(TAC) were applied to rural two-lane highways of Newbrunswick. As a result, MicroBENCOST produced the highest error rate of 75%~190%, and the IHSDM CPM – although it required many data for analysis – produced a forecast closest to the actual results (Eric Hildebrand et al., 2008)

Using the CPM, 4,746 roadway segments in Louisiana were examined; the number of predicted accidents was close to that of actual accidents, but there was a difference in terms of the severity of accidents, and the rate and number of accident by type of accident. In terms of types of accidents, the CPM predicted many single-vehicle accidents caused by wild animals, but actual data indicated that there were more accidents between vehicles due to left turns and rear-end collision. Also, the CPM predicted 10% lower severity of accidents (Hong Zhang., 2003).

The CPM applied to the rural two-lane highways of Pennsylvania in the USA. Two different segments were examined, resulting in different predicted figures. In one segment, the prediction was close to the actual figure by a 5% margin, but in the other segment, there was a big 73.5% difference. When actual accident data applied to the relevant segment, a 32.5% difference was shown, although the prediction improved. (Eric T. Donnell., 2007)

In addition to the evaluation of the prediction ability of the IHSDM's CPM, Conkin(2004) examined the impact of horizontal composition and geometric changes in roadway segments on roadway safety, targeting the projected improvement segment (US 119 Pine Mountain). Using the CPM, the safety of the whole targeted segment was examined, and after changing the lane width, the radius of curve, and the horizontal composition in the same segment, the corresponding accident rate and frequency were studied so as to define the impact. As a result, the widening of the roadway, and the installation of a climbing lane for trucks reduced the accidents the most on the relevant roadway.(Will Conkin et al., 2004)

Using the IHSDM CPM, the safety of three segments (US-40, US-6, SR-150), which had the highest accident rate of the rural two-lane highways of Utha, was examined. In all of the three 3 segments, there was no statistical significant difference between when the past accident history was applied and when it was not applied, and as with the Louisiana case above, the CPM failed to reflect the actual accident pattern. (Mitsuru Saito, 2008)

Not many researches into the applicability of the IHSDM modules were conducted after they were used in other nations and other regions in the USA, although it has been around for quite a time. However, some researches indicated that there are deviations in the CPM-based prediction of accident frequency and accident rate according to regions or road segments. This still indicates the CPM's limitations as a universal program because it should call for the reflection of a regional correction parameter, the past accident history, and regional characteristics. Among other things, in the event that a regional correction is required in order to better reflect regional characteristics in addition to the accident history, many data are needed, but such sufficient data may not exist.

Thus, this study examines whether the IHSDM's CPM can be used to evaluate the safety of roadways in Korea or not, and compares the performance between the IHSDM CPM and a road design safety evaluation model developed in Korea.

DEVELOPMENT OF KOREA HIGHWAY SAFETY EVALUATION MODEL

Data Collection

In this study, roadway segments on rural highways outside Seoul, which is the biggest metropolitan city and a Capital of Korea Area, as well as roadway segments equipped with characteristics of level and rolling terrain in a Jeonbuk were selected. For the accident data, National Policy Agency data were used. The information on roadway situations such as roadway geometric conditions, traffic operation factors and roadside environments was gathered through on-site surveys and design drawings.

To develop prediction model and AMF, 104.4km of the rural highways outside Seoul and 218.5km of the rural highway in Jeonbuk were surveyed. Table 1. features variables of geometric conditions, roadside design variables, variables of traffic conditions, and other variables.

Table. 1 Road Segment Information

Item	Jeonbuk Highway No. 37	Gyeonggi-do Highway No. 37
Station number	8+200 ˜ 18+500	0+000 ˜ 5+080
Traffic Volume	1009veh/day	5147veh/day
Total Length of Segment(km)	10.3	5.08
Number of Homogeneous Segments	80 (100%)	38 (100%)
Number of Curves	60 (75%)	17 (45%)
Number of Tangents	20 (25%)	21 (55%)
Average Lane Width(m)	3.32	3.5
Average Shoulder Width(m)	0.72	1.06
Average Driveways Density(dwys/km)	2.32	1.95

Variables of geometric conditions of roadway include the radius of curve, vertical alignment, lane width, roadway segment length, the number of driveways, and type and width of roadway shoulders. Roadside design variables include the number of lighting facilities, and the type and width of median. Variables of traffic conditions include posted speed, traffic volume, traffic volume of heavy vehicles, and existence of enforcements. And, other variables include the land-use, the number of crosswalks, the number of bus stops, and visibility improvement facilities.

