Crash Modification Factors for High-Friction Surface Treatment in Pennsylvania

FINAL REPORT

June 12, 2023

By Vikash V. Gayah, Eric T. Donnell and Pengxiang Zhang

The Pennsylvania State University

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16. Abstract
The objective of this project was to develop a suite of crash modification factors (CMFs) to quantify the safety impacts of installing high-friction surface treatments (HFSTs) on horizontal curves and intersections within the Commonwealth of Pennsylvania. An empirical Bayes observational before-after study was performed to develop CMFs for this countermeasure. The propensity score matching framework was also used to identify an appropriate reference group of horizontal curves as comparison sites. CMFs were estimated for horizontal curves on two-lane rural roads, and the analysis found that HFST was associated with a statistically significant reduction in crash frequency of between 30% and 76% for all crash types considered. At intersections, HFST was associated with a statistically significant reduction in crash frequency of between 66% and 76%. The results are in line with engineering expectation, as HFST provides additional friction on the roadway surface that can help drivers maintain control.

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INTRODUCTION

High-friction surface treatment (HFST) is a specialized pavement treatment used to increase the friction between vehicle tires and the roadway surface. The treatment involves applying a thin coating of durable, high-friction material to the roadway surface. By improving friction, HFST enhances skid resistance, reduces stopping distances, improves curve negotiation, increases intersection safety, and mitigates the risk of hydroplaning, all contributing to a safer driving experience and potentially reducing traffic crashes. Since repaving is not needed, HFST is often considered a low-cost treatment. However, the actual impact of HFST on crash frequency at curve or intersection locations is not clear.

The Pennsylvania Department of Transportation (PennDOT) has installed over 80 miles of HFST along individual curves and intersections throughout Pennsylvania. The objective of this project is to develop a set of crash modification factors (CMFs) that can be used to quantify the safety impacts of installing HFST at these locations. The CMFs developed within this project are compatible with both the methods proposed in the *Highway Safety Manual* (HSM) (American Association of State Highway and Transportation Officials, 2010) and in Pennsylvania's safety management processes as described in PennDOT Publication 638A. This report documents the steps taken to perform this evaluation and the final CMFs that were obtained.

The remainder of this document is organized as follows. The first section summarizes the data that were obtained from PennDOT and other sources for use in this safety evaluation. The second section describes the development of the analysis database used to support the evaluation. The third section provides a description of the analysis plan, specifically the empirical Bayes before-after methodology that was used. The fourth section documents the final CMFs. The final section provides some summary remarks.

DATA SUMMARY

This section describes the data provided from PennDOT that were used to identify HFST locations for inclusion in this study.

Roadway segments

An inventory of HFST locations along roadway segments within Pennsylvania was provided by PennDOT for the purpose of this study. The inventory consisted of the following information for each HFST installation within Pennsylvania:

- Location of the HFST installation, including:
    - PennDOT Engineering District
    - County
    - State route number
    - Beginning segment/offset location
    - Ending segment/offset location
    - Length of installation
    - Roadway functional classification
- Installation date
- Type of epoxy binder

The research team thoroughly reviewed this information to identify potential erroneous or questionable data. Examples of issues that were identified included:

- Missing installation dates
- Overlapping HFST installations
- Duplicate HFST information
- Incorrect location information

These issues were noted and discussed with PennDOT and, with PennDOT guidance, the research team revised particular entries to reflect actual conditions. The final set of locations consisted of a total of 84.27 miles of HFST sites. Table 1 provides a summary of these installations categorized by PennDOT Engineering District. As shown, several PennDOT Engineering Districts have no (District 3) or a negligible (Districts 1, 4, and 11) amount of HFST sites available for use in the study.

Table 1. Summary of HFST sites by PennDOT Engineering District

PennDOT Engineering District	Number of HFST locations	Total length (miles)
1	5	1.041
2	29	5.999
3	0	0
4	17	2.150
5	101	10.441
6	158	18.458
8	66	10.592
9	45	12.900
10	45	8.391
11	19	2.348
12	37	11.948
Total	**522**	**84.27**

Intersections

A list of intersections with HFST installed were also obtained from PennDOT. This included:

- Intersection location, including:
  - PennDOT Engineering District
  - County
  - Major state road
  - Beginning segment/offset location of HFST application
  - Ending segment/offset location of HFST application
  - Intersection roadway
- Installation date

A total of 64 intersections had HFST applied and were candidates for inclusion in this study. Table 2 provides a summary of these locations based on the installation year of the HFST application.

Table 2. Summary of intersections with HFST by installation year

Installation year	Number of intersections
2012	3
2013	4
2014	27
2015	7
2016	22
not available	1
Total	**64**

ANALYSIS DATABASE DEVELOPMENT

This section describes the analysis databases that were developed to estimate the CMFs in this study. Two databases were developed: one for roadway segments and one for intersections.

Segment analysis

The roadway segment analysis focused on individual curves that had HFST applied. These curves were identified using a database of curves within PennDOT's roadway management system (RMS) and then supplemented with additional data elements, as described in this section.

Mapping of HFST sites to horizontal curves

An inventory of horizontal curves on state roads in Pennsylvania[1] was obtained from PennDOT for use in this analysis. This database included the following information for each horizontal curve:

- Location information
    - County
    - State route
    - Starting segment and offset
    - Ending segment and offset
- Curve information
    - Radius
    - Central angle
    - Length

The research team matched up HFST locations to individual curve locations to determine the number of curve sections with HFST applied that would be available for the analysis. This matching was done using the PennDOT RMS linear referencing system, which uses the county, state route number, segment number, and offset location to identify both individual HFST applications and curve sections. Only horizontal curves with HFST applied to the entire boundary were considered in this analysis. Table 3 provides a summary of the number of curve sections and total length of curves with HFST by PennDOT Engineering District, and Table 4

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[1]   https://www.penndot.pa.gov/TravelInPA/Safety/Documents/PA-HSM-Tools_and_Data/C-Data/Curve%20Inventory.xlsm

provides a summary by HFST along these curve segments by installation year. Note that, given the analysis period of 2007 to 2021, sites with HFST installed in 2021 were excluded from the analysis due to lack of available data in the period after HFST was installed.

Table 3. Summary of curves with HFST by PennDOT Engineering District

PennDOT District	Number of curves with HFST	Total length (miles)
1	5	0.465
2	27	5.392
3	0	0
4	19	1.609
5	108	8.339
6	219	13.274
8	113	7.988
9	98	7.578
10	58	6.758
11	18	1.578
12	35	4.364
Total	**700**	**57.35**

Table 4. Summary of curves with HFST by installation year

Install year	Number of curves with HFST	Total length (miles)
2012	15	0.789
2013	8	0.844
2014	49	5.292
2015	144	11.047
2016	32	2.607
2017	58	5.482
2018	104	10.145
2019	139	10.606
2020	54	4.190
2021	97	6.345
Total	**700**	**57.35**

Supplemental data collection

Additional data elements were obtained and appended to the horizontal curve database. The PennDOT RMS data were used to obtain and append the following data elements to each curve in the database:

- Traffic volumes for each year of the analysis period (years 2007 to 2021, inclusive)
- Divisor information
- Location type (urban vs. rural)
- Maintenance functional classification
- Number of lanes
- Access control type

These data elements were merged using information for the segment that included curve. If a curve was included in multiple segments and these data elements changed across these elements, the segment that the majority of the curve section was contained within was used to describe the curve.

Additionally, horizontal signage information was obtained from PennDOT and appended to the entire curve database. This information was used to help account for the impact of these warning signs on safety performance in the analysis. The following sign/warning types were available for inclusion:

- Horizontal curve warning signs
- Arrow signs indicating a curve
- Chevron markings
- Sideroad on curve warnings

The complete list of signs that were used is too large to include; however, the set of signs were provided by PennDOT for use in this project. An example of each of the signs considered is shown in Figure 1. Signs that were placed either within the curve extends or within 300 ft upstream/downstream of the curve were associated with each curve.

