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Transferring and calibrating safety performance functions among multiple States

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ABSTRACT

Safety performance functions (SPFs), statistical regression models, by predicting traffic crash counts by crash type, severity and facility type, aid traffic engineers in the process of identifying high frequency crash locations. Developing SPFs requires the collection and processing of traffic, crash, road design and other characteristics' data. Jurisdictional agencies may choose not to develop their own SPFs and cut back on their resources by adopting SPFs provided by the national Highway Safety Manual (HSM). The HSM also provides a technique to calibrate its SPFs to the specific jurisdictions' conditions. Yet, the technique is subject to criticism. This research is aimed at exploring the transferability of SPFs of rural divided multilane highway segments of Florida, Ohio, Illinois, Minnesota, California, Washington and North Carolina. The SPFs are negative binomial (NB) models as are those provided by the HSM. We address the fault of instinctively applying the HSM's SPFs to a particular locality without verifying whether the SPFs are transferable to the locality and compare different states' crash patterns. Remarkably, it is found that specific SPFs of Ohio, Illinois, Minnesota and California are transferable to either of the four states. In addition, in this research, a calibration technique is proposed as an alternative to that of the HSM and two other calibration methods introduced in the traffic safety literature. They are the calibration function and the calibration of the transferred model's constant term in conjunction with the over-dispersion parameter. Our proposed calibration technique, namely local regression, is demonstrated to be more reliable than the HSM's and the ones previously proposed in the literature.

1. Introduction

In 2015, 15,293 fatal traffic crashes were reported on rural roads incurring 17,114 fatalities nationwide. Even though only 19% of the population resides in rural areas, the proportion of crash fatalities on rural roads is 49% of the total traffic fatalities on all roadway facilities (Traffic Safety Facts 2015 Data Rural/Urban Comparison of Traffic Fatalities, 2016). Therefore, it is the traffic engineer's duty to identify high frequency crash locations, known as hot spots, and provide the necessary safety countermeasures to reduce crashes and crash severity. The national Highway Safety Manual (HSM), provided by the American Association of State Highway and Transportation Officials (2010), is a guidance tool for traffic engineers in both the public and the private sectors. It outlines the empirical Bayes (EB) method for identifying hot spots. As part of the procedure, safety performance functions (SPFs), which are regression models used for estimating crash frequencies by crash type, severity and roadway facility type ought to be developed. Count models, such as the Poisson and negative binomial (NB) models, are appropriate for regressing crash frequencies. Yet, the NB modeling structure is preferred and is used as the conventional framework since it accounts for over-dispersion, which is the condition in which the variance of the crash counts is larger than the mean (Lord et al., 2005). Jurisdictional agencies may opt to collect traffic, crash, geometric characteristics' and other characteristics' data to develop own localized SPFs. The other alternative is to borrow SPFs from neighboring jurisdictions. Furthermore, the HSM provides a series of SPFs by facility type and crash type. The HSM also provides a simple method for calibrating its SPFs to local conditions. This research is specifically dedicated to rural divided multilane highway segments which are four-lane rural roads with a median or a two-way left-turn lane separating both opposing traffic streams. In the road safety literature, a multitude of studies were aimed at calibrating the HSM's SPFs to conditions of specific states. However, the transferability of SPFs among multiple regions in the nation is rarely investigated. Also, the HSM's calibration technique is an aggregate inaccurate method for adjusting the HSM's SPFs to local conditions. The SPF's output is multiplied by a calibration factor computed as the ratio of the sum of the observed crash counts in all sites, selected for calibration, to that of the predicted counts of the

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same select sites. Efforts were made in the past to propose calibration methods as substitutes to the HSM calibration method.

In this research, rural divided multilane highway segments' SPFs are developed for seven states namely, Florida, Ohio, Illinois, Minnesota, California, Washington and North Carolina. That is to assess each state's SPFs' transferabilities to the other states' conditions and describe the implications regarding the impact of regional differences on crash patterns. The transferability of SPFs is infrequently assessed let alone the transferability of SPFs of a variety of states in the nation. In addition, recommendations are put forth for roadway agencies, not inclined to collect and process data to develop SPFs, as to which models to adopt from which states. In this research, the SPF configurations are similar to those of the HSM. For each state, SPFs are developed for total (KABCO) crashes, fatal-and-injury (KABC) crashes, fatal-and-injury (KAB) crashes not including possible injury crashes, fatal-and-incapacitating injury (KA) crashes and single-vehicle (SV) crashes. The transferability of such SPFs to each state's data is assessed. Also, as part of this research, a calibration technique is proposed and its performance is compared with those of the calibration methods in the literature. This is because the currently implemented calibration methods are aggregate methods subject to faults.

2. Literature review

Few researchers have considered examining the transferability of SPFs from one jurisdiction to another. Instead, the calibration of the HSM's SPFs to localities in the nation and abroad was investigated. Calibration refers to transferring an SPF to a specific locality and adjusting the model to conditions of the destination. As noted previously, the HSM offers its own method to calibrate SPFs to conditions of where the SPFs are transferred. Furthermore, an effort was made by Sawalha and Sayed (2006) to calibrate SPFs. In addition, more recently, Srinivasan et al. (2016) proposed an alternative method to the HSM calibration technique. Following are discussions of HSM SPF calibration studies, SPF transferability studies, Sawalha and Sayed (2006) suggested calibration method, Srinivasan et al. (2016), limitations of the studies in the literature and the value added to the literature from our research.