To evaluate the applicability of applying the IHSDM in evaluating the safety of Korean roadways, two segments, 10.3km segment of National highways in Jeonbuk and 5.08km segment of National highways in Gyeonggi-do, were additionally surveyed. Compared with the highways in Jeonbuk, the highway in Gyeonggi-do has a greater lane width, a greater roadway shoulder width, a smaller driveway density, and a greater number of segments without any curve, thereby having good geometric structures. Gyeonggi-do segment has a shorter road segment length but, has five times the traffic volume. Corresponding this, roadway segments in the Gyeonggi-do presumably has a bigger exposure to accidents.

Modeling and AMF Development

The crash prediction model for the rural two-lane highway was developed using a statistical package LIMDEP 8.0. The gathered data were applied in developing the model after considering both accident occurrence segments and non-occurrence segments in homogenous segments in a bid to eliminate the possibility of distorting predictions or involving distorting variables in the model. Roadway segments were divided according to geometric elements, such as the radius of curve, vertical alignment, and lane width. Additional segmentation items would further divide road segments into excessively shorter sections. In order to adopt variables to prevent the duplication of independent variables and to secure independence between variables, the correlation test between dependent variables and independent variables, and between independent variables was conducted to be within a level of confidence 90%(α=0.1). As a result, the accident model for the rural two-lane highways is shown in Equation (4), and variables - namely, vertical alignment, the number of driveways, and the neighborhood with bus stops and roadside dwelling facilities - were found to increase accidents.

To evaluate the prediction, Mean Absolute Deviation(MAD) for assessing the prediction deviation Mean Prediction Bias(MPB) for assessing the bias of prediction were used The closer the value of MAD and MPB is to 0, the more accurate the prediction is. MAD and MPB are calculated by Equation (2) and Equation (3), respectively, as follows.

$$MAD = \frac{1}{n} \times \sum_{i=1}^{n} |Y_i - \hat{Y}_i| \quad (2)$$

$$MPB = \frac{1}{n} \times \sum_{i=1}^{n} (Y_i - \hat{Y}_i) \quad (3)$$

Y_i= predicted value, $\hat{Y}_i$= measured valued

The suitability of the model was evaluated using likelihood ratio(ρ^2), which was defined to be 0.185. MAD and MPB were determined to be -0.138 and 0.359, respectively, indicating that the deviation of average yearly accident frequency was below 1 case.

$$\hat{Y} = EXPO \times \exp\,(-7.249 + 0.102X_1 + 32.757X_2 + 21.590X_3 + 1.797X_4 \qquad (4)$$

$EXPO = 365 \times ADT \times Length \times Year / 10^{-6}$

X_1 : Gradient (slope)

X_2 : Number of driveways (driveways/m)

X_3 : Number of bus stops (bus stops/m)

X_4 : Land use level (residential purpose)

In the meantime, the AMF was firstly calculated based on accident models for the two-lane roadway to reflect roadway geometric and traffic operation elements. However, since the final model did not involve many road design variables, additional AMFs for several major variables for evaluating roadway design safety were developed by reflecting experts' opinions. These AMF development methods are the same as that used in the Highway Safety Manual and IHSDM were used.

Six AMF including vertical alignment and driveways density were developed on the basis of KHSEM, and their value is outlined as shown in Table2.

Table.2 KHSEM's AMFs

Variables	Unit and scope	AMF
Crosswalk	< 0.02 crosswalks/m	$AMF_{CW} = e^{48.392*CW}$
	≥ 0.02 crosswalks/m	$AMF_{CW} = 2.63$
Terrain	Mountainous	$AMF_{MN}=1.22$
Driveways Density	< 0.02 driveways/m	$AMF_{DD} = e^{32.966*DD}$
	≥ 0.02 driveways/m	$AMF_{DD} = 1.93$
Vertical Alignment	VG= ABS%	$AMF_{VG} = e^{0.084*VG}$ (VG=ABS,%)
Median Strip		$AMF_{MS} = 1.39$
Land Use	Residential area	$AMF_{LU} = 5.44$

The AMFs for crosswalks and driveways density were calculated by dividing the number of relevant facilities by the length of the homogeneous segment and applying the resultant density value.

