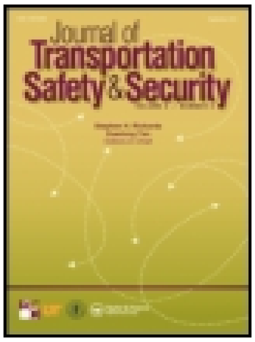

Journal of Transportation Safety & Security

ISSN: 1943-9962 (Print) 1943-9970 (Online) Journal homepage: http://www.tandfonline.com/loi/utss20

Developing jurisdiction-specific SPFs and crash severity portion functions for rural two-lane, two-way intersections

Xiao Qin, Zhi Chen & Razaur Rahman Shaon

To cite this article: Xiao Qin, Zhi Chen & Razaur Rahman Shaon (2018): Developing jurisdiction-specific SPFs and crash severity portion functions for rural two-lane, two-way intersections, Journal of Transportation Safety & Security, DOI: 10.1080/19439962.2018.1458052

To link to this article: https://doi.org/10.1080/19439962.2018.1458052

Published online: 18 Apr 2018.

JOURNAL OF TRANSPORTATION SAFETY & SECURITY
https://doi.org/10.1080/19439962.2018.1458052

Developing jurisdiction-specific SPFs and crash severity portion functions for rural two-lane, two-way intersections

Xiao Qin, PhD, PE, Zhi Chen, and Razaur Rahman Shaon, MD

Department of Civil and Environmental Engineering, University of Wisconsin-Milwaukee, Milwaukee, Wisconsin USA

ABSTRACT

Transportation agencies rely on the *Highway Safety Manual*'s (*HSM*) scientific predictive procedures to quantify road safety; however, the *HSM* methods may not be accurate for use by local jurisdictions. This study used data from rural two-lane, two-way intersections in South Dakota to compare jurisdiction-specific safety performance functions (SPFs) and *HSM* SPFs to determine which functions were more accurate when used locally. Jurisdiction-specific SPFs—without the use of a calibration factor—were found to be most accurate. The study also compared fixed severity proportion with a severity proportion function calibrated by local data. The authors assumed that the site-specific severity proportion would be more appropriate than a fixed value because the former reflects the relationship between severity proportion and site characteristics. However, results showed that the severity proportion function did not contribute significantly to prediction accuracy. The conclusion offers certain level of assurance for practitioners who are more likely to use a fixed injury severity proportion as a viable alternative to a site-specific severity proportion.

KEYWORDS

Highway Safety Manual; safety performance functions; severity proportion function; rural two-lane two-way intersections

1. Introduction

The *Highway Safety Manual* (*HSM*), published by the American Association of State Highway and Transportation Officials (AASHTO), provides scientific predictive procedures to help transportation agencies quantify road safety. The predictive methods include three core components: safety performance functions (SPFs), crash modification factors (CMFs), and calibration factors (Cr for segments and Ci for intersections). Within each highway facility type, the SPF predicts crash frequency for an entity with a set of specific characteristics (which are defined as base conditions). If one characteristic deviates from the base conditions, the corresponding CMF should be applied to account for the change in crash prediction.

CONTACT Xiao Qin, PhD, PE qinx@uwm.edu Associate Professor, Department of Civil and Environmental Engineering, University of Wisconsin-Milwaukee, NWQ 4414, P.O. Box 784, Milwaukee, WI 53201.

Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/utss.

Unobserved or unavailable attributes such as climate, animal population, driver populations, crash reporting threshold, and crash reporting practices can cause crash reports to vary significantly between different areas and jurisdictions (AASHTO, 2010). As a countermeasure, the calibration factor offers a simple way to adjust the *HSM* models to local conditions.

The *HSM* predictive methods may not be accurate when used with local jurisdictions, as the SPFs were developed with data from select states that may not sufficiently represent the safety performance of local jurisdictions. The calibration factor can help mitigate this issue, but its scalar value also means it can carry a high degree of uncertainty as the ratio of the *HSM* estimated crash frequency to observed crash frequency can vary significantly across sites. It was found such ratios may change considerably over different ranges of annual average daily traffic (AADT) (X. Sun, Li, Magri, & Shirazi, 2006) and across different regions (Qin, Rahman Shaon, & Chen, 2016). Furthermore, the calibration factor acts as a ratio that equalizes the predicted value with the observation, but it does not provide additional insights on crash prediction. Neither does it change the quantitative effect of AADT. It is possible that the AADT variables, when used in local jurisdictions, contribute differently than the *HSM* models. It is also assumed that predicted crash injury severity proportion is identical for all sites within the rural two-lane two-way facility; this may be an unrealistic assumption as roadway characteristics vary from one site to another, resulting in diverse distributions of severity levels.

