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Literature Search on Oklahoma-Specific SPFs for Data-Driven Highway Safety Improvements
“Development of roundabout crash-specific safety performance functions in Kentucky using different techniques” *Journal of Safety Research*, 2025

<https://www.sciencedirect.com/science/article/abs/pii/S0022437525000490>

Roundabouts are one of the innovative intersection designs that can reduce the number of fatal and serious injury crashes compared to traditional intersections. Nevertheless, relatively limited studies are available that have developed roundabout crash-specific safety performance functions (SPFs) using different modeling techniques. This study develops roundabout crash-specific SPFs using crashes in the state of Kentucky over a four-year period (2019–2022). *Method:* Crash data exhibited over-dispersion; hence, negative binomial (NB) and heterogenous negative binomial (HTNB), as well as Conway-Maxwell-Poisson (CMP) modeling approaches with fixed and varying dispersion parameters (while accounting for unobserved heterogeneity) were investigated. The performance of the fitted models was evaluated using different goodness-of-fit (GOF) statistics, e.g., Akaike information criterion “AIC,” Bayesian information criterion “BIC,” and McFadden pseudo R². *Results:* The GOF measures showed that the heterogeneous CMP (or HTCMP) model was the best-fit model for developing roundabout SPFs. The results of the HTCMP model showed that annual average daily traffic (AADT) on major and minor approaches to the roundabout and inscribed circle diameter (ICD) were significantly associated with increased crash frequency at roundabouts. Conversely, single circulatory lanes, presence of two lanes along the major roundabout approach, and wider circulatory roadway width (greater than 16 feet) were significantly associated with reduced crashes at roundabouts. *Practical Applications:* Based on the study results, safety countermeasures were proposed to enhance safety at roundabouts. One example is ensuring roundabout circulatory roadway widths greater than 16 feet to provide adequate room for driving error rectification while navigating roundabouts. 2

“Developing safety performance functions incorporating pavement roughness using Poisson regression and Machine learning models on Jordan’s Desert Highway” *Transportation Research Interdisciplinary Perspectives*, 2025

<https://www.sciencedirect.com/science/article/pii/S2590198225003380>

This research advances traffic safety analytics by deploying a hybridized modelling framework juxtaposing conventional statistical techniques with state-of-the-art machine learning algorithms to forecast crash frequency on a significant national corridor. The empirical findings decisively favor the application of SVR and XGBoost, demonstrating superior predictive fidelity and model stability across multiple validation metrics. SVR, in particular, achieved an exceptional R² of 0.983, with tightly constrained residual dispersion, highlighting its proficiency in capturing subtle, non-linear

patterns embedded within high-dimensional traffic datasets. These models outperformed the traditional Poisson regression, which, while theoretically aligned with count data modelling, was encumbered by restrictive distributional assumptions and insufficient flexibility in modelling variance heterogeneity.

The analytical process was fortified by a comprehensive Spearman correlation analysis, which confirmed the dominant influence of exposure-based variables (e.g., AADT), and Variance Inflation Factor (VIF) diagnostics, which ruled out multicollinearity as a source of model distortion. Cross-validation protocols further reinforced the generalizability of the machine learning models, and residual diagnostics underscored their capacity to minimize systematic bias across a broad spectrum of crash frequencies.

Collectively, the results affirm that when properly validated and interpreted, machine learning algorithms offer a robust and scalable alternative to classical modelling in the context of crash frequency prediction. Their ability to adapt to complex feature interactions and nonlinearities makes them particularly well-suited for modern roadway safety analysis, where the interplay of geometric, environmental, and behavioral factors defies simplistic modelling assumptions.

“Developing safety performance functions to inform transport policies on urban two-lane roads” *Research Transportation Business & Management*, 2025

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Road safety is a critical concern in urban areas, where complex networks and high levels of interaction between road users contribute to severe crashes. This study explores how various risk factors influence crash likelihood in urban settings and discusses their implications for transport policies aimed at improving safety and sustainability. We present 3 a Safety Performance Function (SPF) and related Crash Modification Factors (CMFs) tailored for Italian urban two-lane roads, covering 160 km across 10 provinces of the Tuscany Region, Central Italy. By analyzing 2519 Fatal and Injury (FI) crashes from 2008 to 2016, we identify risk factors such as traffic flow, road alignment, cross-section geometry, density of driveways, and density of intersections. Our findings reveal that non-compliance with infrastructure standards, such as too-wide roads, may contribute to higher crash risks. However, even compliance with regulations, such as the presence of frequent driveways or closely spaced urban intersections, could increase crash frequency due to traffic turbulence and heightened conflict points. These results highlight the necessity for evidence-based policies that not only enforce compliance but also reevaluate current standards to address residual risks. Targeted interventions, such as optimizing traffic flow and pedestrian mobility, regulating driveway density, and improving intersection design, can enhance urban road safety while aligning

with broader sustainability goals. By addressing these specific risk factors, policymakers can create safer and more sustainable transport systems in urban environments.

