Incorporating Crash Severity to Improve Highway Safety Project Prioritization

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1. Introduction

The Highway Safety Manual (HSM) provides guidelines for evaluating highway safety improvements and prioritizing potential projects. Adopting the HSM methodology, several states in the US use Excess Expected Crashes (EEC), a parameter dependent on Safety Performance Functions to rank safety projects. However, this method is limited by several methodological disadvantages (e.g., the severity of the observed crashes and the magnitude of the projected crashes by the Empirical Bayes (EB) method are not considered). This paper aims to improve highway safety project ranking and describes a new safety scoring method developed for the Kentucky Transportation Cabinet (KYTC). It is now being used in KYTC's Strategic Highway Investment Formula for Tomorrow (SHIFT) project prioritization process. The method considers crash severity and incorporates EB estimates and the EEC metric in a multifactor score. Additionally, it introduces a "goal-driven" EEC, which represents the potential for reaching targets specified in the State's Strategic Highway Safety Plan. To demonstrate the methodology, the method is tested on KYTC's list of potential projects for the 2020 SHIFT cycle.

2. Methodology

2.1 Data

Roadway Data - The roadway data (traffic flow, functional classification, various roadway features) for all state-maintained roads in Kentucky were obtained from the road centerline network and highway information system (HIS) data.

Crash Data -The crash data classified using the KABCO severity scale[2] were collected for five years (2013-2017) from the Kentucky State Police (KSP) maintained database and the crashes were linked to corresponding road segments and intersections.

Sample Projects - In this study, a project is defined as the combination of several roadway network elements i.e., roadway segments, intersections, or ramps with no fixed length. KYTC has developed a project prioritization system titled "SHIFT" whose main objective is to compare capital improvement projects and prioritize transportation funding [1]. For each SHIFT cycle, KYTC starts with a list of projects identified by state and local transportation leaders. There were 1274 potential projects for SHIFT 2020 cycle. This study used roadway and crash data to develop SPFs and then evaluated the proposed project ranking methods using the SHIFT project list.

2.2 Development of SPF

SPFs are exclusive to each roadway type and intersection [2]. In this study, the SPFs for segments and intersections were developed using Equation 1 and Equation 2 as shown below [3]. Moreover, SPFs were developed for three combinations of crash severity: **KAB:** More severe crashes; **CO:** Less severe

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[2] K= fatal, A = incapacitating injury, B = non-incapacitating injury, C = possible injury, and O = no injury/property damage only (PDO)

crashes, and **KABCO**: Total crashes. A script in RStudio named "SPF-R" was used to develop all the models for this study [4].

$$N_{SPF}(segment\ or\ ramp) = e^{\alpha} * L * AADT^{\beta} * AF_1 * AF_2 * \ldots. \quad (1)$$

$$N_{SPF}(intersection) = e^{\alpha} * AADT_{Major}^{\beta 1} * AADT_{Minor}^{\beta 2} \quad (2)$$

Where, N_{SPF} = The predicted number of crashes by SPF; L= Length of a segment; AADT = Average Annual Daily Traffic; α = Regression parameter for intercept; β = Regression parameter for AADT; AF = Adjustment Factors.

2.3 Empirical Bayes (EB) Estimate

Empirical Bayes method estimates the expected average crash count by combining the historical crash frequency for a site and the predicted number of crashes derived from SPF. This technique accounts for regression-to-the-mean bias by estimating the magnitude of the expected crashes and generates a more accurate estimate of the long-term mean at a site [5]. Equations 3 and 4 were used to calculate the EB expected total, KAB and CO crashes for every roadway segment, intersection, and ramp [3]:

$$N_{EB} = w * N_{SPF} + (1 - w) * N_{observed} \quad (3)$$

$$w = \frac{1}{1 + \frac{N_{SPF}/L}{\theta}} \quad (4)$$

Where, NEB = Expected average crash frequency by EB method; NSPF = Predicted average crash frequency using SPFs; w = weight factor, 0≤w≤1; Nobserved = Historical crash frequency; θ = Inverse overdispersion parameter (theta); L = roadway segment length (L = 1 for intersections)

2.4 Excess Expected Crashes (EEC)

The difference between EB expected crashes (N_{EB}) and SPF predicted crashes (N_{SPF}) is defined as EEC (See Equation 5). EEC measures the number of crashes occurring at a site more or less than expected for sites with similar characteristics [4]. To evaluate a site's potential for crash reduction, EECs (EEC_{total}, EEC_{KAB}, and EEC_{CO}) were calculated using Equation 5. **Figure 1** shows a visual representation of the relationship between SPF predicted crashes, observed crashes, EB expected crashes and EEC.