W1-1
(a)

W1-6
(b)

W1-8
(c)

W1-10c
(d)
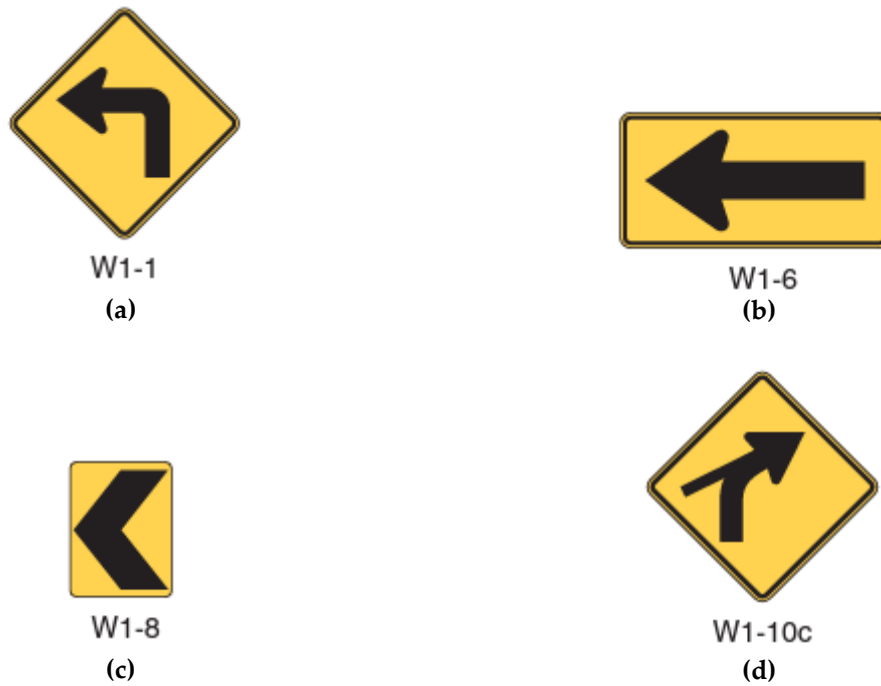
Source: (Federal Highway Administration, 2022)

Figure 1. Examples of curve warning signs considered in this project. (a) Horizontal curve warning sign; (b) Arrow sign; (c) Chevron markings; and (d) Side road warning sign.

After merging these additional data elements, the research team summarized the set of curves with HFST to determine if they shared similar characteristics. Table 5 provides a summary of these locations based on the number of travel lanes and if the curve was divided or undivided. Note that – consistent with PennDOT roadway segmentation – the number of lanes for undivided segments refers to both travel directions, while the number of lanes for divided segments refers to a single travel direction. As shown, the majority (86%) of curve sections with HFST were on two-lane undivided roadway segments. For this reason, the research team focused exclusively on two-lane undivided roadway segments for the safety evaluation of HFST applied to curve sections.

Table 5. Summary of curve sections with HFST based on divisor and number of lanes

Segment type	Number of curves (Total length in miles)			
	1 lane	2 lanes	3 lanes	4 lanes
Undivided	0 (0.00)	607 (45.46)	17 (1.69)	5 (0.41)
Divided	2 (0.35)	62 (8.70)	5 (0.27)	2 (0.47)
Total	2 (0.35)	669 (54.16)	22 (1.96)	7 (0.87)

Finally, the two-lane undivided curve sections were filtered to remove potentially erroneous values or observations that would not be useful in the analysis. This specifically included short curves (i.e., those listed in the PennDOT database as being less than 50 ft long) or those missing shoulder or speed limit information. In the end, a total of 530 curves representing 40.32 miles of roadway were retained and used in this analysis.

Crash data

The research team obtained the most recent crash data to estimate CMFs for the evaluation. Crash datafiles were obtained from the Pennsylvania Crash Information Tool (PCIT) website (https://crashinfo.penndot.gov/PCIT/queryTool.html) for the years 2007 to 2021, inclusive. The following data elements were used in this analysis:

- Crash location: defined using the PennDOT linear referencing system, via county, state route number, segment number, and offset
- Crash date
- Collision type
- Injury severity level

Several of the crash data elements were used to identify crashes occurring on roadway segments of interest for the present study. For example, crashes in construction work zones were not included in the analysis files, as these conditions are temporary.

Crashes were then assigned to individual unidirectional roadway segments in the analysis database based on the location of the crash (county, route, segment). Two cases were considered: (1) crashes that occurred only within the limits of the curve defined in the PennDOT curve inventory database; and (2) crashes that occurred within the limits of the curve plus 250 ft

upstream and downstream of these curve extents. The latter is likely to more comprehensively representative of curve safety, since a vehicle that lost control within the curve extents might come to rest outside the curve extents.

Crash counts for each roadway segment were then generated for each analysis year for various crash types that were considered in this analysis. These included:

- All crashes
- All fatal + injury crashes
- All PDO crashes
- Al run-off-road crashes
- All hit-fixed-object crashes
- All wet-road crashes
- All head-on crashes
- All sideswipe crashes
- Fatal + injury run-off-road crashes
- Fatal + injury hit-fixed-object crashes
- Fatal + injury wet-road crashes
- Fatal + injury head-on crashes
- Fatal + injury sideswipe crashes

Locations that did not experience a crash during any one or more years were retained in the analysis database. These segments and intersections with no crashes were included with an observed frequency of zero crashes for the respective crash types.

Intersection analysis

A separate intersection analysis database was developed to estimate the safety performance of HFST when applied at intersection locations. This section describes the process used to assemble this database.

Traffic volume information

The major roads of all HFST intersections were all state routes. Traffic volumes for these major roads were obtained from the PennDOT RMS database and appended to the intersection information. However, minor road volumes were also needed to accurately capture traffic at these intersection locations. The research team used the PennDOT RMS database to obtain traffic volumes for the minor roads that were also state roads. A total of 21 intersections had minor roads that were also state routes and thus had available traffic volume information.

However, this did not provide an adequate sample size for a safety evaluation of HFST applied to intersections.

The research team also examined available local route traffic volume information provided by PennDOT[2] to see if minor road traffic volume information was available for any of the intersections, but data for these local roads were not available.

To address this concern, PennDOT performed manual traffic counts at a subset of the remaining locations (i.e., those that did not have a state route as a minor road) during the spring of 2023 to supplement the available volume information – these data were provided to the research team. The traffic counts were then converted to AADT values for each year in the analysis period (2007 to 2021, inclusive) using available conversion factors. These additional counts were performed at a total of 12 intersections, which increased the number of intersections with full traffic volume information to 33.

Crash data

Similar to the curve segments, crash data were obtained from PennDOT and appended to each intersection in the analysis database. An influence area of 250 ft upstream/downstream from each intersection location was used to assign crashes to each intersection. Note that only crashes on the major road (which was a state route in all cases) were considered for this analysis to ensure consistency in crash counts across all intersections; crashes on the minor road were not available for all intersections, since these minor roads were not always state routes. Only the following two crash types were considered due to the availability of existing SPFs that would be needed to apply the EB before-after safety evaluation methodology:

- All crashes
- Fatal + injury crashes

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[2]   https://www.penndot.pa.gov/TravelInPA/Safety/Documents/PA-HSM-Tools_and_Data/C-Data/Local%20Road%20Count%20ADTs%20-Web.xlsx   and https://www.penndot.pa.gov/TravelInPA/Safety/Documents/PA-HSM-Tools_and_Data/C-Data/Local%20Road%20Counts%20Final%20(April%202021).xlsx

ANALYSIS METHODOLOGY

The research team implemented the EB before-after approach (Hauer, 1997) for this project to develop CMFs to describe the expected change in crash frequency along curve locations and at intersections with HFST installations. This method is widely accepted as the state-of-the-practice in observational before-after studies of crash data (Gross et al., 2010). The proposed EB analysis properly accounts for statistical factors such as: regression-to-the-mean, differences in traffic volume, and crash trends (time series effects) between the periods before and after HFST was installed.

The EB approach is comprised of three basic steps, each defined as follows:

Step 1: Develop safety performance functions (SPFs) to predict what the safety performance at locations with HFST installed would have been had the HFST not been implemented.

Step 2: Estimate what the actual (reported) safety performance should be for treatment sites (i.e., locations where HFST was installed) in the after period if HFST was not applied.

Step 3: Compare the predicted safety performance obtained from Step 2 with the reported safety performance to determine the safety effect of HFST.

Each of these steps is described in more detail below.

Step 1 – Prediction of safety performance

In this step, a reference group is used to account for the effects of traffic volume changes and temporal effects on safety due to variations in weather, demographics, and crash reporting. This is done through the development of SPFs, which relate the frequency of different crash types and severities to traffic volumes and other safety-influencing factors for a reference group of sites. This accounts for temporal and possible regression-to-the-mean effects, as well as those related to changes in traffic volume.