“Calibration and development of safety performance functions for two-way stop-control intersections on rural two-lane highways in Louisiana” *IATSS Research*, 2024

<https://www.sciencedirect.com/science/article/pii/S0386111224000219>

The results from the NB modes show that in addition to AADTs, curve radius, and intersection skewness have impacts on intersection safety. The greater curve radius leads to a smaller expected number of crashes for rural two-lane, three-leg, and four-leg intersections. However, intersection skewness increases the likelihood of crashes at intersections with three legs, contrary to the results of four-leg TWSC intersections.

Comparison of the Louisiana-specific SPFs with the calibrated HSM SPFs reveals that the HSM models underpredict crashes at a lower level of major road volumes but start to overpredict the number of crashes when the AADT on the major road exceeds 2500 on three-leg intersections. There are several potential reasons for the difference between the Louisiana-specific SPFs and the HSM SPFs results. The HSM models were developed a long time ago and, thus, may not present the current roadway safety situation since lots of effort and funding have been invested into crash reduction, particularly on rural two-lane highways that have been long recognized as the type of roadway with the highest traffic *fatality rate*. The *data sources*, sample size, modeling structure, and variable selection could have also contributed to the difference. It is believed that the Louisiana-specific models work better than calibrated HSM models. 4 The Louisiana-specific SPFs developed herein with the data from all parishes can be used to predict and evaluate the level of safety for TWSC intersections on rural two-lane roadways. The presence of intersections on horizontal curves is especially notable as these locations have characteristics that differ significantly from tangent intersections. Ultimately, the findings of this research offer several analytical resources to allow proactive safety planning practices, such as network screening and high-risk location identification.

“Full data imputation for freeway time-specific safety performance functions' estimation”

Accident Analysis & Prevention, 2023

<https://www.sciencedirect.com/science/article/pii/S0001457523002257>

Due to the lack of traffic data, especially the lack of high-resolution traffic data, many of the states in the United States cannot develop time-specific SPFs to evaluate freeway safety. This study proposed an iterative imputation method to solve this problem and used two sets of data (FL and VA, KS and TN) to verify the usability of this imputation method.

First, this study processed the crash data for eighteen states and calculated their crash rates. The ANOVA test was utilized to decide which states that have similar crash rates may transfer their SPFs

to the other states in the same group. Moreover, this study considered the location of the states in the same group and then selected FL/VA and KS/TN to apply the proposed imputation method. Second, the existing imputation methods do not include 100% missing data cases. Hence, this study used FL and VA to verify the feasibility of imputing the FL traffic data from VA by utilizing the iterative imputation method. The comparison between the imputed FL traffic data and the real-collected FL traffic data has a low MAE on Volume of 2.47 vehicles for each segment for three hours, and has a low MAE on AvgSpeed of 1.36 mph, which illustrates the imputed traffic data follows a similar data structure to the real-collected data. Moreover, The MAPE between the imputed Ln Volume and the real-collected Ln Volume is 11.07%. meanwhile, the MAPE between the imputed Ln AvgSpeed and the real-collected Ln AvgSpeed is 7.40%, which is both better than all the existing imputation methods. In addition, the results in [Table 2](#) indicate that the developed time-specific SPFs with imputed traffic data captured the same significant traffic variables (i.e., Ln Volume and Ln AvgSpeed) that impact the estimation of crash frequency.

Third, this study selected another set of states to apply the imputation method on the state without traffic data (i.e., TN). The results illustrated that the time-specific SPFs developed by imputed traffic data perfectly reflect the significant variables (i.e., Ln Volume and the Ln AvgSpeed) for both morning peak and afternoon peak models. Moreover, the model 5 performance of developed time-specific SPFs by utilizing the imputed traffic data was tested. The results indicate the prediction accuracy is 87.1%.