$$EEC = N_{EB} - N_{SPF} \quad (5)$$

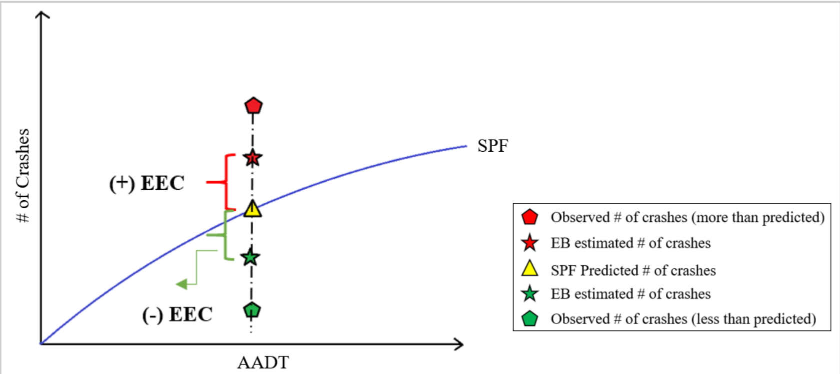

Figure 1: Graphical representation of EB estimate and, EEC

2.5 Proposed Methods for Project Prioritization

This study proposes four methods to improve the project prioritization method and compares the rankings with the "initial ranking method". The initial and proposed methods are described below:

Initial ranking method: Ranking based on EECs of the total crashes (uses base conditions for SPFs).

This method uses SPFs developed from the total crash count, where crashes of different severities are combined and the ranking of each project is determined based on the EEC_{total}. The EEC of a project is estimated by taking the summation of the EECs of all the roadway segments, intersections, and ramps that fall inside that project.

Ranking method 1 (No base conditions): Ranking based on EECs of total crashes (No base conditions for SPFs)

SPFs are preferably developed with specified geometric features or base conditions, and crash modification factors (CMF) are used when a segment's geometric attributes do not match the base conditions used to develop the models [6]. In Kentucky, CMFs are referred to as Adjustment Factors (AF) particularly when used for this purpose. Although there are several resources for AFs including the HSM, and CMF Clearinghouse, there are still several [7]roadway features for which AFs are not available yet. The absence of AFs limits the application of the SPFs. This study recommends developing SPFs from total crashes but without using any base conditions. When the entire dataset is used for model development, no adjustment factors (AFs) are needed to adjust the predicted crashes.

Ranking method 2 (Considering crash severity): Ranking based on the combined score of EECs (KAB and CO)

This method proposes to develop SPFs using two crash severity combinations i.e., KAB and CO, instead of total crashes. This will lead to EEC_{KAB} and EEC_{co} indicating an excess of the expected KAB and CO crashes, respectively. Finally, for each project, these two metrics can be combined using weights parameters, a and b (where, a+b=1) and the final ranking will be based on R_1. The equation is expressed below:

$$R_1 = a * EEC_{KAB} + b * EEC_{CO} \tag{6}$$

It is considered that less serious (CO) crashes are the precursors of more serious (KAB) crashes, and recommended to use the proportion of each severity group as its weight factor. The proportions can be estimated from the crash frequency and cost from the common geographic location of the projects e.g., state, country, etc. For example, in Kentucky, the severity-weighted average cost per KAB crash is 89% and per CO crash is 11% of the total cost (See **Table 1**). Therefore, in equation 6, the value of a and b are going to be 0.89 and 0.11, respectively.

Table 1: Weighted average crash cost by crash severity groups [Source: KYTC]

	Weighted average cost (2019)	%
KAB	$652,612	**89%**
CO	$81,187	**11%**
Total	$733,799	100%

Ranking method 3: Ranking based on a combined score of EB and EEC.

This method proposes to rank each project by combining the EB estimate and EEC computed for total crashes. Both metrics can be weighted by m and n, respectively, where m + n =1 (See Equation 7) to calculate a ranking metric R_2. In this study, EB estimate and EEC were equally weighted with 50% emphasis on each metric as no information is available to determine which metric is more suitable for a given project.

$$R_2 = m * N_{EB(Total)} + n * EEC_{(Total)} \tag{7}$$

Ranking method 4 (Goal-driven method): Ranking based on EEC_{alt} of total crashes.