Negative binomial count regression models were used to estimate all intersection and segment SPFs in this study. The negative binomial regression model was a logical choice to estimate the expected number of crashes per year at these locations because it accounts for the overdispersion common in crash data. The general functional form of the negative binomial regression model is:

$$\ln \lambda_i = \beta X_i + \varepsilon_i \tag{1}$$

where λ_i = expected number of crashes at roadway segment or intersection i; β = vector of estimable regression parameters; X_i = vector of geometric design, traffic volume, and other site-specific data for roadway segment or intersection i; and ε_i = gamma-distributed error term.

The mean-variance relationship for the negative binomial distribution is:

$$\text{Var}(\lambda_i) = E(\lambda_i)[1 + \alpha E(\lambda_i)] \tag{2}$$

where $\text{Var}(\lambda_i)$ = variance of observed crashes occurring at location i; $E(\lambda_i)$ = expected crash frequency at location i; and α = overdispersion parameter.

Equation 3 shows the general form of the SPF that was estimated for roadway segments (i.e., individual curve locations) in this study. This form is consistent with Equation 1.

$$N_{i,SPF} = AADT^{\beta_{AADT}} \times Segment\ Length^{\beta_{Length}} \times \exp\left(\beta_0 + \sum x_{ij}\beta_j\right) \tag{3}$$

where $N_{i,SPF}$ = predicted crash frequency for roadway segment i using a SPF created from the reference group [crashes/year]; β_{AADT} = estimated coefficient for traffic volume on the segment; β_{Length} = estimated coefficient for segment length; β_0 = a regression constant; and β_j = estimated coefficient for other variables x_{ij} that describe the roadway segment.

Equation 4 shows the general form of the SPF that was estimated for intersections, which is also consistent with Equation 1.

$$N_{i,SPF} = AADT\ Major^{\beta_{AADT\ Major}} \times AADT\ Minor^{\beta_{AADT\ Minor}} \times \exp\left(\beta_0 + \sum x_{ij}\beta_j\right) \tag{4}$$

where $N_{i,SPF}$ = predicted crash frequency for intersection i using an SPF created from the reference group [crashes/year]; $\beta_{AADT\ Major}$ = estimated coefficient for traffic volume on major road approach; $\beta_{AADT\ Minor}$ = estimated coefficient for traffic volume on minor road approach; β_0 = a regression constant; and β_j = estimated coefficient for other variables x_{ij} that describe the intersection.

Propensity score matching

As will be described later, the set of reference curve locations without HFST within Pennsylvania was large. This makes estimating SPFs to predict crash frequency at locations had HFST not been applied challenging for two reasons: (1) the large number of sites makes estimating these statistical models time-consuming; and, perhaps more importantly, (2) these reference locations might differ from the sites with HFST in other ways. To account for these and select a reference group that is both smaller and similar to the curve locations with HFST, the research team applied propensity score matching to identify a subset of reference sites that are as similar as possible to the set of treatment sites with respect to the independent variables

considered (e.g., traffic volumes, geometric and roadside design, horizontal curvature, PennDOT Engineeirng District, etc.). The propensity scores framework is applied in causal inference to improve quasi-experimental studies (Dehejia and Wahba, 2002). The method involves using characteristics of individual observations to predict the likelihood, or propensity, that an observation has been treated with some feature (Rosenbaum and Rubin, 1983). These propensity scores are then used to match treated observations with untreated observations. This mimics a randomized experiment by accounting for the non-random assignment of the treatment to an observation by reducing correlation between the treatment and explanatory variables between two samples (i.e., selection bias) (Guo and Fraser, 2010; Hirano et al., 2003; Holmes, 2014). The propensity score is the probability that an observation will receive the treatment based on known characteristics (Holmes, 2014). In this study, a binary logit model was used to estimate the propensity scores. The functional form that describes the conditional probability is shown in Equation 5:

$$P(HFST_i|X_i = x_i) = E(HFST_i) = \frac{e^{x_i\beta_i}}{1+e^{x_i\beta_i}} \tag{5}$$

where *HFST* is the presence of HFST (1 if present; 0 otherwise); x is a vector of covariates; i is the observation number; and β is the vector of estimated coefficients. When estimating this model, variables should be considered based on their relationship to the treatment and not on statistical significance, as omitted variable bias can arise (Kennedy, 2008; Rubin, 1980).

Treated and untreated observations are matched based on their propensity scores. A nearest-neighbor (NN) N:1 method is used in the present study, which identifies the closest N untreated sites based on a propensity score within a predetermined caliper width (e.g., 10 percent of the standard error of estimated propensity scores) for each observation in the treated sample (Holmes, n.d.). The data are randomly sorted prior to matching to avoid potential bias that can arise from matching curves with HFST to adjacent curve sections without HFST. N untreated sites were matched to each treated site; upon matching an untreated observation to the N treated observations, the untreated observation was removed from the sample, as performing the matching without replacement maximizes the efficiency of the estimators (Dehejia and Wahba, 2002). If an entity was unmatched, it was also removed from the dataset.

The goal of matching based on propensity scores is to reduce bias between a set of treated (sites with HFST) and untreated (reference group sites) observations. In order to verify that matching has done this effectively, the two dataset samples (matched and unmatched) are compared using standardized bias—calculated as shown in Equation 6—which quantifies differences in the distribution of the covariates between a set of treated and untreated data (Rosenbaum and Rubin, 1983).

$$SB = 100 \left(\frac{(\bar{x}_T - \bar{x}_{UT})}{\sqrt{\frac{S_T^2 + S_{UT}^2}{2}}} \right)$$ (6)

where SB is the standardized bias between the treated and untreated samples; $\bar{x}_T$ is the sample mean of the treated group for covariate x; $\bar{x}_{UT}$ is the sample mean of the untreated group for covariate x; S_T^2 is the sample variance of the treated group for covariate x; and S_{UT}^2 is the sample variance of the untreated group for covariate x. Previous research suggests that standardized bias values of less than 10 percent for each covariate are desired upon completion of the matching process (Austin, 2011).

Step 2 – Before-After analysis with empirical Bayes

An empirical Bayes adjustment was applied to SPF predictions obtained from Equation 3 to incorporate reported crash frequency in the prediction of crash frequency at each location. This EB adjustment is shown in Equation 7 (Hauer, 1997).

$$N_{i,EB} = w_i * N_{i,SPF} + (1 - w_i) * N_{i,obs}$$ (7)

where $N_{i,EB}$ = predicted crash frequency at location i based on EB adjustment [crashes/year]; w_i = adjustment weight for predicted crash frequency for location i; $N_{i,SPF}$ = predicted crash frequency at location i based on the SPF (e.g., Equation 3) [crashes/year]; and $N_{i,obs}$ = reported or observed crash frequency at location i [crashes/year].

The weight (w_i) used for the EB adjustment for any location i is derived using Equation 8 (Hauer, 1997):

$$w_i = \frac{1}{1 + \alpha * \sum_{all\ study\ years} N_{i,SPF}}$$ (8)

Thus, Equations 3, 7, and 8 were used to determine N_{EB}^{Before} for the treatment sites in the before period by applying the SPFs generated in Step 1.

The SPF was used to calculate the predicted crash frequency using the SPF, N_{SPF}^{After}, for all treated roadway segment and intersections in the after period. Finally, the EB-adjusted expected crash frequency in the after period, N_{EB}^{After}, was calculated using Equation 9 and the adjustment factor, r, from Equation 10.

$$N_{EB}^{After} = N_{EB}^{Before} * r \tag{9}$$

$$r = \frac{\sum_{after\ years} N_{SPF}^{After}}{\sum_{before\ years} N_{SPF}^{Before}} \tag{10}$$

where r = adjustment factor for differences in duration and traffic volume between before and after periods; and N_{EB}^{After} = EB-adjusted crash frequency prediction during the after period.

This EB-adjusted value obtained from Equation 9 provides the expected crash frequency if no treatment was applied. This expected crash frequency was then compared with the reported crash frequency after the treatment was applied to assess the safety effects of the treatment.

Step 3 – Compare predicted to actual safety performance

An unbiased estimate of the safety effect (θ) of the treatment or countermeasure was obtained using Equations 11 and 12.

$$\theta = \frac{N_{observed}^{After}}{N_{EB}^{After}\left[1 + \frac{Var\left(N_{EB}^{After}\right)}{N_{EB}^{After^2}}\right]} \tag{11}$$

$$Var\left(N_{EB}^{After}\right) = \sum_{all\ sites} r^2(1-w)N_{EB}^{After} \tag{12}$$

where θ = unbiased estimate of safety effect of the countermeasure; and $N_{observed}^{After}$ = reported or observed crashes at the intersection during the after period.