The goal of this study is to explore practical and effective approaches to customizing the *HSM* predictive methods for local jurisdictions so that the crash prediction is more accurate. The customization was investigated from two aspects: (1) the jurisdiction-specific SPFs developed with local data from rural two-lane two-way intersections, and (2) the severity model that allows predicted severity proportions to vary between sites.

2. Literature review

The *HSM* predictive methods have been implemented and calibrated in several states (e.g., Alabama, Florida, Missouri, Oregon, South Dakota, Utah, and Virginia) (M. Abdel-Aty et al., 2014; Brimley, Saito, & Schultz, 2012; Dixon, Monsere, Xie, & Gladhill, 2012; Kweon, Lim, Turpin, & Read, 2014; Mehta & Lou, 2013; Qin et al., 2016; C. Sun, Edara, Brown, Zhu, & Rahmani, 2014). Because local crash data exhibits a large deviation from the *HSM* predicted values, some of those studies developed jurisdiction-specific SPFs which were found to provide better prediction performance (Brimley et al., 2012; Kweon et al., 2014; Mehta & Lou, 2013). In the study by Kweon et al. (2014), the *HSM* SPF variables and equation specifications were adopted to customize crash predictions for Virginia highways. In other studies, additional variables were included in jurisdiction-specific SPFs (Brimley et al., 2012; Mehta & Lou, 2013), some of which are new to the *HSM* predictive methods (i.e., speed limit, truck percentage). Although including more variables in the SPF may increase the sample size and provide better prediction performance, model specification, variable correlation, and interaction need to be carefully considered when more variables are involved. For example, it was found that the lane width is better modeled in a nonlinear form rather than a linear form in SPFs (Park & Abdel-Aty, 2017) and that lane width and shoulder are correlated and their interaction need to be modeled in SPFs (Rahman Shaon & Qin, 2016).

The HSM suggests that "the jurisdiction-specific SPF should use the same base conditions as the corresponding SPF defined in the HSM," and that it be developed with only data representing the base conditions (AASHTO, 2010). Qin et al. (2016) questioned that the *HSM* base conditions might not be realistic or representative of local facilities. They investigated the most representative conditions of three facility types in South Dakota, rural two-lane two-way, rural multilane undivided, and rural multilane divided highways, and adopted those conditions as new base conditions in developing new SPFs. The new base conditions of three facility types are all different from those defined in the *HSM*. For example, for rural multilane divided highways, the *HSM* base conditions have a 13-ft lane width and a 6-ft shoulder width, and the new base conditions have a 12-ft or longer lane width and a 4ft to 6 ft shoulder width, whereas conditions of all the other roadway characteristics are the same. The jurisdiction-specific SPF was developed with sites conforming to the new base conditions and was found to provide better prediction accuracy with adjusted CMFs compared to the HSM predictive methods.

The HSM provides a default severity distribution for rural two-lane two-way facilities to help predict crash frequency and obtain predicted crash frequencies of different severities (AASHTO, 2010). The *HSM* recommends substituting a jurisdiction-specific distribution for the default severity distribution to account for local differences. Several studies found that this approach significantly improved the prediction accuracy (Brimley et al., 2012; Dixon et al., 2012; Xie, Gladhill, Dixon, & Monsere, 2011); however, a fixed severity distribution presumes that predicted severity proportion is identical across all sites within the same facility. Studies have found significant correlations between the probabilities of different crash severities and intersection characteristics, such as skewed angle, number of left-turn lanes, and lighting (M. Abdel-Aty & Keller, 2005; Haleem & Abdel-Aty, 2010; Huang, Chin, & Haque, 2008). Given the diversity of factors contributing to injury severity, a severity proportion function rather than a fixed proportion can better reflect the impact of intersection characteristics on crash injury severity levels at individual sites.

