Cause-based Crash Modification Factors of Safety Countermeasures in Korean Expressways

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Abstract: The crash modification factors (CMFs) are the key of roadway safety analysis. CMFs indicate the benefits of safety countermeasure by the reduction ratio. The advanced method, empirical Bayes (EB), accounts for the potential bias and is widely used for recent two decades. There is an issue with the countermeasure that has different effects on different crash cause and it is related to another issue that the transferability of CMF. This research develops the cause-based CMF of countermeasure which has been installed in Korean expressway by EB method to find out the different effect quantitatively. The transferability of the CMF must be related different effect on different causes of treatment and proportion of crash cause in treated site. Also, the cause-based CMF could be the quantitative index of countermeasure selection.

Keywords: Crash Modification Factor, Empirical Bayes, Safety Countermeasure, Crash Cause

1. INTRODUCTION

Evaluation of the benefits of safety countermeasures is a key element for developing efficient and economical investment plans for roadway safety. The crash modification factors (CMFs) are used extensively to measure the ratio of crash reduction that might be expected after installing safety countermeasures. Due to the importance of the CMFs, the American Association of State Highway and Transportation Officials (AASHTO), (2010) published the first edition of "Highway Safety Manual" and described the meaning and usage of the CMF. Also, Federal Highway Administration (FHWA) operates a web site named "CMF clearing house" for collecting the researches about the CMF.

Reliable methodology is important developing the CMF. According to Persaud *et al.* (2010), the empirical Bayes (EB) method described by Hauer (1997) has been widely used for the past two decades. Gross *et al.* (2010) also recommends that the EB method has an advantage of accounting for the potential bias. The three biases which are the regression-to-the-mean (RTM), traffic volume change effects and time trend, are corrected by EB method. The observed accident counts always fluctuate around some unknown expected count. If an entity is treated because the crash count of before the treatment is abnormally high or unusually low, the RTM effects would arise.

The issue that this research focuses on is the different effects on different crash causes that is pointed out by Persaud and Lyon (2007). The safety countermeasure is designed to reduce the number of crashes for one or several crash causes. Thus, the impact of safety countermeasure on different crash causes varies. The cause-based CMFs must be studied for achieving more reliable CMFs and their transferability. The transferability of the CMF is the key issue of the recent research by Hauer *et al*. (2012) and it must be related different effect on different causes of treatment and proportion of crash cause in treated site.

In the CMF clearing house, there are collections of the CMF that are categorized as countermeasures, methods, crash type and severity. In the crash type category, only 'speed related' is the option related to the crash cause. Only four researches with 'speed related' option were founded (Griffin and Reinhardt, 1996; Tribbet *et al*., 2000; Tsyganov *et al*., 2009; Park *et al*., 2010). These researches did not use the Bayes approach except for Park *et al*. (2010).

The purpose of this research is to develop the cause-based CMF of safety countermeasure, which has been installed in Korean expressways using EB method to correct the bias. This research introduces the step by step procedure of EB method and develops the CMF for all crash cause and specific crash cause.

2. EMPIRICAL BAYES METHOD

The empirical Bayes method described by Hauer (1997) was developed to account for the RTM effect when sites with randomly-high, short-term (generally 3 to 5 years) crash frequencies are selected for treatment. The crash frequencies at selected sites regress toward their true long-term means. The EB method makes joint use of two clues to account for the RTM effect, i.e., the observed accident record and the predicted accident frequency at similar entities, shown in equation 1. The equation form is followed the "Highway Safety Manual" (AASHTO, 2010) but notation is revised.

$$N_{expected,before} = \omega(N_{predicted,before}) + (1 - \omega)(N_{observed,before}) \quad (1)$$

where,

$N_{predicted,before}$: number of crashes estimated by the SPF in the before-period
$N_{expected,before}$: number of crashes estimated by the EB method in the before-period
ω: weighting factor

It should be noted that the concept of 'predicted' differs from that of 'expected'. The number of predicted crashes is estimated by the safety performance function (SPF) while the number of expected crashes is estimated by the EB procedure. The SPF is an equation giving an estimate of average accident per year on a site, as a function of some explanatory values (e.g., daily traffic, site length, etc.) and SPF is developed from the crash data of the reference group. A weighting factor is obtained by equation 2, where, k is an over-dispersion parameter from a negative binomial regression model with the use of a maximum likelihood procedure described by Washington *et al*. (2003).

$$\omega = \frac{1}{1 + k(\sum_{1}^{\text{all past year}} N_{predicted,before})} \quad (2)$$