Finally, the standard error associated with this safety effect estimate was computed using Equations 13 and 14.

$$Std\ Error(\theta) = \sqrt{\theta^2\left[\frac{\left[\left(\frac{Var\left(N_{observed}^{After}\right)}{N_{observed}^{After^2}}\right) + \left(\frac{Var\left(N_{EB}^{After}\right)}{N_{EB}^{After^2}}\right)\right]}{\left(1 + \frac{Var\left(N_{EB}^{After}\right)}{N_{EB}^{After^2}}\right)^2}\right]} \tag{13}$$

$$Var\left(N_{observed}^{After}\right) = \sum_{all\ sites} N_{observed}^{After} \tag{14}$$

CMF DEVELOPMENT

Curve sections

Step 1 – SPF development

As described in Step 1 of the EB before-after process, SPFs are required to predict the safety performance of individual curve sections at which HFST are not installed. Since Pennsylvania-specific SPFs for curves do not currently exist, these SPFs had to be developed for this project.

The research team originally considered using the set of all curve sections on two-lane undivided roadways without HFST as a reference group to develop these SPFs. However, there are over 123,000 curves that meet these criteria in the PennDOT curve database. This large number made estimating SPFs computationally infeasible. Furthermore, the large number of curve segments were not "similar" to those curve sections with HFST. Thus, the research team applied the propensity score matching methodology described in the "Analysis Methodology" section to identify a set of reference curves for use in the SPF development.

Propensity score model

The first step in this process was to estimate a binary logit model that was used to describe the likelihood or propensity that a given curve section had HFST installed. This model was not meaningful or insightful, but instead provided a mathematical relationship between individual curve features and the presence of HFST. This model is provided in Appendix A of this report.

Propensity score matching

Using the propensity score model, the research team computed the propensity score for each individual segment (with or without HFST) in the analysis database. Sites with HFST were then used to match with sites without HFST; this matching would identify those reference locations that are as similar as possible with respect to measurable characteristics to the sites with HFST. In this case, a 20:1 matching process was used in which each HFST location was matched to 20 reference curve locations without HFST. This was done to ensure sufficient sample size to estimate a reliable SPF for curve sections without HFST. Figure 1 shows the standardized bias values computed to compare continuous variables between the reference and HFST groups for both the unmatched (original) data and matched data that were obtained using this matching process. The results show the original (unmatched) dataset has significant bias (>10%) in traffic volumes, lengths, degree of curvature, and number of adjacent curves. This means that the

curves with HFST and the curves without HFST are significantly different in terms of these features. The matched data, on the other hand, are more balanced with standardized bias values all within or near 10%, which suggests statistically unbiased datasets.

Standardized bias for continuous variables
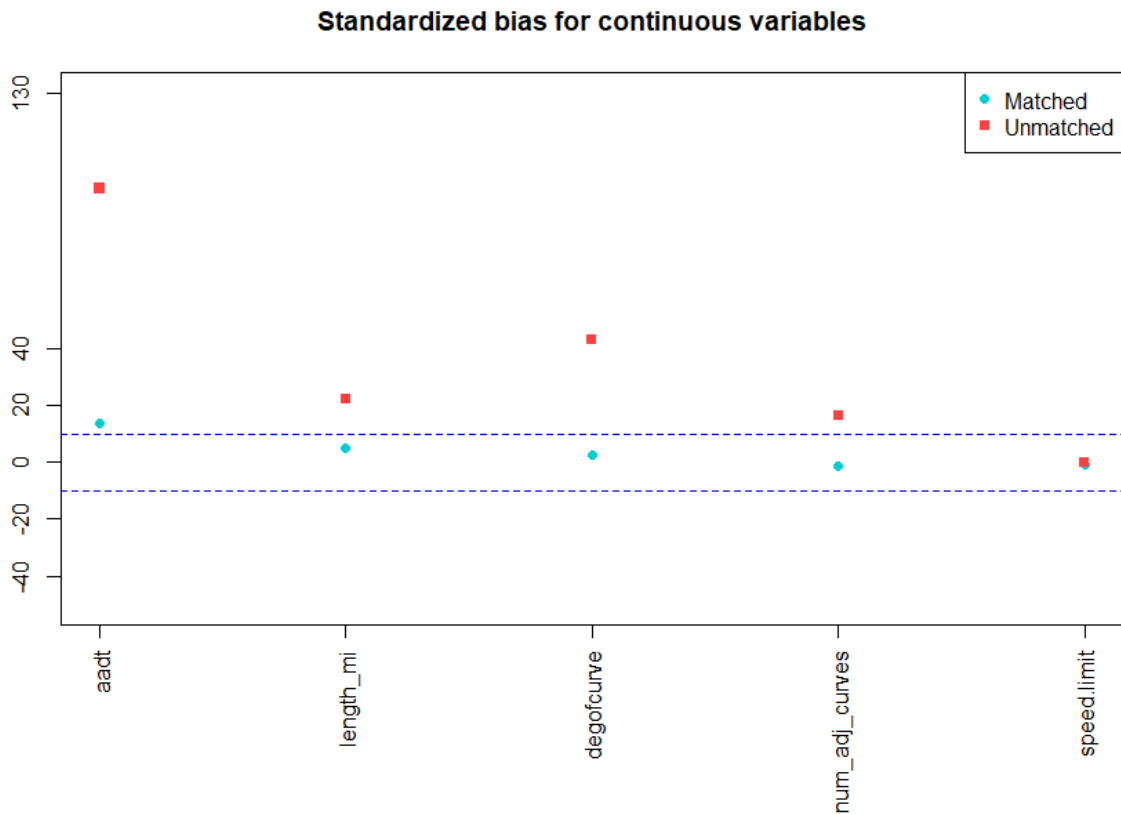
Notes: aadt = Average annual daily traffic (veh/day); length_mi = curve length (mi); degofcurve = degree of curvature per mile (degrees/mile); num_adj_curves = number of adjacent curves to subject curve (#); and speed.limit = posted speed limit (mph).

Figure 2. Standardized bias for continuous variables in matched and unmatched curve data

SPF development

As a result of the matching process, a total of 9,551 unique curve segments (691.45 miles) were available for SPF development. Each of these segments had 15 years of data available for SPF development (2007 to 2021, inclusive). Of these, 4,901 curves (320.96 miles) represented urban locations and 4,650 curves (370.49 miles) represented rural locations. A summary of the urban and rural curve databases used for SPF development is provided in Table 6 and Table 7.

Table 6. Summary of data used for development of urban curve section SPFs

Continuous variable	Mean	Standard deviation	Min.	Max.
Total crashes per year (on curve section)	0.314	0.768	0	12
Total fatal + injury crashes per year (on curve section)	0.152	0.470	0	8
Total property damage only (PDO) crashes per year (on curve section)	0.162	0.491	0	9
Total run-off road crashes per year (on curve section)	0.146	0.440	0	8
Total hit-fixed objective crashes per year (on curve section)	0.129	0.411	0	8
Total wet road crashes per year (on curve section)	0.105	0.393	0	12
Total head-on crashes per year (on curve section)	0.019	0.144	0	3
Total sideswipe crashes per year (on curve section)	0.011	0.110	0	4
Total run-off road fatal + injury crashes per year (on curve section)	0.064	0.268	0	4
Total hit-fixed objective fatal + injury crashes per year (on curve section)	0.055	0.246	0	4
Total wet road fatal + injury crashes per year (on curve section)	0.043	0.227	0	6
Total head-on fatal + injury crashes per year (on curve section)	0.013	0.119	0	2
Total sideswipe fatal + injury crashes per year (on curve section)	0.006	0.078	0	3
Total crashes per year (on curve + tangent* sections)	0.750	1.282	0	26
Total fatal + injury crashes per year (on curve + tangent* sections)	0.366	0.783	0	17
Total property damage only (PDO) crashes per year (on curve + tangent* sections)	0.385	0.785	0	13
Total run-off road crashes per year (on curve + tangent* sections)	0.315	0.672	0	11
Total hit-fixed objective crashes per year (on curve + tangent* sections)	0.277	0.625	0	11
Total wet road crashes per year (on curve + tangent* sections)	0.241	0.624	0	23
Total head-on crashes per year (on curve + tangent* sections)	0.043	0.223	0	8
Total sideswipe crashes per year (on curve + tangent* sections)	0.023	0.162	0	7
Total run-off road fatal + injury crashes per year (on curve + tangent* sections)	0.137	0.399	0	5
Total hit-fixed objective fatal + injury crashes per year (on curve + tangent* sections)	0.117	0.366	0	5
Total wet road fatal + injury crashes per year (on curve + tangent* sections)	0.100	0.358	0	15
Total head-on fatal + injury crashes per year (on curve + tangent* sections)	0.030	0.180	0	6
Total sideswipe fatal + injury crashes per year (on curve + tangent* sections)	0.012	0.113	0	5
Average annual daily traffic (AADT, veh/day)	7,273	5,073	151	23,709
Curve length (miles)	0.066	0.049	0.010	0.323
Degree of curvature (degree)	14.172	15.222	2.262	154.853
Categorical variable	**Category**		**Proportion (%)**	
High posted speed limit (larger or equal to 40 mph)	Yes		55.28	
	No		44.72	
Shoulder exists	Yes		80.42	
	No		19.58	