3. Data description

The study analysis was limited to two types of intersections on rural two-lane two-way roads: unsignalized three-leg (stop-control on minor-road approaches) (RT3ST) and unsignalized four-leg (stop control on minor-road approaches) (RT4ST). The other rural multilane intersection types in South Dakota have a

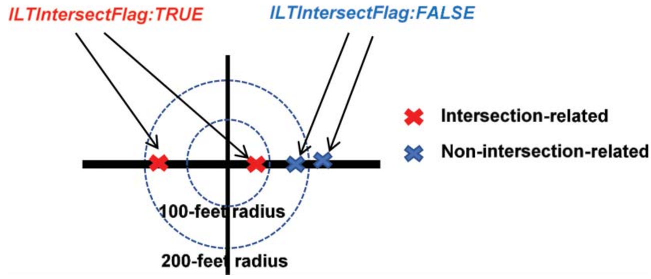

Figure 1. Illustration of intersection-related crashes.

small number of sites which does not meet the recommended minimum sample size in the *HSM*, that is, 30 to 50 sites that experience at least 100 crashes per year (AASHTO, 2010). The South Dakota Department of Transportation (SDDOT) provided intersection data in a geographic information system (GIS) shapefile format. The *HSM* requires complete data elements for state intersections, which are intersections that are either between one state highway and another state highway or between one state highway and one federal-aid non-state highway. Among state intersections, there are 337 RT3STs and 582 RT4STs. SDDOT also provided crash data from 2009 through 2014. Crash data from 2009 to 2011 were used to develop customized approaches. The remaining data (2012 – 2014) were used for validation and evaluation. An intersection-related crash is defined by SDDOT as (1) a crash that happens within a 100-ft. radius from the center of the intersection and (2) any crash occurring within a 200-ft. radius from the intersection that is flagged by the police officer in the accident database as intersection-related. All crashes beyond the 200-ft. radius were considered to be non-intersection-related. Figure 1 illustrates how intersection-related crashes were identified. ILTIntersectFlag is a file in the accident database used by the police officer to flag intersection-related crashes with TRUE being intersection-related and FALSE being non-intersection-related. Based on these criteria, from 2009 to 2011 there are 158 crashes related to 337 RT3STs and 384 crashes related to 582 RT4STs, respectively. Table 1 presents the descriptive statistics of the two intersection types.

4. Modifications of the *HSM* methods

The modifications to the *HSM* predictive models are limited to SPFs and severity proportions. CMFs in the HSM are developed using large data samples, rigorous design, and sound methodologies and should not be redeveloped unless necessary. This article used the CMFs provided in *HSM* Part C.

4.1. Developing SPFs with a regional factor

Developing jurisdiction-specific SPFs with local data “is likely to enhance the reliability of the Part C predictive method” (AASHTO, 2010). It is recommended that the jurisdiction-specific base conditions should be the same as those defined in the

Table 1. Descriptive statistics of rural two-lane two-way intersections, 2009–2011.

Facility Type	Variable	Mean	*SD*	Minimum	Maximum
RT3ST	Total crash frequency	0.469	0.876	0	5
	FI crash frequency[a]	0.142	0.467	0	5
	$AADT_{major}$	1,172	915	62	5,515
	$AADT_{minor}$	307	446	5	4,181
	Skew Angle[b]	10.786	21.939	0	80
	Left-turn lane count	0.193	0.417	0	2
	Right-turn lane count	0.089	0.285	0	1
	Lighting[c]	0.059	0.237	0	1
RT4ST	Total crash frequency	0.660	1.146	0	10
	FI crash frequency[a]	0.225	0.550	0	4
	$AADT_{major}$	1,299	1,075	22	8,193
	$AADT_{minor}$	373	499	8	4,055
	Skew Angle[b]	3.033	8.972	0	60
	Left-turn lane count	0.199	0.567	0	2
	Right-turn lane count	0.072	0.313	0	2
	Lighting[c]	0.055	0.228	0	1

[a]FI = fatal and injury crashes, including KABC crashes using KABCO injury scale: K = fatal, A = incapacitating injury, B = nonincapacitating injury, C = possible injury, and O = property damage only (PDO);
[b]The unit is degree.
[c]Value is 1 if the site has lighting and 0 otherwise.

HSM and the jurisdiction-specific SPF could be developed with only data of sites under the base conditions (AASHTO, 2010). If the base conditions are representative of the local sites, the jurisdiction-specific SPF can effectively reflect how the AADTs affect safety in local jurisdictions.

As mentioned earlier, the calibration factor is used to account for the impacts of geographical characteristics (i.e., climate, animal population, driver populations, crash reporting threshold, and crash reporting practices) on local jurisdictions. Because a jurisdiction-specific SPF is developed with local data, it should better capture the aforementioned local and regional characteristics, and the calibration factor may not be necessary. It was found that jurisdiction-specific SPFs developed with local data render calibration factors that are very close to 1 for three rural segment types in South Dakota, indicating that the calibration factor is not needed with a well-developed jurisdiction-specific SPF (Qin et al., 2016). Moreover, the calibration factor is simply a scalar value equal to the ratio of observed to predicted crash frequency. Researchers should be cautious when considering the calibration factor as there are no solid statistical methods available to prove its validity.