APPLICATION OF IHSDM CPM AND KHSEM TO KOREA RURAL HIGHWAY SEGMENTS

The applicability of CPM and KHSEM to Korean roadways was evaluated by applying them to a 10.3km roadway segments in Jeonbuk and to a 5.08km roadway segments in

Gyeonggi-do, which surrounds the Seoul; the prediction results from two systems were compared with actual accident frequency.

Such examination results are outlined as follows:

CASE 1. The frequency of accidents that occurred in the period of 2005 - 2006 in the segment of 8+200~18+500 of highways in Jeonbuk were examined using the CPM and the KHSEM; the predicted accident frequency was calculated, and was compared with the actual accident frequency to evaluate their applicability. Predicted accident frequencies were calculated for the total roadway section and individual roadway segments. The frequency by segment aimed to identify the points of actual accident occurrence.

CASE 2. In the case of highways in Jeonbuk, the 3-year available accident history data were reflected in predicting accidents in 2007 to measure changes in predicted accident frequency and accident distribution. Thus, the CPM produced predictions both with and without the history of accidents. These two results were compared with KHSDM and actual accident frequency.

CASE 3. The 2007 accident frequency in the segment of 0+000~5+080 of the Greater Seoul Area Highway No. 37 was predicted using the CPM and the KHSEM, and the results were compared.

Analysis of Application

CASE 1.

KHSEM and CPM based examination results for highways in Jeonbuk were explained in Table 3 and Figure 1.

TABLE 3. Jeonbuk Segment's Actual Accidents and Predicted Accidents

Description	CASE1			CASE2			
	CPM	KHSEM	Actual	CPM	CPMh	KHSEM	Actual
Total Crashes	9.1	17.16	13	3.12	3.89	5.87	8
Fatal and Injury Crashes(32%)	2.92	5.49	4.16	1	1.58	1.88	2.56
Property-damage-only Crashes(68%)	6.18	11.67	8.84	2.12	2.31	3.99	5.44
Average Future Road ADT	1,009	1,009	1,009	1,035	1,035	1,035	1,035
CrashRate/km/yr	0.3	0.56	0.42	0.3	0.4	0.57	0.78
Fatal and Injury CrashRate/km/yr	0.1	0.18	0.13	0.1	0.2	0.18	0.25
Property-damage-only CrashRate/km/yr	0.2	0.38	0.29	0.2	0.2	0.39	0.53
Fatal and Injury CrashRate(MVK)	0.3	0.48	0.37	0.8	1	1.55	2.11
Property-damage only CrashRate(MVK)	0.5	1.03	0.25	0.3	0.4	0.50	0.67