Have adjacent curves within 250 ft	Yes	36.45
	No	63.55
Chevron mark exists	Yes	10.61
	No	89.39
Arrow mark exists	Yes	13.90
	No	86.10
Curve warning exists	Yes	65.57
	No	34.43
Sideroad warning exists	Yes	8.68
	No	91.32
Year	2010	9.03
	2011	8.81
	2012	8.80
	2013	8.85
	2014	8.45
	2015	7.44
	2016	8.65
	2017	8.46
	2018	7.79
	2019	7.53
	2020	8.30
	2021	7.90
Engineering district	1	0.34
	2	0.30
	3	0
	4	1.45
	5	16.71
	6	48.51
	8	18.40
	9	4.17
	10	3.22
	11	3.54
	12	3.36

* tangent section refers to 250 ft section upstream/downstream of the curve

Table 7. Summary of data used for development of rural curve section SPFs

Continuous variable	Mean	Standard deviation	Min.	Max.
Total crashes per year (on curve sections)	0.157	0.502	0	9
Total fatal + injury crashes per year (on curve sections)	0.077	0.315	0	6
Total property damage only (PDO) crashes per year (on curve sections)	0.080	0.329	0	7
Total run-off road crashes per year (on curve sections)	0.111	0.395	0	7
Total hit-fixed objective crashes per year (on curve sections)	0.097	0.364	0	6
Total wet road crashes per year (on curve sections)	0.067	0.312	0	8
Total head-on crashes per year (on curve sections)	0.008	0.090	0	3
Total sideswipe crashes per year (on curve sections)	0.005	0.072	0	3
Total run-off road fatal + injury crashes per year (on curve sections)	0.052	0.248	0	5
Total hit-fixed objective fatal + injury crashes per year (on curve sections)	0.044	0.225	0	5
Total wet road fatal + injury crashes per year (on curve sections)	0.027	0.178	0	4
Total head-on fatal + injury crashes per year (on curve sections)	0.006	0.077	0	3
Total sideswipe fatal + injury crashes per year (on curve sections)	0.003	0.053	0	2
Total crashes per year (on curve sections)	0.294	0.708	0	10
Total fatal + injury crashes per year (on curve + tangent* sections)	0.144	0.436	0	6
Total property damage only (PDO) crashes per year (on curve + tangent* sections)	0.150	0.462	0	8
Total run-off road crashes per year (on curve + tangent* sections)	0.206	0.555	0	9
Total hit-fixed objective crashes per year (on curve + tangent* sections)	0.180	0.509	0	9
Total wet road crashes per year (on curve + tangent* sections)	0.121	0.431	0	9
Total head-on crashes per year (on curve + tangent* sections)	0.012	0.116	0	3
Total sideswipe crashes per year (on curve + tangent* sections)	0.008	0.094	0	3
Total run-off road fatal + injury crashes per year (on curve + tangent* sections)	0.097	0.343	0	6
Total hit-fixed objective fatal + injury crashes per year (on curve + tangent* sections)	0.082	0.311	0	6
Total wet road fatal + injury crashes per year (on curve + tangent* sections)	0.049	0.244	0	6
Total head-on fatal + injury crashes per year (on curve + tangent* sections)	0.009	0.098	0	3
Total sideswipe fatal + injury crashes per year (on curve + tangent* sections)	0.005	0.069	0	2
Average annual daily traffic (AADT, veh/day)	2,206	2,806	150	22,257
Curve length (miles)	0.079	0.058	0.010	0.324
Degree of curvature (degree)	16.276	16.661	2.260	150.778

Categorical variable		Category	Proportion (%)
High posted speed limit (larger or equal to 40 mph)		Yes	85.80
		No	14.20
Shoulder exists		Yes	93.70
		No	6.30
Have adjacent curves within 250 ft		Yes	45.81
		No	54.19
Chevron mark exists		Yes	16.75

	No	83.25
Arrow mark exists	Yes	27.19
	No	72.81
Curve warning exists	Yes	73.81
	No	26.19
Sideroad warning exists	Yes	8.25
	No	91.75
Year	2010	9.05
	2011	9.10
	2012	8.75
	2013	9.17
	2014	8.62
	2015	7.16
	2016	8.84
	2017	8.34
	2018	7.77
	2019	7.33
	2020	8.13
	2021	7.75
Engineeringing district	1	1.03
	2	1.34
	3	0
	4	3.29
	5	16.26
	6	8.47
	8	21.20
	9	28.91
	10	15.36
	11	0.32
	12	3.81

* tangent section refers to 250 ft section upstream/downstream of the curve

SPFs were developed separately for urban and rural curve sections due to the differences in safety performance between these two location types. For each of the urban and rural settings, SPFs were developed for the following crash types:

- All crashes
- Fatal + injury crashes
- PDO crashes
- Run-off-road crashes
- Hit-fixed-object crashes
- Wet-road crashes
- Head-on crashes
- Sideswipe crashes

- Run-off-road fatal + injury crashes
- Hit-fixed-object fatal + injury crashes
- Wet-road fatal + injury crashes
- Head-on fatal + injury crashes
- Sideswipe fatal + injury crashes

For each crash type and location (urban vs. rural) combination, SPFs were developed for crashes that occurred within the curve boundaries and crashes that occurred within the curve and adjacent tangent sections. The resulting SPFs are summarized in Appendix A of this report.

Note also that the SPFs include indicator variables to account for each year in the analysis period (using prior to 2010 as the base condition). This was done to account for changes in safety performance over time, since the analysis period is long (2007-2021). For this reason, these SPFs should not be used outside of the scope of this safety evaluation or for design decision purposes.

Step 2 – Before-after analysis with empirical Bayes

The SPFs identified and developed as part of Step 1 were used to predict crash frequencies at all treatment locations using the EB procedure outlined above. These predicted values were then combined with reported crash frequencies using a weighting factor (Equation 5) to estimate expected crash frequencies at each treatment site in the before period. Then, the expected crash frequencies in the before period were used to estimate the expected crash frequencies in the after period (Equation 7) based on changes in traffic volumes. Expected crash frequencies in the after period were computed for each location (either curve section or intersection) in this manner.

Step 3 – Compare predicted to actual safety performance

In this step, predicted and actual safety performance were compared to estimate CMFs for the installation of HFST on curved roadway sections. Table 8 provides a summary of the CMFs estimated for crashes that occur within the curve boundaries for all crashes (total), fatal + injury crashes (FI), property-damage-only crashes (PDO), run-off-road crashes (ROR), hit-fixed-object crashes (HFO), wet-road crashes (WR), head-on crashes (HO), sideswipe crashes (SS), ROR FI crashes, HFO FI crashes, and WR FI crashes. The standard error of each CMF was also estimated and used to identify if the CMF was statistically significant at the 95% confidence level; those that were statistically significant are noted in the table. As shown, the installation of HFST is found to be associated with a statistically significant decrease in all crash types that

were considered. The associated reductions range from 30% (sideswipe crashes) to 76% (wet-road crashes). The large reduction associated with wet-road crashes was expected, given the increased friction provided by the HFST.

Note that while all CMFs are statistically significant, some crash types have relatively few crashes expected in the after period or observed in the after period; these are italicized in the table. These low numbers suggest that the actual CMF estimate would be highly subject to randomness in the number of observed crashes. Thus, while HFST is expected to significantly decrease these crash types, the magnitude of these decreases should be further refined when additional years of crash data are available.