Three methods can help account for a jurisdiction's regional effect: (1) calculating a region-specific calibration factor, (2) developing region-specific SPFs, and (3) estimating region-specific constants. The first method experiences all the same problems that arise in developing the calibration factor for the whole state. The second method requires only the data from one specific region when developing separate SPFs, meaning the small sample issue may arise (for rural areas especially). Therefore, this study uses the third method along with a categorical variable which represents different regions in a jurisdiction. AADT variables were used to help develop the SPFs. Estimating region-specific constants helps to avoid the low-sample size issue by using all sites in a jurisdiction and to enhance the researcher's confidence by employing sound statistical techniques.

4.2. Developing severity proportion models

The *HSM* obtains predicted crash frequencies of varying severity for rural two-lane two-way intersections by applying a distribution for crash severity level. Every site within one intersection facility shares the same proportions of different crash severity levels. However, severity proportions may be affected by roadway characteristics such as skew angle, left-turn lane count, and right-turn lane count. Several studies have shown how some roadway characteristics can lead to varying severity proportions (M. Abdel-Aty & Keller, 2005; Haleem & Abdel-Aty, 2010; Huang et al., 2008). Instead of applying a fixed distribution for all sites, a researcher should consider a severity proportion function of roadway characteristics to predict severity proportions.

The *HSM* provides the distribution of fatal and injury (FI) and property damage only (PDO) crashes. FI crashes include KABC crashes using the KABCO injury scale, i.e., K for fatal, A for incapacitating injury, B for nonincapacitating injury, C for possible injury, and O for property damage only (PDO) (AASHTO, 2010). In this study, a severity proportion function was developed for FI crashes using the logistic regression model. Predicted FI crash frequency can be computed once the FI proportion is obtained through the prediction model. PDO crash frequency equals the difference between the predicted total and FI crash frequency.

5. Results

5.1. Jurisdiction-specific SPFs

The first step in developing jurisdiction-specific SPFs is identifying jurisdiction-specific base conditions. RT3ST and RT4ST have same base conditions defined in the *HSM*: (1) 0° intersection skew angle, (2) no left-turn lanes on approaches without stop control, (3) no right-turn lanes on approaches without stop control, (4) no lighting. The data show that the *HSM* base conditions could be applied for RT3ST and RT4ST in South Dakota. Forty-eight percent of SD RT3ST sites that are associated with 31% of total crashes have the *HSM* base conditions, and 70% of SD RT4ST sites that are associated with 56% of total crashes have the *HSM* base conditions. Therefore, the *HSM* base conditions for RT3ST and RT4ST are representative of the local sites in South Dakota.

In addition to including AADTs in major and minor approaches for *HSM* SPFs, regional factor was included as a categorical variable for jurisdiction-specific SPFs. The regional factor was also tested in developing jurisdiction-

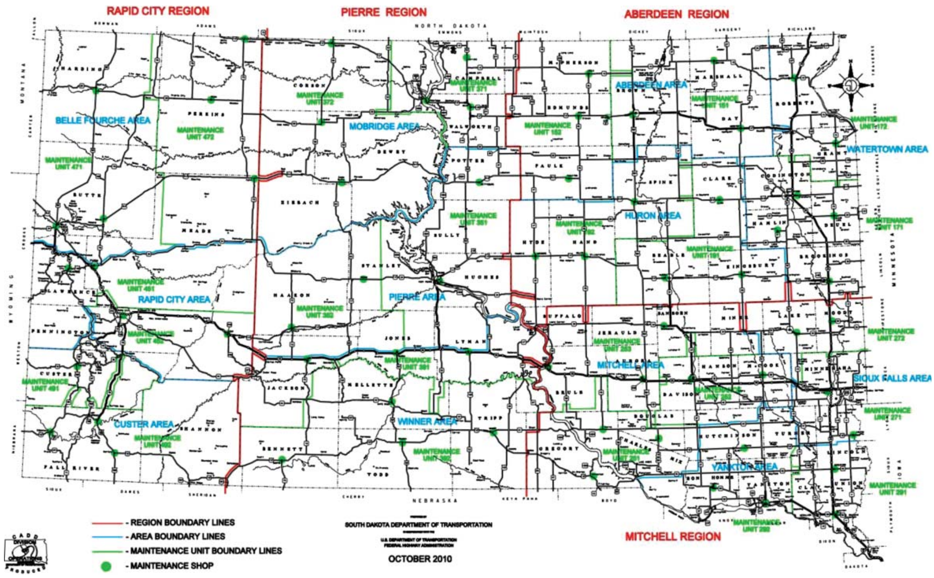

Figure 2. Region map of South Dakota.