This method proposes a project ranking criterion which is a modified version of EEC, and terms it as "Alternate EEC" or "EEC_{alt}". EEC_{alt} is a goal-driven metric that considers that a project has the potential to reduce crashes even if it is already performing at or near the average of similar facilities. To implement this, the SPF predicted crash value is modified by multiplying it by the ratio of the SHSP goal for fatalities and current frequency of fatal crashes and used for the EEC_{alt} calculation. The equation for EEC_{alt} is given below with a graphical presentation in **Figure 2.**

$$EEC_{alt} = N_{EB(Total)} - \left(\frac{SHSP\ fatalities\ goal}{Current\ fatal\ crashes}\right) * N_{SPF(Total)} \tag{8}$$

According to the Kentucky 2020-2024 Strategic Highway Safety Plan, there are 750 fatal crashes in Kentucky per year and SHSP aims to reduce enough crashes that the annual fatalities fall at or below 500 by 2024 [8]. This leads to the ratio of 2:3 for the SHSP goal to current fatalities.

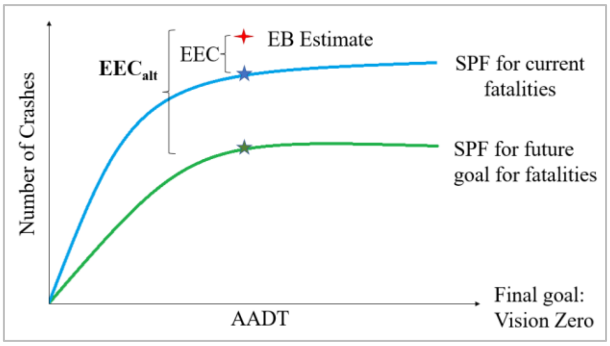

Figure 2: Graphical representation of EECalt

3. Analysis and Results

Each of the four above-mentioned proposed methods was applied to the 1274 SHIFT projects separately to produce ranks of projects. Later, for each project, the rank by every method was individually compared to the rank from the initial method to evaluate the differences between rankings. The differences in rankings are summarized in **Table 2.** For example, when one project was ranked 8th by the initial method and 16th by method 1, it was categorized as "± 10 positions". Similarly, when another project was ranked 89th by the initial method but 74th by method 1, it was assigned "± 20 positions".

Table 2: Differences in ranking between four methods compared to the initial method

Ranking Difference	Method 1 vs Initial Method		Method 2 vs Initial Method		Method 3 vs Initial Method		Method 4 vs Initial Method	
	# of projects	%	# of projects	%	# of projects	%	# of projects	%
± 10 positions	528	41.4	95	7.5	112	8.8	97	7.6
± 20 positions	209	57.8	75	13.4	77	14.8	66	12.8
± 50 positions	230	75.9	178	27.4	198	30.3	172	26.3
± 100 positions	122	85.5	252	47.2	206	46.5	218	43.4
> 100 positions	185	14.5	674	52.9	682	53.5	721	56.6
Total	1274		1274		1274		1274	

From the analysis shown above, the results can be summarized in **Table 3**.

Table 3: Summary of the results

Methods	Description	A significant difference in the ranking?*
Initial	EEC_{total} (with base conditions for SPFs)	N/A
1	EEC_{total} (no base condition for SPFs)	No
2	Combination of EEC_{KAB} and EEC_{CO}	Yes
3	Combination of EB_{total} and EEC_{total}	Yes
4	$EEC_{alt\ (total)}$	Yes

*In comparison to the initial method

4. Discussion and Conclusion

Although there are several differences in the project rankings, the majority of the projects did not get significantly different ranks by method 1. In this case, using SPFs developed without using base conditions is usually more feasible to use since it does not require any AFs. On the other hand, the other three models have shown significant effects on the rankings, and all of them have the potential to account for the issues with the current ranking method. Therefore, a recommendation is made to use a combination of the four methods instead of any single one for project ranking.

To account for severity, KAB crashes are weighted at 89 percent, with 11 percent allocated to CO crashes, based on the relative cost for each group of crashes in Kentucky. Initially, it is recommended that EB and EEC metrics each be weighted to 50 percent of the above-mentioned weights (44.5 percent for KAB and 5.5 percent for CO for each metric). Equation 9 describes the overall project ranking metric R and is used to rank projects in descending value.

$$R = 0.445 * N_{EB(KAB)} + 0.445 * EEC_{alt(KAB)} + 0.055 * N_{EB(CO)} + 0.055 * EEC_{alt(CO)} \quad (9)$$

Finally, while additional research is recommended to determine the appropriate weights between EB and EEC scored, the goal-driven component of the proposed methodology is policy sensitive to the safety goals of a highway authority.

References

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