The HSM's SPFs were calibrated to conditions of a variety of states nationally. The calibration method, implemented, was that of the HSM, described previously. It should be noted that as per the HSM, it is not recommended to calibrate the HSM's SPFs to conditions of localities with fewer than 30 sites and fewer than 100 reported crash records even though Banihashemi (2012) recommended larger samples. For Missouri's rural divided multilane highway segments, Sun et al. (2014) applied the HSM's SPFs and crash modification factors (CMFs), which are adjustment factors for the HSM's SPFs, to predict KABCO crash frequencies. A calibration factor of 0.98 was computed indicating that the HSM almost accurately predicted the frequency of crashes in Missouri's conditions. The authors also undertook a similar exercise for unsignalized three-leg and four-leg intersections. They achieved calibration factors of less than 0.4 for both types of intersections. Possibly, this was because there were fewer than 100 crash records sampled from both intersections' data, a factor that was in direct violation with the HSM's standards. In North Carolina, Srinivasan and Carter (2011) carried out a similar study and obtained a calibration factor of 0.97 for rural divided segments and 0.49 for four-leg signalized intersections. Such results were consistent with those of the Missouri study. Xie et al. (2014) calibrated the HSM's SPF of KABCO crashes to Oregon's rural divided segments while accommodating CMFs. The computed calibration factor was 0.78 indicating 22% over-prediction of crash counts by the HSM's SPF. In Alabama, Mehta and Lou (2013) applied a local SPF of rural divided multilane highway segments to own conditions. The research team also adopted the appropriate SPF of the HSM and compared its predictive performance with the local one. More accurate crash frequency predictions were achieved using the local SPF. In Utah, Brimley et al. (2012) borrowed the HSM's SPF of KABCO crashes at rural two-lane roads and computed a calibration factor of 1.16 after incorporating CMFs. That signifies that the HSM's SPF under-predicted crashes by 16% for Utah's conditions. The authors were also able to develop a local SPF superior to that borrowed from the HSM. Young and Park (2012) undertook a similar study in Regina, Saskatchewan, Canada for signalized and un-signalized intersections and concluded that developing local SPFs is recommended over adopting those of the HSM.

Calibration of the HSM's SPFs was not only conducted within North America but also overseas. Al Kaaf and Abdel-Aty (2015) calibrated the HSM's SPFs of fatal-and-injury crashes of urban roads to conditions of counterpart roads in Riyadh, Saudi Arabia. A calibration factor of 0.31 was obtained implying a substantial over-prediction. In addition, the authors developed own localized SPFs with various configurations and achieved better fits. Also, investigations were made for testing whether the HSM's SPFs were transferable to the A-18 motorway in the Messina-Catania region, Italy (Cafiso et al., 2012; D'Agostino, 2014). Similarly, calibration factors were computed and indicated considerable under-prediction of crash counts. Cunto et al. (2015) calibrated the HSM's SPFs of urban intersections to conditions of Fortaleza City, Brazil. The research team achieved a calibration factor of 0.98 for signalized intersections implying marginal over-prediction of crash frequencies and 2.15 for un-signalized intersections indicating an under-prediction of crash frequencies by 115%.

Other than the adoption of the HSM's SPFs by agencies in specific jurisdictions, two SPF calibration methods were proposed in the past. One was proposed by Sawalha and Sayed (2006) while the other was proposed by Srinivasan et al. (2016). In the study, undertaken by Sawalha and Sayed (2006), a model was estimated for Vancouver's urban arterials and calibrated to conditions of Richmond, British Columbia. The regression framework was that of the NB model. The research team specifically calibrated the SPF's constant term and over-dispersion parameter. The team also suggested their calibration method. As a side note, the HSM's calibration method is equivalent to calibrating the transferred SPF's constant term only. On the other hand, Srinivasan et al. (2016) introduced the following calibration equation, referred to as the calibration function from this point onward. It is aimed at modeling the observed crash counts, $N_{obs\ i}$, per site, i, as a function of the predicted ones, $\hat{N}_{SPFi}$, assuming the observed crash frequencies follow an NB distribution.

$$N_{obsi} = \hat{a} \times \hat{N}_{SPFi}^{\hat{b}} \tag{1}$$

Since the model's assumption is that the observed crash frequencies follow the NB distribution, the equation's output, for site, i, is the mean of the distribution, which is the calibrated crash frequency. The terms $\hat{a}$ and $\hat{b}$, are regression coefficients obtained using maximum likelihood estimation (MLE). It is critical to note that with the coefficient, $\hat{b}$, equal to 1, the equation is simplified to that of the HSM calibration technique. It should be noted that regressing the observed crash frequencies in Eq. (1) assuming that such crashes follow an NB distribution is not necessary. The regression can be undertaken assuming N_{obsi} follows a Poisson distribution.

Another substitute technique for calibrating SPFs, namely the Bayesian model averaging method (Hoeting et al., 1999), was suggested by Chen et al. (2012). It is an approach in which multiple models are developed and weights are assigned to each model's output. The weighted outputs are all used to achieve the predictions. Chen et al. (2012) recommended the approach over the HSM's calibration method.

As researchers attempted to calibrate the HSM's SPFs to particular localities, few have investigated the transferability of SPFs from one jurisdiction to another. In one generic study, La Torre et al., 2016 undertook an extensive study to develop SPFs for Europe, as a whole. With that, the authors, evaluated the transferability of CMFs. Studies involving the transferability of SPFs are discussed.

Persaud et al. (2002) developed SPFs for signalized and stop-