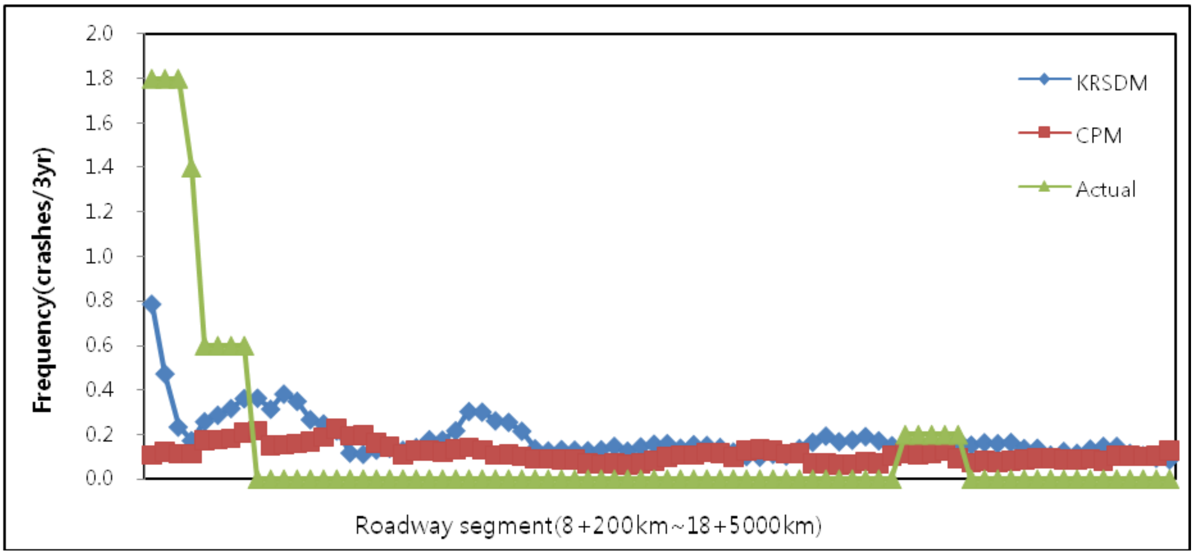

FIGURE 1. Predicted Accident Frequency for Highways in Jeonbuk in 2005 – 2006

The CASE 1 examination indicated that, in the Jeonbuk 10.3km segment, for 3 years, the CPM predicted 9.1 accidents, and the KHSEM predicted 17.16 accidents. These figures can be compared with the 13 actual accidents. When evaluating the errors of the two models, in the case of total accidents, the bias of error is different, but the size of error is similar. Thus, the two models are thought to have similar prediction ability.

However, Table 4 for accident prediction ability and Figure 1 for accident distribution show a difference in total predicted accidents.

TABLE 4. Jeonbuk Segment's MAD, MPB

	CASE 1		CASE 2		
	KHSEM	CPM	KHSEM	CPM_h	CPM
$\sum(Y_i - \hat{Y}_i)$	-0.83	25.95	-2.11	-4.14	-4.95
$\sum\lvert Y_i - \hat{Y}_i\rvert$	21.74	42.89	13.35	10.26	10.87
MPB	-0.010	0.324	-0.026	-0.052	-0.062
MAD	0.272	0.536	0.167	0.128	0.136

In Table 4, the CPM's MAD and MPB were calculated to be 0.324 and 0.536, respectively, predicting an average 0.324 more accidents than the number of actual accidents, and the average total error was 0.536. The KHSEM's MAD and MPB were -0.010 and 0.272, respectively, predicting an average 0.010 smaller accidents than the number of actual accidents, and the average total error was 0.272. KHSEM, which produced smaller MAD and MPB, is thus thought to have a better prediction ability than the CPM.

Also, from the Figure 1 graph, which shows the distribution of accident occurrence points and predicted risky points, the validity of the models' calculation of segments of risk was evaluated. In the roadway segment of highways in Jeonbuk, 9 of 13 actual accidents occurred for 3 years in the section stretching 150m from the entrance of the target segment. Thus, the

KHSEM shows the same pattern. The entrance area of the segment shows a high accident frequency, indicating a high-risk accident frequency. However, the CPM shows ordinary-risk figures from the entrance to the final point, and thus fails to define a segment of high risk.

CASE 2.

The CPM's correction function using the history of accidents was evaluated. Based on two years of accident data from 2005 to 2006 for the roadway segment of highways in Jeonbuk, the two models-based 2007 accidents were predicted, and the results were compared with the actual 2007 accident frequency.