specific SPFs for rural segments in South Dakota (Qin et al., 2016). South Dakota's four regions, as shown in Figure 2, include Rapid City, Pierre, Aberdeen, and Mitchell. Jurisdiction-specific SPFs were formulated for both RT3ST and RT4ST in Equation 1 using the negative binomial regression.

$$N_{spf} = \exp\left(\beta_0 + \beta_1 \times \ln\left(AADT_{major}\right) + \beta_2 \times \ln(AADT_{minor}) + Regional\ Factor\right) \quad (1)$$

Where,

N_{spf} = estimate of intersection – related predicted average crash frequency for base conditions

$AADT_{major}$ = AADT on the major road

$AADT_{minor}$ = AADT on the minor road

$Regional\ Factor$ = the effect of one specific region

Table 2 presents parameter estimations of jurisdiction-specific SPFs (*SD* presented in parenthesis) and parameter estimations of the *HSM* SPFs for RT3ST and RT4ST, respectively. It shows that the Aberdeen and Mitchell regions did not differ significantly in their safety performance. It could be because that Aberdeen and Mitchell, both located on the eastern side of the state, share many commonalities in terms of terrain, weather, and animal populations and have similar crash patterns. The two regions were then combined as one region, eastern region, in the RT3ST SPF. As the eastern region has the largest sample size of all sites, it was

Table 2. Parameter estimations of jurisdiction-specific and *HSM* SPFs.

Variable	Jurisdiction-Specific SPF	*HSM* SPF
RT3ST		
Intercept (β_0)	−7.033 (1.364)	−9.86
Major AADT (β_1)	0.451 (0.206)	0.79
Minor AADT (β_2)	0.424 (0.128)	0.49
Regional Factor		
Eastern South Dakota[a]	—	—
Pierre Region	−0.6697 (0.356)	—
Rapid City Region	−1.2864 (0.525)	—
RT4ST		
Intercept (β_0)	−9.339 (0.751)	−8.56
Major AADT (β_1)	0.801 (0.114)	0.60
Minor AADT (β_2)	0.380 (0.071)	0.61

Note. HSM = Highway Safety Manual; SPF = safety performance function; RT3ST = rural two-lane two-way unsignalized three-leg intersection (stop-control on minor-road approaches); AADT = annual average daily traffic; RT4ST = rural two-lane two-way unsignalized four-leg (stop control on minor-road approaches) intersection.
Standard error is presented in parenthesis.
[a]Eastern SD includes Aberdeen Region and Mitchell Region and is treated as base level of regional factor.

considered as the base level of the regional factor. The parameter estimation of the Rapid City Region deviates farther from 0 than the Pierre Region, indicating that the Rapid City Region may have more distinguished regional characteristics than the Pierre Region.

The regional factor for RT4ST did not contribute significantly to safety performance prediction that implies that the between-region variations in characteristics are marginal for RT4ST in South Dakota. Hence, only major and minor AADTs were included in the jurisdiction-specific SPF of RT4ST.

Compared with the *HSM* coefficients for AADTs, jurisdiction-specific SPFs show relatively different parameter estimations which indicates that the *HSM* SPFs may produce biased results. For example, compared to the jurisdiction-specific SPF, the *HSM* SPF of RT4ST underestimates the effect of the major AADT by 18.2% (= 1-exp (0.60–0.801)) while overestimating the effect of the minor AADT by 25.9% (= exp (0.61–0.380)-1). It was also found that the major AADT and the minor AADT had comparable effects (0.451 vs. 0.424) on the crash frequency for RT3ST in SD, whereas the major AADT contributed more than the minor AADT (0.801 vs. 0.380) for RT4ST in SD. However, the HSM SPFs suggested the opposite trends (0.79 vs. 0.49 for RT3ST and 0.60 vs. 0.61 for RT4ST). It indicates that the crash patterns for base conditions in SD may be different from these in the selected states for developing the HSM SPFs.

