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A new approach for calibrating safety performance functions

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ABSTRACT

Safety performance functions (SPFs) are statistical regression models used for estimating crash counts by roadway facility classification. They are required for identifying high crash risk locations, assessing the effectiveness of safety countermeasures and comparing road designs in terms of safety. Roadway agencies may opt to develop local SPFs or adopt them from elsewhere such as the national Highway Safety Manual (HSM), provided by the American Association of State Highway and Transportation Officials. The HSM offers a simple technique to calibrate its SPFs to conditions of specific jurisdictions. A more recent calibration technique, also known as the calibration function, is similar to that of the HSM. In this research, we develop SPFs of total crashes for rural divided multilane highway segments in four states. The states are Florida, Ohio, California and Washington. We also calibrate each SPF to each state using the HSM calibration method and the calibration function. Furthermore, we propose the use of the K nearest neighbor data mining method for calibrating SPFs. According to the goodness of fit (GOF) results, our proposed calibration method performs better than the other two methods.

1. Introduction

Safety performance functions (SPFs) are analytical tools used for predicting crash counts by roadway facility classification, crash severity and crash type. SPFs are used for detecting high crash risk locations, a process known as network screening, and analyzing crash sites before and after deployment of safety countermeasures, a technique known as before-and-after analysis. A before-and-after analysis requires the application of the empirical Bayes (EB) method for gauging the efficacies of safety countermeasures deployed at hazardous sites while accounting for varying crash trends. Another application of SPFs is the comparison of alternative site designs in terms of safety. In the national Highway Safety Manual (HSM), provided by the American Association of State Highway and Transportation Officials (2010), Part C, a series of default SPFs are provided for a variety of roadway facilities. Jurisdictional agencies may develop their own SPFs or calibrate ones from elsewhere, such as those of the HSM, to local conditions. Developing own local SPFs is recommended (Lu et al., 2014; Young and Park, 2013) because the local SPFs represent crash characteristics better than calibrated SPFs, adopted from elsewhere. However, the disadvantages of developing SPFs are that additional efforts are required for data collection and expert manpower is needed for data processing. Calibrating SPFs considerably cuts the costs and labor hours for obtaining the SPFs (Srinivasan et al., 2013). The HSM provides not only SPFs for jurisdictions, unwilling to develop own local SPFs, but also a simple albeit faulty SPF calibration technique. The technique specifies the computation of a single calibration factor and the selection of sites for calibration. The factor is multiplied by the predicted crash frequencies of each select site. This technique is subject to questioning because the calibration factor may not correct the predicted crash counts for each designated site. Hence, we propose the use of K nearest neighbor (KNN) regression, a data mining method, to calibrate SPFs. We develop and transfer SPFs of total crashes at rural divided multilane highway segments. The SPFs belong to four states, namely Florida, Ohio, California and Washington. When transferring the SPFs, we calibrate them using our proposed technique, one proposed by Srinivasan et al. (2016), also known as the calibration function, and the HSM calibration technique. The aim is to demonstrate that the KNN regression calibration method, proposed, performs better than the other two. In the following sections, the justification for calibrating adopted SPFs, past SPF calibration studies, employment of KNN regression in the road safety literature, data used for our research, methodology, results and conclusions are discussed.

2. Literature review

Calibrating SPFs is a valid alternative to developing them. Even though developing local SPFs is suggested (Lu et al., 2014; Young and

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Park, 2013) because such SPFs fit the data the best, agencies may prefer calibrating SPFs. That is to curtail data collection and processing costs. According to a study by Srinivasan et al. (2013), concerning SPFs intended for analyzing the safety impacts of different road designs, the man-hours required for data collection and preparation for developing SPFs are three times those required for calibrating adopted SPFs. Also, additional hours are required for experienced data analysts to process the data.

Since jurisdictions, willing to save costs and man-hours, have the choice of calibrating SPFs instead of developing them using local data, it is worth investigating the currently accepted calibration techniques. A robust calibration technique that is considerably more accurate than the HSM's was not proposed in the past. Researchers mainly investigated sample size requirements for calibrating SPFs. In other past studies, the HSM's predictive SPFs were calibrated to roadway facilities' conditions of specific localities. The calibration function (Srinivasan et al., 2016), which is a modified version of the HSM calibration method, and Sawalha and Sayed's (2006) calibration technique are other calibration methods in the road safety literature. However, both methods have substantial potential for improvement. Hence, our calibration technique is introduced. Further details about the literature studies are discussed in the following sub-sections.