The next step is to estimate the expected number of crashes in the after-period using the $N_{expected,before}$ and the adjustment factor r_i. $N_{predicted,after}$ is the output value of SPF using the average annual daily traffic (AADT) of the after-period. The adjustment factor r_i reflects the changes in crash frequency as a result of changes in the traffic volume. The variance of $N_{expected,after}$ can be estimated approximately from equation 5. The CMF can be estimated by equation 6.

$$r_i = \frac{\sum N_{predicted,after}}{\sum N_{predicted,before}} \tag{3}$$

$$N_{expected,after} = N_{expected,before} \times r_i \tag{4}$$

$$Var(\sum N_{expected,after}) = \sum((r_i)^2 \times N_{expected,before} \times (1-\omega)) \tag{5}$$

$$OR`(Odd\ Ratio`) = \frac{\sum N_{observed,after}}{\sum N_{expected,after}} \tag{6}$$

A more precise estimate of the CMF can be obtained by equation 7 and its variance can be obtained by equation 8. The standard error is obtained by taking the square root of the variance. By applying equation 1 through 8, the CMF by the EB method can be developed, which accounts for RTM effect of the treatment site and changes in the traffic volume.

$$CMF(Odd\ Ratio) = \frac{OR`}{1 + \frac{VAR(\sum N_{expected,after})}{(\sum N_{expected,after})^2}} \tag{7}$$

$$Var(CMF) = \frac{(OR`)^2 \left(\frac{1}{\sum N_{observed,after}} + \frac{Var(\sum N_{expected,after})}{(\sum N_{expected,after})^2} \right)}{\left(1 + \frac{Var(\sum N_{expected,after})}{(\sum N_{expected,after})^2}\right)^2} \tag{8}$$

3. DEVELOPMENT OF CMF

3.1 Data Collection and Development of SPF

The data for this study were collected from five Korean expressways that are operated by the Korea Expressway Corporation, i.e., Gyeongbu, Honam, Namhae, Seohaean, and Yeongdong. From 2003 to 2005, eight safety facilities were installed on these expressways at several sites, and the facilities included speed enforcement cameras, rumble strips, delineator posts, barriers on the roadside, barriers in the median, a slide-prevention devices, illumination and delineators. Crash data for implementing the EB method were needed for at least three years of the before-and-after periods. Thus, crash data from 2000 - 2008 were used for this study. Treatment sites and reference group has the same before-and-after period, and geometric features were not specified for either of them and directional AADT data were used.

In this study, a multivariate negative binomial regression was used to develop the SPF for the EB method and the independent variables were AADT and segment length as shown in equation 9. The dependent variable is the number of crashes per year at a site. The over-dispersion parameter (k) also was calibrated in the regression process. In this research, three SPFs were used for reflecting the different countermeasure implementing (2003-05). The result of parameter calibration was shown in Table 1. The coefficient of β_1 and β_2 is statistically significant at 99% level of confidence.

$$N_{spf,year} = \exp(\alpha + \beta_1 \cdot L + \beta_2 \cdot AADT) \quad (9)$$

where,

AADT: average annual daily traffic (veh/day)
L: segment length (km)
α, β_1 and β_2: regression parameters

Table 1. Results of SPF parameter calibration

Year	Number of crashes	α	β_1	β_2	Over-dispersion parameter	Log likelihood
2003	4,864	0.31169*	0.14603*	0.0000112*	0.36050	-2338.2
2004	4,862	0.07176	0.14344*	0.0000128*	0.47248	-2735.6
2005	4,494	0.05390	0.13892*	0.0000118*	0.42965	-2654.2