5.2. Severity proportion function

A severity proportion function was developed to predict the proportion of FI crashes among the total crashes for RT3ST and RT4ST. It is equivalent to predicting the probability of a FI or a non-FI crash on the condition of a crash occurrence. This dichotomous question requires each site to have at least one

Table 3. Estimated parameters of FI proportion functions of RT3ST and RT4ST.

RT3ST		RT4ST	
Variable	Estimation	Variable	Estimation
Intercept	−0.6426 (0.2108)	Intercept	−0.73941 (0.11438)
Left-turn lane count	−0.9131 (0.3580)	Skew angle	0.02934 (0.01287)
Lighting	1.6131 (0.6746)		

Note. FI = fatal and injury; RT3ST = rural two-lane two-way unsignalized three-leg intersection (stop-control on minor-road approaches); RT4ST = rural two-lane two-way unsignalized four-leg (stop control on minor-road approaches) intersection.
Standard error is presented in parenthesis.

crash and can be solved by the logistic regression. Data from 216 RT3ST and 146 RT4ST crashes were collected to develop the function. The function predicting the proportion of FI crashes has the form presented in Equation 2.

$$\log\left(\frac{p_{FI}}{1-p_{FI}}\right) = \beta_0 + \mathbf{X}^{'}\boldsymbol{\beta} \tag{2}$$

Where,

$$p_{FI} = \text{the proportion of FI crashes}$$

$$\mathbf{X}^{'} = \text{a vector of explanatory variables}$$

$$\boldsymbol{\beta} = \text{a vector of slope parameters}$$

Table 3 summarizes the estimation results (*SE* presented in parenthesis) of FI proportion functions for RT3ST and RT4ST and only statistically significant variables are presented. The results show that left-turn lane count and lighting condition contribute significantly to the proportion of FI crashes for RT3ST, and that the proportion of FI crashes for RT4ST is significantly related with skew angle. With the CMF for the installation of left-turn lanes being less than 1 for RT3ST, it indicates that the installation of left-turn lanes cannot only lower the crash frequency but reduce the severity level when the crash occurs. With the CMF for the lighting being also less than 1 for RT3ST, it indicates that the lighting can reduce the crash frequency but may elevate the severity level when the crash occurs. Intuitively, the lighting option should help reduce injury severity, but this was not observed in the data. Although we do not have actual speed data to corroborate, one possible explanation is that drivers tend to drive faster with lighting than the pitch-dark condition. The findings suggest that a large skew angle would increase the likelihood of a FI crash for RT4ST because skewed angles present challenges for sight distance at intersections. These findings are consistent with Haleem and Abdel-Aty's study (2010). Along with the corresponding CMF being larger than 1, a larger skew angle would both increase the crash frequency and raise the severity level.

Table 4. Summary of three options for predicting crash frequency by severity level.

Option	SPF	CMFs	Ci	Severity Proportion
1	Default	HSM CMFs	Yes	Jurisdiction-specific fixed proportion
2	Jurisdiction-specific	HSM CMFs	No	Jurisdiction-specific fixed proportion
3	Jurisdiction-specific	HSM CMFs	No	Severity proportion function

Note. HSM = Highway Safety Manual; CMF = crash modification factor.

6. Validation and comparison

All models were developed from 2009 to 2011 crash data. Crash data from 2012 to 2014 were used to validate the results and were compared with *HSM* model estimations. It is recommended that a jurisdiction-specific fixed severity proportion be used with *HSM* predictive methods. As shown in Table 4, three options were considered to predict crash frequency by severity level, and all three options used CMFs from Part C of the *HSM*. Option 1 uses default SPFs from the HSM and a calibration factor derived from the 2009 to 2011 predicted and observed crash data. Options 2 and 3 used jurisdiction-specific SPFs without applying any calibration factors. The regional factor has been tested and incorporated into the jurisdiction-specific SPFs because it is statistically significant; therefore, using a calibration factor is redundant because both represent the effects of factors with strong regional characteristics (e.g., weather, animal population, driver behavior, crash reporting thresholds, to name a few). Options 1 and 2 used jurisdiction-specific fixed severity proportion based on 2009 to 2011 crash data, and Option 3 used the SPF.