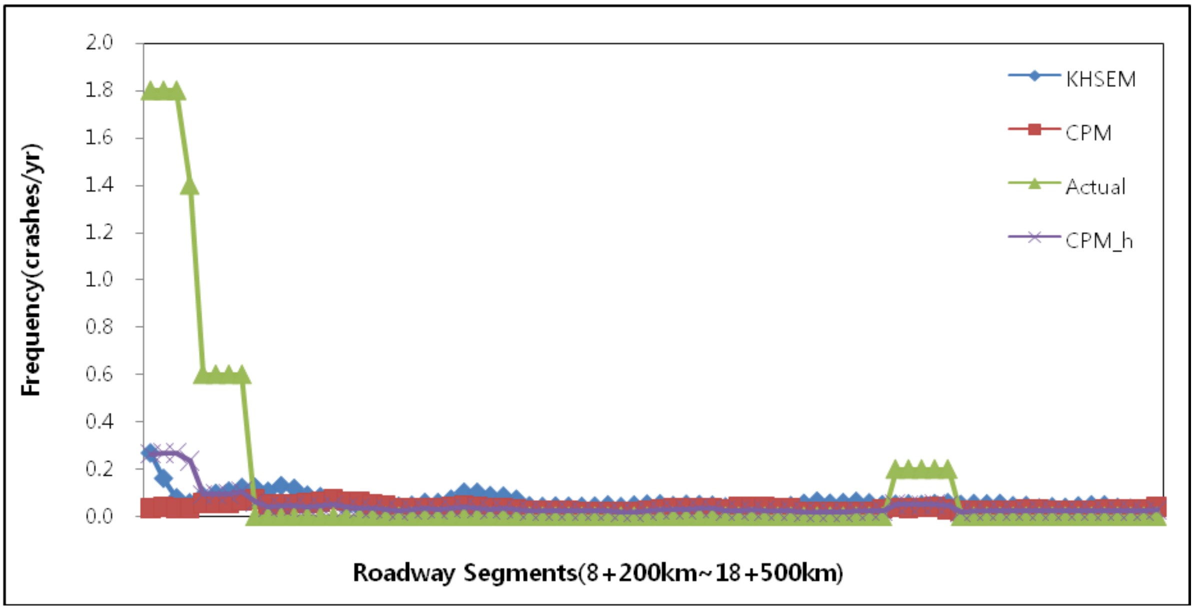

FIGURE 2. Predicted Accident Frequency for Highways in Jeonbuk in 2007

In Table 3, the CPM predicted 3.12 accidents without reflecting the accident history, and 3.89 accidents with the reflection of the accident history(CPMh), showing no significant difference. The KHSEM predicted 5.87 accidents, higher than the CPM predicted.

Since the 2007 actual accident total was 8, the KHSEM better predicted. Also, the CPM's correction by reflecting the accident history predicted a higher accident frequency, producing a correction effect, but failed to produce a better effect.

In Table 3, CPM, CPMh, and KHSEM all predicted a smaller number of accidents than the number of actual accidents. The KHSEM produced the lowest MPB, indicating a high prediction ability, and the CPMh produced the lowest MAD, indicating the best prediction ability.

In Figure 3, the CPM does not show a particularly risky section across the target segment. However, in Figure 4 with the reflection of the accident history, the CPM showed a high accident frequency at the starting area compared with other sections, predicting the risky section reliably.

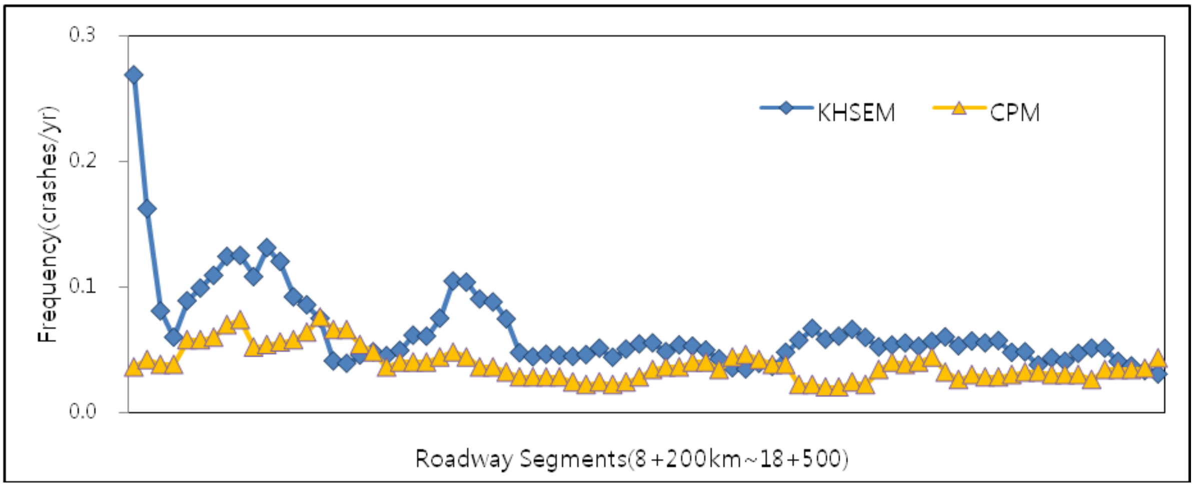

FIGURE 3. Predicted Accident Frequency for Highways in Jeonbuk Without Reflecting Accident Data (CASE 2)