* Significant at 1% level

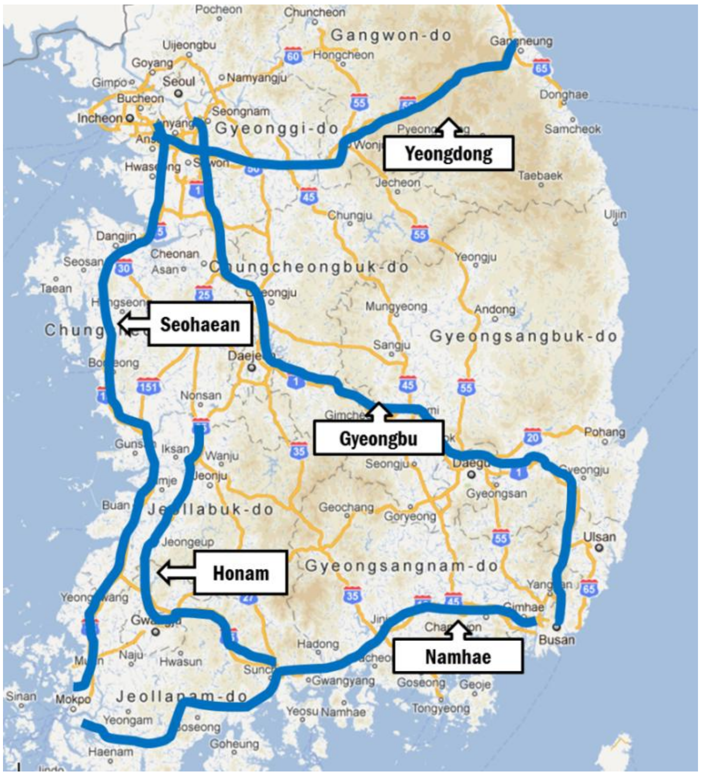

Figure 1. Five major expressways in Korea

3.2 Result of Developing CMFs

To develop the CMFs for all crash cause, the time trend was corrected by using the yearly multiplier because there was significant reduction of crashes at the reference group. According to Hauer *et al*. (2002), the yearly multiplier is calculated as the sum of observed crashes divided by the sum of predicted crashes by SPF in that year.

The results of the development of CMFs are shown in Table 2. The speed enforcement camera is 0.7819 with the 0.0785 of standard error. Illumination shows the best performance, as 0.7724 of CMF, but delineator post affected the increase of crash. The standard error is increased by decreasing of crash data.

According to Elvik (1997), RTM effect can be also calculated by the difference in the expected number of crashes and the observed number of crashes divided by the observed number of crashes. The data of this study show that the RTM effects of the safety countermeasure occurs randomly, + and -, low and high.

Table 2. CMFs of safety countermeasures

Safety countermeasure	Number of crashes (before & after)	CMF	Standard error	RTM effect
Speed enforcement camera	643	0.7819	0.0785	0.0012
Rumble strips	280	0.8357	0.1187	0.2468
Delineator post	433	1.1009	0.1364	-0.0046
Barrier on road side	102	0.8725	0.2188	-0.0003
Barrier on median	62	0.9629	0.2937	0.1225
Slide-prevention device	58	1.0133	0.3356	-0.0136
Illumination	51	0.7724	0.2982	-0.2175
Delineator	55	0.9768	0.3480	-0.0504

4. DEVELOPMENT OF CAUSE-BASED CMF

4.1 Data Categorization by Crash Cause

All crashes were divided into five categories to develop the cause-based CMF, i.e., driving while drowsy (DWD), speeding (SPD), lack of visual attention (LVA), excessive steering (ES), and other (OTHER). The crashes of the four categories excluding the OTHER represented 76% of all crashes. DWD was the largest portion (25%), and SPD was second (22%). The third and fourth portions were LVA (15%) and ES (14%), respectively, while the ‘other’ category (OTHER) accounted for 24% as shown in Figure 2. SPFs are estimated by all crash cause of the reference group and 5 categories per year (2003, 2004 and 2005). The result of multivariate negative binomial regression for SPFs is presented in Table 3. The coefficient of β_1 and β_2 is statistically significant at 99% level of confidence except for the β_2 of SPD. This is a common assumption that the crash by speeding is more observed in the expressway which has low traffic.