Mean absolute difference (MAD) and symmetric mean absolute percentage error (SMAPE) were chosen to measure the crash prediction accuracy, as shown in Equations 3 and 4. MAD measures the absolute difference between prediction and observation whereas SMAPE measures the relative difference.

$$MAD = \frac{1}{n}\sum_{i=1}^{n}|y - \hat{y}| \tag{3}$$

$$SMAPE = \frac{1}{n}\sum_{i=1}^{n}\frac{|y-\hat{y}|}{y+\hat{y}} \tag{4}$$

Where, y = observation and $\hat{y}$ = prediction.

Table 5. Performance measures of predicting total crashes for three options.

	Performance Measure	Option 1	Option 2 & 3
RT3ST	MAD	0.536	0.509
	SMAPE	0.860	0.878
RT4ST	MAD	1.235	1.205
	SMAPE	0.762	0.761

Note. MAD = mean absolute difference; SMAPE = symmetric mean absolute percentage error.

Table 6. Performance measures of predicting crashes by severity for three options.

		Performance Measure	Option 1	Option 2	Option 3
RT3ST	FI	MAD	0.219	0.203	0.212
		SMAPE	0.976	0.984	0.983
	PDO	MAD	0.406	0.383	0.373
		SMAPE	0.900	0.916	0.917
RT4ST	FI	MAD	0.291	0.292	0.310
		SMAPE	0.734	0.739	0.735
	PDO	MAD	0.558	0.555	0.549
		SMAPE	0.591	0.591	0.586

Note. RT3ST = rural two-lane two-way unsignalized three-leg intersection (stop-control on minor-road approaches); FI = fatal and injury; MAD = mean absolute difference; SMAPE = symmetric mean absolute percentage error; PDO = property damage only; RT4ST = rural two-lane two-way unsignalized four-leg (stop control on minor-road approaches) intersection.

Table 5 compares results of all options. Performance measures of Options 2 and 3 were combined because they only differed in terms of their severity proportion estimation. The calibration factor Ci should be applied to the *HSM* SPFs in Option 1. Based on the 2009 to 2011 crash data, Ci is 0.852 for RT3ST and 0.505 for RT4ST. In other words, the actual number of crashes was 85.2% of the predicted average number of crashes for RT3ST and 50.5% of predicted crashes for RT4ST. Without the calibration factor, Options 2 and 3 would outperform Option 1 with a smaller MAD. Although the SMAPE of Options 2 and 3 is greater than Option 1, the difference (2%) is marginal.

The three options were compared in terms of ability to predict crash frequency by severity. Total crash frequency was predicted for each site, and jurisdiction-specific severity proportion was applied to obtain predicted crash frequency by severity for Options 1 and 2. For Option 3, predicted FI proportion was computed for each site. Based on site-specific FI proportion, predicted FI crash frequency can be obtained for each site. PDO crash prediction equals the difference between predicted total crashes and FI crashes.

Table 6 compares all options' abilities to predict crashes of different severities. Surprisingly, the comparison results show that the site-specific severity proportion derived from the severity function does not offer additional accuracy when compared with jurisdiction-specific fixed severity proportion. Option 3 is only slightly better in predicting PDOs for both RT3ST and RT4ST. Option 2, which applied the fixed severity proportion, seems to perform better in most categories.

7. Conclusions

This article investigated practical and effective ways of customizing the current HSM predictive methods for use with local jurisdictions. The study uses safety data from rural two-lane two-way intersections during 2009–2011 in South Dakota. Jurisdiction-specific SPFs containing the categorical regional variable for four regions (Rapid City, Pierre, Aberdeen, and Michelle) were developed to estimate the influence of any possible unobserved or unavailable factors associated with different geographic regions. The calibration factor was not necessary because a well-developed SPF should sufficiently account for local characteristics, especially when regional factors are statistically significant. The methods based on the *HSM* SPF and the jurisdiction-specific SPF were validated using the 2012 to 2014 crash data. The comparison results show that jurisdiction-specific SPFs perform at a higher level.

Fixed severity proportion was replaced by a severity proportion function calibrated by local safety data. The hypothesis is that the attribute-specific severity proportion should reflect the relationship between severity proportions and roadway characteristics and more accurately predict injury severity when compared with a fixed value's prediction. Three predictive methods were compared: (1) the *HSM* SPF with the calibration factor and jurisdiction-specific fixed severity distribution, (2) a jurisdiction-specific SPF with a jurisdiction-specific fixed severity distribution, and (3) a jurisdiction-specific SPF with a severity proportion function. According to MAD and SMAPE, the results are mixed. Option 3 slightly outperformed Options 1 and 2 in PDO crashes for both intersection facilities, but Option 2 did better in FI crashes.