In general, this study proposed a new method that can solve the problem of total traffic data missing when developing time-specific SPFs. The imputation and modeling results could help traffic operators in the states without high-resolution traffic data to determine the factors contributing to crash occurrence on freeway segments during a specific time period. In the future, other variables could be considered once more related data were collected. The time-specific SPFs' performance would improve by considering more variables. Moreover, the network screening, which is reviewing a transportation network to identify and rank sites from most likely to least likely to benefit from a safety improvement, could be considered. This work also could be performed in the future to have a better understanding of the actual and imputed data and determine if the sites identified are consistent with actual and imputed data.

“From the past to the future: Modeling the temporal instability of safety performance functions” *Accident Analysis & Prevention*, 2022

<https://www.sciencedirect.com/science/article/pii/S0001457522000288>

This study proposed a modeling framework that integrates temporal modeling and time-series analysis to strengthen the current SPF estimation methods. The outcome of the framework is a set

of *Future SPFs* that capture the temporal unobserved heterogeneity in safety data and describe the anticipated relationships between safety performance and site characteristics in the future (as relative to the safety data collection period). The temporal modeling approach is the Temporally Weighted Negative Binomial Regression (TWNBR) that extends the current SPF estimation methods (American Association of State Highway and Transportation Officials, 2010, Brimley et al., 2012, Mehta and Lou, 2013, Srinivasan and Bauer, 2013). The TWNBR captures the temporal heterogeneity by allowing the local estimation of SPF parameters (model coefficients) at different time points. A case study using datasets from the State of Georgia was conducted to illustrate the key components of the modeling framework: temporal modeling and time-series modeling. The case study developed temporal-local SPF for multilane rural highway segments with non-traversable medians. And parameters are found to have significant variations across time, indicating the existence of temporal heterogeneity in the safety data. The parameters for AADT and segment length are associated with an increasing trend with time, and for access point density there is a descending trend. The parameters are found to have a strong seasonality that repeats the patterns over a one-year period. 6 Compared to traditional SPF estimation methods, the proposed Future SPF method requires additional work to prepare the data for model estimation. For example, the crash count data need to be prepared for successive time windows for each site, and the traffic count data (AADT) need to be adjusted for corresponding time windows which cross one year to another. With modern programming techniques, the processes of data preparation and model estimation can be easily programmed with the same input data (AADT, crash records and roadway data) as the traditional methods.

Continuing research is needed to examine the modeling framework with datasets covering longer periods through the inconsistency in data collection procedures that may affect the research outcome. This study estimated the SPFs for total crash numbers, and future research needs to estimate SPFs for crashes of different severities and types. Besides, the modeling methods are not limited to the ones tested in this study. To conform to the HSM methods this study estimated the negative binomial models in temporal modeling. For time-series modeling, only the SARIMA and ANN methods were tested. Other modeling methods including both regression and machine learning methods could be tested to model the crash frequency and explain the temporal variations of model estimates.

“A note on estimating safety performance functions with a flexible specification of traffic volume” *Accident Analysis & Prevention*, 2022

<https://www.sciencedirect.com/science/article/pii/S0001457522000070>

The brief note presented a flexible approach to allow for variation in the impact of AADT across different ranges of AADT. The approach generalizes a recently proposed approach by Gayah and Donnell (2021). The note establishes the equivalence of the proposed approach with Gayah and Donnell (2021) and subsequently presents a more flexible model structure that improves on the Gayah and Donnell (2021) approach. We document the advantages of our proposed approach in terms of model estimation, parameter significance testing and the flexibility to consider multiple AADT ranges for analysis. Subsequently, we also discuss how the proposed methodology addresses the limitation of GD approach in accommodating for unobserved heterogeneity and thus can be easily extended to accommodate for unobserved heterogeneity and temporal instability. Finally, it would be interesting for future research efforts to compare the proposed approach with semi-parametric approaches or generalized additive models that offer alternative approaches that allow for varying impact of AADT. For the comparison, it might be beneficial to employ a comprehensive experimental design framework for simulating data generated using a wide range of independent variable distributions (see Eluru, 7 2013, Bhowmik et al., 2021, Xu et al., 2021 for example studies employing simulation for model comparison).