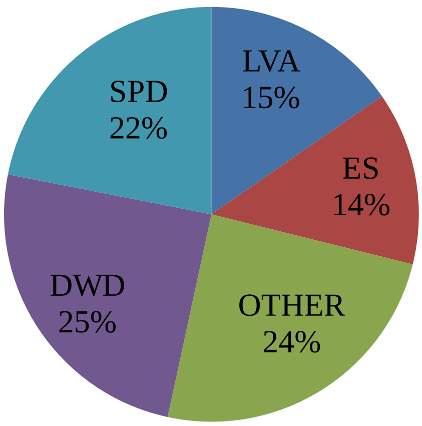

Figure 2. Proportion of crash causes

Table 3. Results of cause-based SPF parameter calibration

Year	Crash cause	Number of crashes	α	β_1	β_2	Over-dispersion parameter	Log likelihood
2003	DWD	1,148	-1.08220*	0.12880*	0.0000123*	0.40318	-1298.6
	SPD	922	-1.03190*	0.13294*	0.00000433	0.72641	-1210.6
	LVA	929	-1.27572*	0.13213*	0.0000114*	0.57187	-1190.9
	ES	523	-1,82112*	0.11639*	0.0000144*	0.88715	-904.2
	OTHER	1,342	-0.75089*	0.10908*	0.0000118*	0.48925	-1449.6
2004	DWD	1,186	-1.24427*	0.12520*	0.0000130*	0.46717	-1492.4
	SPD	988	-1.11011*	0.12561*	0.00000361	0.92607	-1402.5
	LVA	860	-1.58954*	0.13121*	0.0000124*	0.65823	-1270.7
	ES	544	-2.08571*	0.11846*	0.0000169*	0.90366	-1007.0
	OTHER	1,284	-1.13528*	0.11204*	0.0000154*	0.57590	-1591.3
2005	DWD	1,083	-1.25471*	0.11778*	0.0000122*	0.40531	-1432.5
	SPD	995	-0.90814*	0.11423*	-0.000000112	0.90225	-1421.0
	LVA	745	-1,17319*	0.12614*	0.0000126*	0.55812	-1172.3
	ES	515	-2.17479*	0.11421*	0.0000181*	0.67606	-967.8
	OTHER	1,156	-1.27674*	0.11961*	0.0000147*	0.60412	-1505.5

* Significant at 1% level

4.2 Result of Developing Cause-based CMFs

The cause-based CMF also developed by using the EB method and yearly multiplier for correcting the potential bias. Due to the lack of sample size by categorization, only three of those facilities, such as speed enforcement camera, rumble strips, and delineator post, have statistically significant estimates, appeared as small standard errors. The results of cause-based CMF are shown in Table 4.

Examining each safety countermeasure in detail, the speed enforcement camera was the most effective on crash reduction of LVA(0.6452) followed by ES(0.6930), SPD(0.7239), OTHER(0.7776), and DWD(0.7820). In Korea, the warning post for the speed enforcement camera is 2 km away. This study assumed that the effective range of a speed enforcement camera is 2 km upstream of where the sign is posted. The effective range, however, is not generally clear on treatments and especially on the speed enforcement camera. The rumble strips had the largest benefit on crashes by SPD(0.3978) followed by LVA(0.4788), ES(0.6951), OTHER(0.7298) and DWD(0.7908). The delineator post had a negative benefit on DWD(1.1516), SPD(1.2645) and ES(1.1940) while it had a positive benefit on LVA(0.6840) and OTHER(0.7243)

The view of crash cause and countermeasure benefits, speed enforcement camera and rumble strips were almost same positive effects of DWD. However, rumble strips have better positive effects on SPD and LVA than speed enforcement camera while delineator post have negative benefit. All three safety countermeasure have almost same positive effect of ES and OTHER.

Table 4. Cause-based CMFs of safety countermeasures

Safety countermeasure	Crash cause	Number of crashes (before & after)	CMF	Standard error
Speed enforcement camera	DWD	153	0.7820	0.1373
	SPD	149	0.7239	0.1370
	LVA	105	0.6452	0.1779
	ES	83	0.6930	0.1470
	OTHER	153	0.7776	0.1514
Rumble strips	DWD	81	0.7908	0.1716
	SPD	42	0.3978	0.1361
	LVA	36	0.4788	0.1896
	ES	49	0.6951	0.1737
	OTHER	72	0.7298	0.1870
Delineator post	DWD	96	1.1516	0.2288
	SPD	119	1.2645	0.2863
	LVA	63	0.6840	0.2317
	ES	63	1.1940	0.2739
	OTHER	102	0.7243	0.1962

5. CONCLUSIONS

The safety countermeasures affect all type of crash cause. However, the extents of effects by safety countermeasures on different causes are different because countermeasure is designed for several target crash causes. The transferability of CMF, which is a issue of recent researches, is also related to the different effect of countermeasure on different cause of treatment and proportion of crash cause in treated site.

This research develops the CMF and cause-based CMF of safety countermeasure in Korean expressways using the empirical Bayes method to account for the potential bias. It is not easy to determine the one main cause because the crash is affected by the interaction of several causes or factors which are not independent. However, most of them dominated by one or two causes. This research quantitatively examined that the countermeasure has different benefits on different crash cause. Thus, cause-based study of CMF is needed to improve the safety research although it still has independent problem of crash cause. The cause-based CMF could be the quantitative index of countermeasure selection. To this end, more research of reliable and widely developed cause-based CMF is needed. Further research to solve the independent problem of crash cause and the low sample problem by using full Bayes study is a good supporting for this research.

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