Table 8. Summary of HFST CMFs for crashes within curve boundaries

Crash type	Number of curves	Total length (miles)	Reported crashes in after period	EB estimate in after period	Unbiased CMF	CMF standard error
Total			610	1,445.13	0.422*	0.019
FI			297	568.14	0.522*	0.034
PDO			313	749.88	0.417*	0.026
ROR			423	924.17	0.457*	0.035
HFO			379	793.79	0.477*	0.027
WR	530	40.322	206	845.33	0.244*	0.018
HO			*35*	*69.55*	*0.501**	*0.091*
SS			*33*	*46.82*	*0.700**	*0.134*
ROR FI			194	298.54	0.649*	0.051
HFO FI			167	248.12	0.672*	0.057
WR F+I			87	266.65	0.326*	0.037

* statistically significant to the 95% confidence level

Table 9 provides the CMFs for HFST when considering crashes that occur both within the curve boundaries and in adjacent tangent sections (250 ft). The results are all statistically significant and similar to those CMFs for crashes within curve boundaries. The largest reduction in crash frequency associated with HFST is for wet-road crashes, while the smallest is for sideswipe FI crashes.

Table 9. Summary of HFST CMFs for crashes near curve limits

Crash type	Number of curves	Total length (miles)	Reported crashes in after period	EB estimate in after period	Unbiased CMF	CMF standard error
Total			1,266	2,853.05	0.444*	0.014
FI			568	1136.38	0.500*	0.023
PDO			698	1533.78	0.455*	0.019
ROR			847	1848.06	0.458*	0.018
HFO			767	1630.07	0.470*	0.019
WR			416	1687.41	0.246*	0.013
HO	530	90.51	*65*	*132.32*	*0.490**	*0.066*
SS			*42*	*89.68*	*0.467**	*0.077*
ROR FI			360	616.07	0.584*	0.034
HFO FI			312	519.34	0.600*	0.037
WR FI			160	536.21	0.298*	0.025
HO FI			*47*	*87.01*	*0.539**	*0.083*
SS FI			*27*	*39.89*	*0.673**	*0.138*

* statistically significant to the 95% confidence level

CMFs were also estimated for urban and rural curves, separately. Table 10 provides the disaggregated results for urban and rural curves for crashes that occur within the curve boundaries, while Table 11 provides the CMFs when considering crashes that occur both within the curve boundaries and adjacent tangent sections. The results are consistent with the previous CMFs, though generally have wider confidence intervals (including some statistically insignificant CMFs) due to the reduced sample size and lower observed crash frequencies. This also leads to some CMFs being subject to randomness (italicized in the table).

Table 10. Summary of disaggregated HFST CMFs for crashes within curve boundaries

Crash type	Number of curves	Total length (miles)	Reported crashes in after period	EB estimate in after period	Unbiased CMF	CMF standard error
Curves on urban roadways						
Total			349	899.40	0.388*	0.023
FI			173	348.09	0.496*	0.042
PDO			176	479.67	0.366*	0.031
ROR			228	498.14	0.457*	0.034
HFO			205	443.22	0.462*	0.036
WR	252	16.04	118	530.80	0.222*	0.022
HO			*27*	*50.19*	*0.534**	*0.112*
SS			*23*	*34.14*	*0.667**	*0.153*
ROR FI			105	151.33	0.692*	0.075
HFO FI			91	126.95	0.715*	0.083
WR FI			52	160.11	0.324*	0.048
Curves on rural roadways						
Total			261	545.73	0.478*	0.033
FI			124	220.05	0.563*	0.055
PDO			137	270.22	0.506*	0.048
ROR			195	426.04	0.457*	0.036
HFO			174	350.57	0.496*	0.041
WR	278	24.29	88	314.53	0.279*	0.032
HO			*8*	*19.36*	*0.409**	*0.150*
SS			*10*	*12.67*	*0.776*	*0.264*
ROR FI			89	147.21	0.603*	0.069
HFO FI			76	121.17	0.626*	0.077
WR FI			*35*	*106.54*	*0.327**	*0.058*

* statistically significant to the 95% confidence level

Table 11. Summary of disaggregated HFST CMFs for crashes near curve limits

Crash type	Number of curves	Total length (miles)	Reported crashes in after period	EB estimate in after period	Unbiased CMF	CMF standard error
Curves on urban roadways						
Total			796	1,844.28	0.431*	0.018
FI			362	735.29	0.492*	0.029
PDO			434	1,020.19	0.425*	0.023
ROR			486	1,092.44	0.445*	0.023
HFO			444	972.05	0.456*	0.024
WR			253	1,091.45	0.232*	0.016
HO	252	39.90	*54*	*102.57*	*0.524**	*0.079*
SS			*31*	*68.17*	*0.453**	*0.087*
ROR FI			206	341.51	0.603*	0.047
HFO FI			179	290.31	0.616*	0.051
WR FI			98	349.63	0.280*	0.030
HO FI			*40*	*64.53*	*0.617**	*0.105*
SS FI			*22*	*31.98*	*0.683**	*0.157*
Curves on rural roadways						
Total			470	1,008.77	0.466*	0.024
FI			206	401.09	0.513*	0.039
PDO			264	513.59	0.514*	0.035
ROR			361	755.62	0.477*	0.028
HFO			323	658.02	0.491*	0.030
WR			163	595.96	0.273*	0.023
HO	278	50.62	*11*	*29.76*	*0.368**	*0.114*
SS			*11*	*21.52*	*0.506**	*0.161*
ROR FI			154	274.56	0.560*	0.049
HFO FI			133	229.03	0.580*	0.054
WR FI			*62*	*186.59*	*0.332**	*0.044*
HO FI			*7*	*22.48*	*0.310**	*0.119*
SS FI			*5*	*7.92*	*0.625*	*0.287*

* statistically significant to the 95% confidence level

Intersections

<u>Step 1 – SPF development</u>

As described in Step 1 of the EB before-after process, SPFs are required to predict the safety performance at individual intersections that did not have HFST installed. For this study, existing SPFs developed by the research team for PennDOT (Donnell et al., 2019, 2016) were used as part of the EB process. The research team reviewed the functional classification of the 33 intersections with HFST; a summary of these intersections is provided in Table 12. Also provided in this table is the specific SPF that was applied to each intersection type as a part of the EB process. As noted, most of the intersections were 3-leg minor stop-controlled intersections.

Table 12. Summary of intersection types with HFST

Intersection Type	Number of intersections	SPF Used
3-leg minor stop-controlled intersection on urban-suburban collectors	14	3-leg minor stop-controlled intersection on urban-suburban collectors
3-leg all-way stop-controlled intersection on urban-suburban collectors	2	3-leg all-way stop-controlled intersection on urban-suburban collectors
4-leg minor stop-controlled intersection on urban-suburban collectors	1	4-leg minor stop-controlled intersection on urban-suburban collectors
3-leg minor stop-controlled intersection on urban-suburban arterials	1	3-leg minor stop-controlled intersection on urban-suburban arterials
4-leg signalized intersection on urban-suburban arterials	1	4-leg signalized intersection on urban-suburban arterials
3-leg minor stop-controlled intersection on rural collectors	5	3-leg minor stop-controlled intersection on two-lane rural roads
3-leg minor stop-controlled intersection on rural arterials	8	3-leg minor stop-controlled intersection on two-lane rural roads
4-leg signalized intersection on rural arterials	1	4-leg signalized intersection on two-lane rural roads

<u>Step 2 – Before-after analysis with empirical Bayes</u>

The SPFs identified and developed as part of Step 1 were used to predict crash frequencies at all treatment locations using the EB procedure outlined above. These predicted values were then combined with reported crash frequencies using a weighting factor (Equation 5) to estimate expected crash frequencies at each treatment site in the before period. Then, the expected crash frequencies in the before period were used to estimate the expected crash frequencies in the after period (Equation 7) based on changes in traffic volumes. Expected crash frequencies in the after period were computed for each location (either curve section or intersection) in this manner.

<u>Step 3 – Compared predicted to actual safety performance</u>

Table 13 provides a summary of the CMFs obtained for HFST applied to intersections. Note that fewer CMFs are provided since the research team had to rely on available SPFs. For this reason, CMFs were only estimated for total and FI crash frequency. Even though the sample size was relatively small (33 intersections), both CMFs were statistically significant at the 95% confidence level. The results suggest that the application of HFST at intersections is associated with a 66.6% reduction in total crash frequency and a 76.6% reduction in FI crash frequency.