“Comparison of the highway safety manual predictive method with safety performance functions based on geometric design consistency” *Journal of Transportation Safety & Security*, 2021 <https://www.tandfonline.com/doi/full/10.1080/19439962.2020.1738612>

Road safety is a major public health concern in our society. Effective road design and accurate safety analyses must be a component of programs focused on reducing and eliminating roadway injuries and deaths. Various methodologies exist to determine the expected number of crashes on rural two-lane rural roads. This research compares different procedures which allow for the estimation of the number of crashes on homogeneous road segments. In this effort, a total of 27 two-lane rural road sections located in North Carolina were considered, resulting in 59 homogeneous road segments composed of 350 horizontal curves and 375 tangents along 150 km of road. Four methods were applied to the selected roadways: the Highway Safety Manual predictive method, two jurisdiction-specific Safety Performance Functions (SPFs), and a SPF which includes a consistency parameter.

This research found that the use of SPFs which incorporate a consistency parameter allows highway engineers to consider human factor impacts on road safety assessment. The use of a consistency parameter can also simplify the crash estimation process. Analysis methods which only included local geometric variables provided unreliable results due to the calibration of only the specific road elements instead of their relationship with other road elements along homogeneous road segments.

“Crash analysis and development of safety performance functions for Florida roads in the framework of the context classification system” *Journal of Safety Research*, 2021

<https://www.sciencedirect.com/science/article/abs/pii/S002243752100102X>

Safety performance functions (SPF) are employed to predict crash counts at the different roadway elements. Several SPFs were developed for the various roadway elements based on different classifications such as functional classification and area type. Since a more detailed classification of roadway elements leads to more accurate crash predictions, multiple states have developed new classification systems to classify roads based on a comprehensive classification. In Florida, the new roadway context classification system incorporates geographic, demographic, and road characteristics information. *Method:* In this study, SPFs were developed in the framework of the FDOT roadway context 8 classification system at three levels of modeling, context classification (CC-SPFs), area type (AT-SPFs), and statewide (SW-SPF) levels. Crash and traffic data from 2015-2019 were obtained. Road characteristics and road environment information have also been gathered along Florida roads for the SPF development. *Results:* The developed SPFs showed that there are several variables that influence the frequency of crashes, such as annual average daily traffic (AADT), signalized intersections and access point densities, speed limit, and shoulder width. However, there are other variables that did not have an influence in crash occurrence such as concrete surface and the presence of bicycle slots. CC-SPFs had the best performance among others. Moreover, network screening to determine the most problematic road segments has been accomplished. The results of the network screening indicated that the most problematic roads in Florida are the suburban commercial and the urban general roads. *Practical Applications:* This research provides a solid reference for decision-makers regarding crash prediction and safety improvement along Florida roads.

“Development of an accident prediction model for Italian freeways” *Accident Analysis & Prevention*, 2019 <https://www.sciencedirect.com/science/article/pii/S000145751831220X>

In order to provide the Italian freeway agencies with a tool that allows to deal with potential safety assessments, identifying the sites with the largest potential safety improvements and helping in choosing the best treatment to apply, this paper describes two accident prediction models (APMs) for single- and multiple-vehicle fatal-and-injury crashes. Following the HSM approach, these models are based on jurisdictional specific Safety Performance Functions (SPFs) and a set of CMFs, applying the procedure defined in the PRACT Project.

The accident prediction models were developed using a dataset including information about fatal and injury crashes occurred on 884 km of freeway segments in a 5-year period (2009–2013). The models allowed to estimate *fatal-and-injury single- (or multiple-) vehicle crashes per year in one*

direction of travel. The base SPFs developed have the same base conditions than the ones used in the HSM; this allows to account for differences between a given section and the HSM base conditions by means of CMFs without the need of any further transformations due to different base conditions. In order to improve the reliability of the prediction accounting for differences in sites where the CMFs were developed, a calibration factors (C) was then computed for each APM.

“A new approach for calibrating safety performance functions” *Accident Analysis & Prevention*, 2018 <https://www.sciencedirect.com/science/article/pii/S0001457518303233> 9 In this research, NB SPFs of total crashes on rural divided multilane highway segments are developed for four states. The SPF configurations are similar to those of the HSM. The states, for which the SPFs are developed, are Florida, Ohio, California and Washington. Each SPF is calibrated to the other states' conditions. The SPFs are calibrated using the HSM calibration method, [Srinivasan et al.'s \(2016\)](#) calibration function and the KNN data mining regression method, which is proposed. The objective is to demonstrate that the proposed method outperforms the other. Explicitly, in the KNN regression calibration technique, a crash site's calibrated crash count is equivalent to the average of the observed crash counts of the K (4) sites having the nearest crash frequencies predicted by the SPF, applied. Bootstrapping is undertaken to estimate 95th percentile CLs of the GOF metrics used to assess the performances of the calibration methods, employed. The GOF measures, used, are the MAD and MSPE. The proposed method produced the best results. The upper 95th percentile CLs of the GOF values obtained using KNN regression calibration are demonstrated to be better than the lower 95th percentile CLs of the GOF metrics produced by the other calibration methods. Practitioners can readily implement KNN regression as an alternative to the HSM calibration method and the calibration function. An R script file can be provided with instructions on how to run it and interpret the results.