Severity proportion function does not add significant value to prediction performance, which offers certain level of assurance to users and researchers who are in favor of simple proportions. Although the conclusion is somewhat surprising, the severity proportion model can only be as good as the data. The small sample size and absence of many important variables (e.g., driver characteristics, vehicle features, weather, and roadside objects) that help predict injury severity may hinder the model's performance. A fixed injury severity proportion can be considered as a viable alternative to a site-specific severity proportion if this is the case.

Funding

The authors would like to thank the South Dakota Department of Transportation and by the Mountain Plain Consortium at North Dakota State University for funding this research.

ORCID

Xiao Qin http://orcid.org/0000-0003-0073-3485

References

AASHTO. (2010). *Highway Safety Manual (Vol. 1)*. Washington, D.C: AASHTO

Abdel-Aty, M., & Keller, J. (2005). Exploring the overall and specific crash severity levels at signalized intersections. *Accident Analysis & Prevention*, *37*(3), 417–425. doi:10.1016/j.aap.2004.11.002

Abdel-Aty, M., Lee, C., Park, J., Wang, J., Abuzwidah, M., & Al-Arifi, S. (2014). Validation and application of highway safety manual (Part D) in Florida. *Florida Department of Transportation.*

Brimley, B. K., Saito, M., & Schultz, G. G. (2012). Calibration of highway safety manual safety performance function. *Transportation Research Record: Journal of the Transportation Research Board*, *2279*(1), 82–89. doi:10.3141/2279-10

Dixon, K., Monsere, C., Xie, F., & Gladhill, K. (2012). *Calibrating the Future Highway Safety Manual Predictive Methods for Oregon State Highways*. Retrieved from.

Haleem, K., & Abdel-Aty, M. (2010). Examining traffic crash injury severity at unsignalized intersections. *Journal of safety research*, *41*(4), 347–357. doi:10.1016/j.jsr.2010.04.006

Huang, H., Chin, H. C., & Haque, M. M. (2008). Severity of driver injury and vehicle damage in traffic crashes at intersections: A bayesian hierarchical analysis. *Accident Analysis & Prevention*, *40*(1), 45–54. doi:10.1016/j.aap.2007.04.002

Kweon, Y.-J., Lim, I.-K., Turpin, T., & Read, S. (2014). Guidance on customization of highway safety manual for virginia: Development and application. *Transportation Research Record: Journal of the Transportation Research Board*, *2435*, 27–36. doi:10.3141/2435-04

Mehta, G., & Lou, Y. (2013). Calibration and development of safety performance functions for alabama: Two-lane, two-way rural roads and four-lane divided highways. *Transportation Research Record: Journal of the Transportation Research Board*, *2398*, 75–82. doi:10.3141/2398-09

Park, J., & Abdel-Aty, M. (2017). Safety performance of combinations of traffic and roadway cross-sectional design elements at straight and curved segments. *Journal of Transportation Engineering, Part A: Systems*, *143*(6), 04017015. doi:10.1061/JTEPBS.0000033

Qin, X., Rahman Shaon, M. R., & Chen, Z. (2016). Developing analytical procedures for calibrating the highway safety manual predictive methods. *Transportation Research Record: Journal of the Transportation Research Board*, (2583), 91–98. doi:10.3141/2583-12

Rahman Shaon, M. R., & Qin, X. (2016). Use of mixed distribution generalized linear models to quantify safety effects of rural roadway features. *Transportation Research Record: Journal of the Transportation Research Board*, (2583), 134–141. doi:10.3141/2583-17

SDDOT. SDDOT Region/Area/Maintenance Unit Map. Retrieved from http://sddot.com/dot/region/docs/dot_region_area_maint_map.pdf

Sun, C., Edara, P., Brown, H., Zhu, Z., & Rahmani, R. (2014). Calibration of Highway Safety Manual Work Zone Crash Modification Factors (MATC-MU: 177). *Missouri Department of Transportation*.

Sun, X., Li, Y., Magri, D., & Shirazi, H. H. (2006). Application of highway safety manual draft chapter: Louisiana experience. *Transportation Research Record: Journal of the Transportation Research Board*, *1950*(1), 55–64. doi:10.3141/1950-07

Xie, F., Gladhill, K., Dixon, K. K., & Monsere, C. M. (2011). Calibration of highway safety manual predictive models for oregon state highways. *Transportation Research Record: Journal of the Transportation Research Board*, *2241*(1), 19–28. doi:10.3141/2241-03