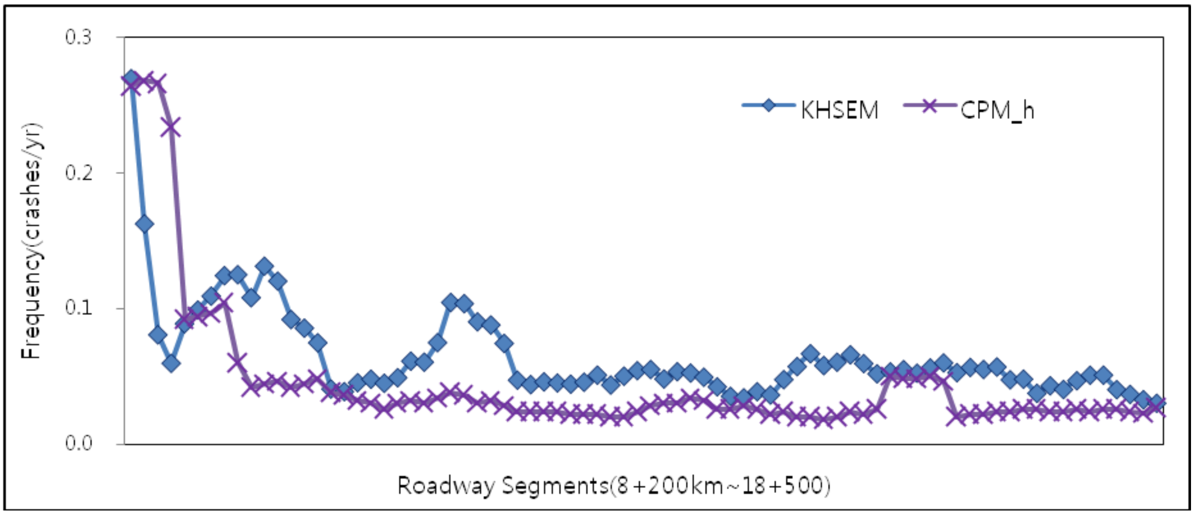

FIGURE 4. Predicted Accident Frequency for Highways in Jeonbuk with Reflection of Accident Data (CASE 2)

CASE 3.

In Table 5 showing the examination of the roadway segment of highways outside Seoul, the CPM predicted 4.95 accidents in 2007, and the KHSEM predicted 8.27 accidents. The CPM's prediction thus is very accurate since 5 actual accidents occurred.

TABLE 5. Actual Accidents and Predicated Accidents in Greater Seoul Area Highways

Description	CASE 3		
	CPM	KHSEM	Actual
Total Crashes	4.95	8.27	5
Fatal and Injury Crashes(32%)	1.59	2.65	3
Property-damage-only Crashes(68%)	3.36	5.62	2
Average Future Road ADT	5,184	5,184	5,184
CrashRate/km/yr	1	0.80	0.49
Fatal and Injury CrashRate/km/yr	0.3	0.26	0.29
Property-damage-only CrashRate/km/yr	0.7	0.55	0.19
CrashRate (MVK)	0.5	2.18	1.32
Fatal and Injury CrashRate(MVK)	0.2	0.70	0.42
Property-damage only CrashRate(MVK)	0.3	1.48	0.90

However, in Table 6 and Figure 5, the KHSEM better predicted in homogenous segments. In Table 6, the KHSEM's MPB and MAD are 0.103 and 0.281, respectively, while those of the CPM are 0.452 and 0.614 which are three times as big as those of the KHSEM.

TABLE 6. MAD and MPB of Greater Seoul Area Highway No. 37

	CASE 3	
	KHSEM	CPM
$\sum(Y_i - \hat{Y}_i)$	3.37	17.17
$\sum\lvert Y_i - \hat{Y}_i\rvert$	10.20	23.35
MPB	0.089	0.452
MAD	0.268	0.614