2.1. Sample size requirements for calibrating SPFs

Researchers investigated the sample size requirements for calibrating the HSM to specific jurisdictions' conditions. The HSM recommends 30–50 sites having a minimum of 100 crashes. Yet, Banihashemi (2012) concluded that a sample of 50 sites is inadequate based on a rigorous sensitivity analysis for Washington State's rural multilane highways among other types of roadway facilities. For each facility type, the author applied the HSM's appropriate SPF and obtained a calibration factor using the HSM's calibration technique. Such factor was termed the ideal factor. Then, multiple samples, having different sizes, were randomly collected from the data. Similarly, for each sample, a calibration factor was computed. The sample calibration factors were assumed to be normally distributed and hypothesis tests were made to check whether they were within a 10% range of the ideal calibration factor. Alluri et al. (2016) undertook a similar sensitivity analysis in Florida for the same facility types and the authors' findings were consistent with those of Banihashemi (2012). Trieu et al. (2014) reached the same conclusion by conducting a similar sensitivity analysis. Shirazi et al. (2016) also conducted a robust sensitivity analysis and provided a guideline for determining the minimum sample size required for calibrating SPFs. The minimum sample size is heavily dependent on the coefficient of variation of the observed crash frequency variable. The coefficient of variation is the ratio of the standard deviation to the mean.

2.2. Calibrating the HSM's SPFs

In North America, the HSM's SPFs were calibrated, using the HSM technique, to roadway facilities, of various types, in multiple states. Specifically, the SPFs were calibrated to Missouri's rural divided multilane highway segments and un-signalized intersections (Sun et al., 2014). In North Carolina, the HSM's SPFs were also calibrated to rural divided segments and four-leg signalized intersections (Srinivasan and Carter, 2011). In Alabama, Mehta and Lou (2013) not only attempted to apply the HSM's calibrated SPF of rural divided segments to local conditions but also developed an own localized SPF to compare its predictive performance with the HSM's. Brimley et al. (2012) mimicked the Alabama study for rural two-lane roads in Utah. Similarly, Young and Park (2012) estimated SPFs for signalized and un-signalized intersections in Regina, Saskatchewan, Canada and compared the SPFs' performances with those of calibrated SPFs borrowed from the HSM. Persaud et al. (2002) estimated SPFs for Toronto's stop-controlled and signalized intersections. The authors also calibrated the SPFs to conditions of Vancouver and California using the HSM calibration technique.

2.3. Safety performance function calibration methods

Three methods for calibrating transferred SPFs to conditions of the destinations have been employed. They are the HSM's method, Sawalha and Sayed's (2006) technique and the most recent one, proposed, which is that of Srinivasan et al. (2016). All three calibration methods are described. In either method, the user need not calibrate a borrowed SPF to all crash sites. The SPF can be calibrated only to a select site group.

In the HSM calibration method, the adopted SPF is applied to predict crash frequencies for each site and the user designates the sites of which the predicted frequencies need to be calibrated. For the designated sites, a calibration factor is calculated as the ratio of the sum of the observed crash frequencies to that of the predicted ones. The computed factor is multiplied by each designated site's predicted crash frequency. The HSM calibration technique is subject to criticism because the multiplicative calibration factor may not correct each designated site's predicted crash frequency. As a side note, in the context of the temporal transferability of SPFs, Connors et al. (2013) tested multiple alternative formulations to compute the calibration factor and not a single formulation produced the best GOF results. Also, as an alternative to re-estimating out-of-date SPFs, Wood et al. (2013) suggested updating the SPFs by calibrating them to current conditions using the HSM calibration method calling it the scale factor method. More information about developing calibration factors, using the HSM technique, is provided by Bahar (2014).

Other than the HSM calibration method, Sawalha and Sayed (2006) proposed a different SPF calibration technique. The research team developed a negative binomial (NB) SPF for Vancouver's urban arterials and attempted two approaches to transfer the model to conditions of Richmond, British Columbia. One involved the calibration of the model's constant term and overdispersion, which is an essential parameter of the NB structure. That is, after applying Vancouver's SPF to Richmond's conditions, the research team re-estimated the constant and overdispersion terms of the applied SPF using Richmond's data. The other approach involved simply applying the developed SPF to predict crash frequencies at the destination without any adjustments. As per the study's findings, the authors suggested the former approach. Note that re-estimating the applied SPF's constant only, using the destination jurisdiction's data, is equivalent to employing the HSM calibration method.

Srinivasan et al. (2016) proposed a modified version of the HSM calibration method, also known as the calibration function. Once an adopted SPF is applied to the data, representing local conditions, a group of sites, of which predicted crash frequencies need to be calibrated, is selected. For the select group, the observed crash frequency, N_{obsi}, is modeled as an NB regression function of the predicted one, $\hat{N}_{SPFi}$, as follows where i represents the site index.

$$N_{obsi} = \hat{A} \times (\hat{N}_{SPFi})^{\hat{B}} \tag{1}$$

The parameters, $\hat{A}$ and $\hat{B}$, are regression coefficients obtained using maximum likelihood estimation (MLE), a statistical technique used for estimating parameters. In Eq. (1), the relationship between the observed and predicted crash counts is not linear as opposed to the underlying assumption of the HSM calibration method. However, that is not the case if the coefficient, $\hat{B}$, is not statistically significantly different from 1. Even though the non-linear relationship between observed and predicted crash counts is captured, the calibration function is still subject to fault. It is plausible that the difference between the observed and predicted crash frequencies of a site are aggravated after calibration.

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