Table 13. Summary of HFST CMFs for intersections

Crash type	Number of intersections	Reported crashes in after period	EB estimate in after period	Unbiased CMF	CMF standard error
Total	33	81	241.747	0.334*	0.042
FI		28	118.742	0.234*	0.048

* statistically significant to the 95% confidence level

SUMMARY

The purpose of this project was to estimate the safety performance of HFST along horizontal curves of two-lane rural highways and at intersections in Pennsylvania. An observational before-after study methodology, using the EB approach, was used to estimate CMFs for a variety of crash types and severity levels. Due to the large sample of horizontal curve sections on two-lane rural highways in Pennsylvania, propensity scores matching was integrated into the EB framework to identify the sample of treated (HFST) and untreated (no HFST) sites for the evaluation. The sample of intersections with HFST did not include the propensity scores matching process because the sample of intersections with and without HFST was smaller.

The CMFs for HFST applied to horizontal curves on two-lane rural roads were all less than 1.0, indicating that the treatment is expected to reduce the crash types included in the present study. All CMFs for HFST on two-lane rural highway horizontal curves were statistically significant, although the sample size for head-on and sideswipe opposite-direction crashes were small and should be interpreted with caution. A national HFST study funded by FHWA (Merrit et al., 2020) reported CMFs ranging from 0.123 to 0.290 for wet-road crashes on horizontal curves (depending on friction levels and traffic volumes), which is similar to the CMF of 0.244 in the present study. Similarly, that study reported a CMF of 0.272 to 0.584 for total crashes, while the present study found a CMF of 0.422. The FHWA study also reported a CMF of 0.266 for run-off-road crashes, which is similar to the present study, which estimated a CMF of 0.457. The present study found a CMF of 0.522 for total fatal + injury crashes on horizontal curves, while the FHWA study reported a CMF of 0.49. Overall, the safety effects of HFST on horizontal curves in Pennsylvania are similar to the results of the national study, which included sites from several states. When disaggregating the Pennsylvania results by area type, the results were similar to the aggregated results.

The CMFs for HFST applied to intersections in Pennsylvania were 0.334 and 0.234 for total and fatal + injury crashes, respectively. Both CMFs were statistically significant, but the number of intersections with HFST in Pennsylvania is small, so the random fluctuations in reported traffic crashes should be considered when interpreting the results. The research team was not able to identify CMFs for intersections as a means of comparison, but the results are consistent with engineering expectations, as higher levels of friction at the pavement—tire interface should reduce braking distances on intersection approaches and also improve the skid resistance of turning vehicles through intersections.

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APPENDIX A: PROPENSITY SCORE MATCHING MODEL

Table 14. Binary logit model developed for propensity score matching

Variable	Coefficient	Standard Error	t-statistic	p-value
Constant	-24.670	1830.000	-0.013	0.989
Natural logarithm of AADT (veh/day)	0.000	0.000	61.095	<0.001
Natural logarithm of length (miles)	4.624	0.209	22.106	<0.001
Degree of curvature per mile (degrees/mile)	0.027	0.001	36.917	<0.001
Indicator variable for the presence of a chevron mark (1 if present, 0 if not)	1.817	0.028	63.997	<0.001
Indicator variable for the presence of an arrow sign (1 if present, 0 if not)	1.047	0.028	37.736	<0.001
Indicator variable for the presence of a curve warning sign (1 if present, 0 if not)	0.953	0.024	39.489	<0.001
Indicator variable for the presence of a sideroad warning sign (1 if present, 0 if not)	0.264	0.038	7.002	<0.001
Indicator variable for no paved shoulder (1 if true, 0 otherwise)	-0.547	0.035	-15.509	<0.001
Indicator variable for at least one curve within 300 ft of subject curve (1 if yes, 0 if no)	0.405	0.022	18.669	<0.001
Indicator for posted speed limit equal to 15 mph (1 if yes, 0 otherwise)	0.030	2000.000	0.000	1.000
Indicator for posted speed limit equal to 20 mph (1 if yes, 0 otherwise)	17.200	1830.000	0.009	0.993
Indicator for posted speed limit equal to 25 mph (1 if yes, 0 otherwise)	15.840	1830.000	0.009	0.993
Indicator for posted speed limit equal to 30 mph (1 if yes, 0 otherwise)	16.490	1830.000	0.009	0.993
Indicator for posted speed limit equal to 35 mph (1 if yes, 0 otherwise)	15.810	1830.000	0.009	0.993
Indicator for posted speed limit equal to 40 mph (1 if yes, 0 otherwise)	15.920	1830.000	0.009	0.993
Indicator for posted speed limit equal to 45 mph (1 if yes, 0 otherwise)	16.320	1830.000	0.009	0.993
Indicator for posted speed limit equal to 50 mph (1 if yes, 0 otherwise)	15.740	1830.000	0.009	0.993
Indicator for posted speed limit equal to 55 mph (1 if yes, 0 otherwise)	16.330	1830.000	0.009	0.993
Indicator for year is 2011 (1 if yes, 0 otherwise)	0.011	0.049	0.219	0.826
Indicator for year is 2012 (1 if yes, 0 otherwise)	0.002	0.049	0.051	0.959
Indicator for year is 2013 (1 if yes, 0 otherwise)	0.025	0.049	0.515	0.607
Indicator for year is 2014 (1 if yes, 0 otherwise)	-0.021	0.049	-0.417	0.677
Indicator for year is 2015 (1 if yes, 0 otherwise)	-0.171	0.052	-3.311	0.001
Indicator for year is 2016 (1 if yes, 0 otherwise)	0.015	0.049	0.301	0.763
Indicator for year is 2017 (1 if yes, 0 otherwise)	-0.025	0.050	-0.509	0.611
Indicator for year is 2018 (1 if yes, 0 otherwise)	-0.091	0.050	-1.796	0.072
Indicator for year is 2019 (1 if yes, 0 otherwise)	-0.143	0.051	-2.786	0.005
Indicator for year is 2020 (1 if yes, 0 otherwise)	-0.026	0.050	-0.529	0.597

Variable	Coefficient	Standard Error	t-statistic	p-value
Indicator for year is 2021 (1 if yes, 0 otherwise)	-0.053	0.050	-1.059	0.290
Indicator for PennDOT Engineering District 2 (1 if yes, 0 otherwise)	-0.848	0.150	-5.660	<0.001
Indicator for PennDOT Engineering District 3 (1 if yes, 0 otherwise)	-14.770	55.590	-0.266	0.791
Indicator for PennDOT Engineering District 4 (1 if yes, 0 otherwise)	-0.143	0.128	-1.117	0.264
Indicator for PennDOT Engineering District 5 (1 if yes, 0 otherwise)	1.178	0.115	10.279	<0.001
Indicator for PennDOT Engineering District 6 (1 if yes, 0 otherwise)	2.000	0.115	17.455	<0.001
Indicator for PennDOT Engineering District 8 (1 if yes, 0 otherwise)	1.388	0.114	12.191	<0.001
Indicator for PennDOT Engineering District 9 (1 if yes, 0 otherwise)	1.438	0.115	12.454	<0.001
Indicator for PennDOT Engineering District 10 (1 if yes, 0 otherwise)	1.074	0.117	9.204	<0.001
Indicator for PennDOT Engineering District 11 (1 if yes, 0 otherwise)	-0.978	0.135	-7.235	<0.001
Indicator for PennDOT Engineering District 12 (1 if yes, 0 otherwise)	-0.195	0.124	-1.575	0.115
Indicator variable for segment in small urban area (1 if yes, 0 otherwise)	0.345	0.053	6.476	<0.001
Indicator variable for segment in urbanized area with population 50,000 to 200,000 (1 if yes, 0 otherwise)	0.188	0.053	3.569	<0.001
Indicator variable for segment in urbanized area with population greater than 200,000 (1 if yes, 0 otherwise)	0.404	0.032	12.687	<0.001