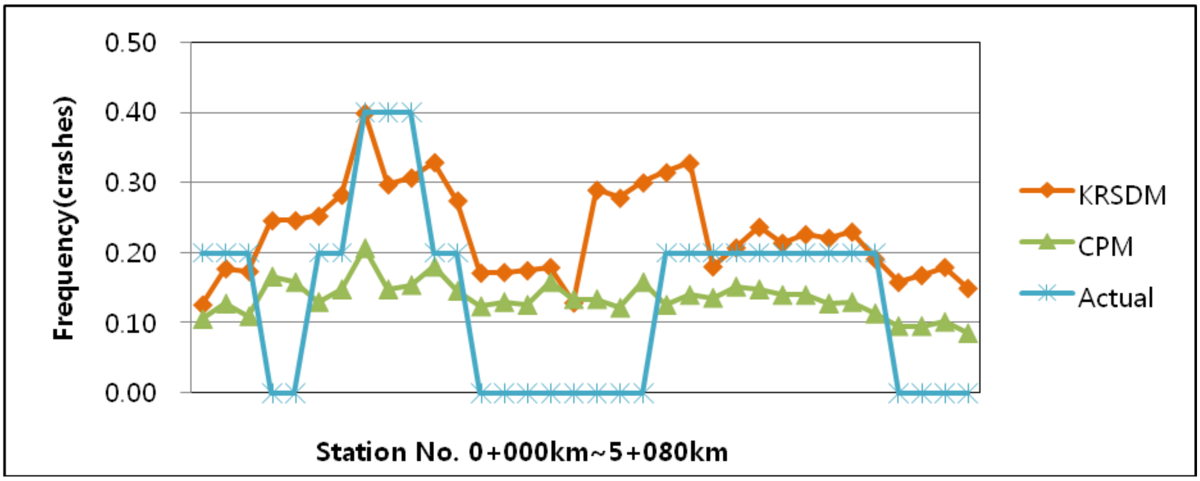

FIGURE 5. Predicted Accident Frequency of Greater Seoul Area Highway No. 37

In Figure 5 showing the accident distribution, the CPM does not forecast the risk section as in the roadway segment of highways in Jeonbuk, but shows a consistent distribution pattern. However, the KHSEM shows a high score for the actual accident place, forecasting the risky section. In the KHSEM graph, segments where accidents were forecast to occur with a great frequency, have more driveways than other segments; thus the driveway density is thought to affect the frequency of accidents. Also, areas with a more frequency of accidents involve driveways and crosswalks, and have greater vertical alignment compared with other segments.

CONCLUSION

This study examined whether the CPM validly evaluated the safety of the rural two-lane highways of Korea, and compared the CPM' prediction ability with that of the Korean roadway design safety evaluation model, KHSEM.

The findings of the study are outlined as follows; the CPM better predicted accidents in certain cases, while the KHSEM better predicted in some other cases. However, in terms of graphs showing the accident frequency by segment, as well as in terms of MAD and MPB devised for evaluating prediction ability by segment, the KHSEM performed better than the CPM except for case 2's MAD with the reflection of the history of accidents. Thus, since the CPM failed to pinpoint risky segments in Korean roadways, the KHSEM was evaluated to be better in evaluating the safety of Korean rural highways.

The CPM focuses on AMFs for roadway geometric and traffic conditions, while the KHSEM focuses on the road environment factors such as land use and the density of crosswalks. As such, this difference played a crucial role in reflecting Korean accident characteristics in the evaluation of Jeonbuk and Gyeonggi-do rural two-lane highways. The CPM bases its evaluation on geometric conditions such as lane width, shoulder width, vertical alignment, and radius of curve; the KHSEM focuses its evaluation on operational and road location characteristics such as terrain, roadside land use, and crosswalk density. This difference is thought to have worked to reflect the accident characteristics of Korea's rural highways.

The KHSEM, when developed, focused on operational and road environment factors rather than on geometric structures of roadway, because Korean rural highways' traffic volume, roadside land use and other external factors exercise great influence on accidents, unlike with rural highways of the USA. For instance, in the case of the roadway segment of highways in Jeonbuk, the entrance area where accidents actually occurred has a cluster of residential facilities close to the roadway. Thus, although the relevant segment had no particular faults in geometric structures of roadway, it had a high accident frequency. However, the CPM, which does not reflect such roadside land use situations, failed to predict the risky segment, while the KHSEM, which involves land use as a major evaluation item, was able to show a high accident frequency for the relevant segment, defining it as the risky segment. The same result was evinced in all of CASE 1, 2, and 3; the CPM did not properly evaluate the risk of Korea's rural highway.

Geometric conditions of roadway are the first priority to be considered in evaluating the safety of roadway. However, not only new roadways, whose surrounding land may be developed and used in the future, but also old roadways are supposed to be affected by road environments. The roadway safety evaluation system, which focuses only on geometric structures, does not properly evaluate roadways with such characteristics as those of Korea's rural highways which involve roadside land use.

To make roadway safety evaluation more practical, not only geometric structures of roadway and facilities, but also the operation of roadway, roadside land use, and terrain should be taken into account.

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