This research is not without limitations. The SPF configuration, used, is simplistic because it only includes the natural log transformation of the AADT, shoulder width and median width as independent variables. The lane width and shoulder pavement variables were included. However, they were not found to influence crash occurrences. It is recommended that roadway agencies, having adequate data on traffic, crash and other characteristics, translating to a multitude of variables, develop own localized SPFs instead of calibrate SPFs, adopted from elsewhere. That is because it is expected that the addition of variables enhances the predictive performances of the SPFs, developed.

“Development of regionalized SPFs for two-lane rural roads in Pennsylvania” *Accident Analysis & Prevention*, 2017 <https://www.sciencedirect.com/science/article/pii/S0001457517303147>

This paper explored the development of regionalized SPFs for two-lane rural roadways in Pennsylvania using methods that are consistent with the *Highway Safety Manual*. SPFs for various spatial scales (statewide with district-specific indicators, district-level and county-level) were estimated using a comprehensive dataset that included over 21,340 unique roadway segments and 8 years of crash data. These SPFs were compared to the existing statewide SPF according to the accuracy of their predictions, which were measured by three goodness-of-fit methods: RMSE, CURE plots and coefficients obtained from a 10-calibration function. The regionalized SPFs were also compared to the SPFs included in the HSM, calibrated at the same spatial scales. The results reveal that regionalization improves SPF accuracy compared to the statewide and the HSM SPFs, even when the latter is calibrated at local scales. For two-lane rural roadways in Pennsylvania, district-level SPFs with county-specific adjustments provided the most accurate predictions. County-level SPFs were not deemed reasonable as several counties did not have sufficient data to estimate their own SPF. For those that did, sufficient variability in the data did not exist at the county level to include variables other than traffic volumes in the SPFs. This suggests that a tradeoff exists between capturing differences in safety performance for individual geographic areas and having sufficient data to develop a robust SPF with many explanatory variables.

Overall, these findings suggest that regionalized SPFs should be considered over statewide SPFs for states that cover large geographic areas in which crash reporting practices, weather, driver population or safety practices and policies might vary. As demonstrated in this paper, regionalized SPFs should be able to more accurately describe safety performance on large roadway networks throughout a state, especially when compared to simple calibration of the SPFs provided in the HSM. This is especially true for states that have decentralized decision-making or design practices, such as Pennsylvania, as significant differences across these individual decision-making units are to be expected. Note that the adoption of regionalized SPFs may limit the applicability of individual parameter coefficients across an entire state. This is because CMFs derived from regression coefficients will not likely be consistent for each region of a state. However, regional SPFs are more suitable to use for prediction (combined with other methods, like the Empirical Bayes adjustment) in network screening processes.

“User’s Guide to Develop Highway Safety Manual Safety Performance Function Calibration Factors” NCHRP, 2014 [https://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-07\(332\)_FinalGuide.pdf](https://onlinepubs.trb.org/onlinepubs/nchrp/docs/NCHRP20-07(332)_FinalGuide.pdf)

This Guide is focused on the predictive method found in Part C of the HSM (2010). The predictive method is used to estimate the expected average crash frequency of an individual site. The expected average crash frequencies of individual sites can be combined to form an entire facility or

road network. The expected average crash frequency of a site is based on the predicted average crash frequency determined using a predictive model appropriate for the individual site and, if applicable, on site's past crash frequency (also referred to as observed crash frequency) recorded for each year of a given time period. The Empirical Bayes (EB) method is used to combine the predicted average crash frequency with observed crash frequency for the given time period. During this time period, the site geometric design and traffic control features are unchanged and traffic volumes are known or forecasted. The predictive models were developed for three facility types, as noted above, and included in Part C of the HSM (2010). Future versions of the HSM will incorporate additional facilities, such as freeway.