APPENDIX B: SUMMARY OF SPFS DEVELOPED FOR CURVE SECTIONS ON TWO-LANE DIVIDED ROADS

Table 15. SPF developed for total crash frequency on urban curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-6.109	0.209	-29.283	<0.001
Natural logarithm of AADT	0.761	0.014	54.284	<0.001
Natural logarithm of length	0.799	0.016	50.467	<0.001
Degree of Curvature	0.018	0.001	22.018	<0.001
Indicator variable for no shoulder exist (1 indicates no shoulder, 0 indicates has shoulder)	0.128	0.025	5.135	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.346	0.030	11.527	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.409	0.028	14.509	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.262	0.032	8.235	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.085	0.043	1.972	0.049
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.026	0.044	-0.600	0.548
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.030	0.043	0.692	0.489
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.289	0.047	-6.204	<0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.138	0.044	3.117	0.002
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.079	0.044	1.819	0.069
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.064	0.044	1.465	0.143
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.128	0.044	2.903	0.004
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.050	0.045	1.107	0.268
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.164	0.046	-3.563	<0.001
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.025	0.045	-0.558	0.577
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.286	0.238	-1.202	0.230
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.068	0.175	-0.389	0.697
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.245	0.160	1.527	0.127
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.043	0.160	0.267	0.790
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.248	0.160	1.547	0.122
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.125	0.167	-0.747	0.455
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.208	0.169	-1.229	0.219
Indicator for Engineering District 11	-0.255	0.166	-1.534	0.125

(1 indicates yes, 0 indicates no)				
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.198	0.168	-1.182	0.237
Overdispersion parameter = 1.332, 2 x LL = -77623.273				

Table 16. SPF developed for total crash frequency on rural curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-5.741	0.185	-31.071	<0.001
Natural logarithm of AADT	0.716	0.014	51.252	<0.001
Natural logarithm of length	0.876	0.022	39.223	<0.001
Degree of Curvature	0.026	0.001	24.670	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.130	0.039	3.383	0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	-0.060	0.026	-2.289	0.022
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.614	0.028	22.240	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.396	0.032	12.586	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.092	0.030	3.100	0.002
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.182	0.040	4.565	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.101	0.056	1.801	0.072
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.055	0.057	0.956	0.339
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.093	0.056	1.646	0.100
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.304	0.062	-4.899	<0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.084	0.059	1.422	0.155
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.085	0.057	1.492	0.136
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.039	0.058	0.667	0.505
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.061	0.059	1.048	0.295
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.024	0.060	0.405	0.686
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.103	0.060	-1.717	0.086
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.186	0.062	-3.017	0.003
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.340	0.159	-2.134	0.033
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.220	0.138	-1.591	0.112
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.032	0.124	0.262	0.793
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.101	0.127	0.791	0.429
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.154	0.123	1.256	0.209
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.278	0.124	-2.245	0.025
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.403	0.126	-3.205	0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	0.061	0.267	0.230	0.818

Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.306	0.136	-2.247	0.025
Overdispersion parameter = 0.995, 2 x LL = -44270.676				

Table 17. SPF developed for fatal + injury crash frequency on urban curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-7.000	0.276	-25.401	<0.001
Natural logarithm of AADT	0.794	0.019	41.831	<0.001
Natural logarithm of length	0.762	0.021	36.887	<0.001
Degree of Curvature	0.017	0.001	14.703	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	-0.072	0.026	-2.729	0.006
Indicator variable for no shoulder exist (1 indicates no shoulder, 0 indicates has shoulder)	0.141	0.034	4.185	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.299	0.039	7.586	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.293	0.038	7.672	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.249	0.042	5.963	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.013	0.054	0.234	0.815
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.108	0.056	-1.935	0.053
Indicator for year 2013 (1 indicates yes, 0 indicates no)	-0.052	0.055	-0.945	0.345
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.343	0.060	-5.742	<0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.079	0.056	1.403	0.161
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.094	0.057	-1.667	0.095
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.045	0.056	-0.807	0.420
Indicator for year 2018 (1 indicates yes, 0 indicates no)	-0.062	0.057	-1.084	0.279
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.160	0.059	-2.700	0.007
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.300	0.060	-5.008	<0.001
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.214	0.060	-3.588	<0.001
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.453	0.327	-1.387	0.165
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.073	0.227	-0.321	0.748
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.242	0.207	1.168	0.243
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	<0.001	0.206	<0.001	1.000
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.163	0.207	0.790	0.430
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.157	0.216	-0.725	0.468
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.110	0.218	-0.502	0.616
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.241	0.214	-1.125	0.261
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.132	0.216	-0.612	0.540

Overdispersion parameter = 1.396, 2 x LL = -48750.506

Table 18. SPF developed for fatal + injury crash frequency on rural curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-5.914	0.236	-25.013	<0.001
Natural logarithm of AADT	0.687	0.018	37.229	<0.001
Natural logarithm of length	0.887	0.030	29.650	<0.001
Degree of Curvature	0.023	0.001	15.988	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.110	0.052	2.132	0.033
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	-0.089	0.035	-2.537	0.011
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.616	0.036	16.944	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.446	0.042	10.608	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.155	0.052	2.987	0.003
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.092	0.072	1.278	0.201
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.025	0.074	-0.335	0.738
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.023	0.073	0.318	0.750
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.386	0.081	-4.739	<0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	-0.067	0.078	-0.853	0.394
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.034	0.074	-0.452	0.651
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.067	0.076	-0.890	0.374
Indicator for year 2018 (1 indicates yes, 0 indicates no)	-0.171	0.079	-2.175	0.030
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.170	0.080	-2.134	0.033
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.214	0.079	-2.718	0.007
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.366	0.083	-4.425	<0.001
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.462	0.209	-2.206	0.027
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.209	0.178	-1.174	0.241
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.006	0.160	0.035	0.972
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.038	0.165	0.232	0.817
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.077	0.159	0.481	0.630
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.375	0.161	-2.333	0.020
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.431	0.163	-2.649	0.008
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	0.139	0.343	0.407	0.684
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.302	0.176	-1.715	0.086

Overdispersion parameter = 0.932, 2 x LL = -27355.809

Table 19. SPF developed for PDO crash frequency on urban curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-6.630	0.273	-24.302	<0.001
Natural logarithm of AADT	0.726	0.018	40.197	<0.001
Natural logarithm of length	0.826	0.020	40.465	<0.001
Degree of Curvature	0.020	0.001	18.413	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.051	0.026	1.968	0.049
Indicator variable for no shoulder exist (1 indicates no shoulder, 0 indicates has shoulder)	0.110	0.033	3.302	0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.366	0.038	9.735	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.492	0.035	13.932	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.291	0.040	7.342	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.150	0.056	2.670	0.008
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.053	0.057	0.930	0.353
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.103	0.057	1.797	0.072
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.232	0.062	-3.745	<0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.196	0.058	3.365	0.001
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.233	0.056	4.129	<0.001
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.181	0.057	3.174	0.002
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.304	0.057	5.368	<0.001
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.250	0.058	4.336	<0.001
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.024	0.060	-0.397	0.691
Indicator for year 2021 (1 indicates yes, 0 indicates no)	0.153	0.058	2.620	0.009
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.117	0.298	-0.391	0.695
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.031	0.229	-0.138	0.891
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.299	0.210	1.424	0.154
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.129	0.209	0.616	0.538
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.365	0.210	1.742	0.081
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.036	0.218	-0.166	0.868
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.232	0.222	-1.044	0.296
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.201	0.217	-0.924	0.355
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.195	0.219	-0.889	0.374

Overdispersion parameter = 1.417, 2 x LL = -50865.538

Table 20. SPF developed for PDO crash frequency on rural curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-6.884	0.255	-26.971	<0.001
Natural logarithm of AADT	0.731	0.019	39.192	<0.001
Natural logarithm of length	0.852	0.030	28.535	<0.001
Degree of Curvature	0.027	0.001	19.961	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.151	0.052	2.904	0.004
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.595	0.037	16.150	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.357	0.042	8.455	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.111	0.040	2.786	0.005
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.222	0.052	4.273	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.103	0.079	1.316	0.188
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.139	0.079	1.767	0.077
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.169	0.078	2.169	0.030
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.221	0.086	-2.579	0.010
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.236	0.080	2.937	0.003
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.198	0.078	2.541	0.011
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.143	0.080	1.791	0.073
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.279	0.078	3.561	<0.001
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.214	0.080	2.667	0.008
Indicator for year 2020 (1 indicates yes, 0 indicates no)	0.009	0.082	0.108	0.914
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.008	0.083	-0.093	0.926
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.208	0.222	-0.934	0.350
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.184	0.196	-0.940	0.347
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.119	0.176	0.679	0.497
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.224	0.180	1.242	0.214
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.296	0.175	1.694	0.090
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.123	0.177	-0.698	0.485
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.300	0.179	-1.677	0.093
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	0.014	0.383	0.036	0.971
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.246	0.193	-1.276	0.202

Overdispersion parameter = 1.212, 2 x LL = -27995.871

Table 21. SPF developed for run-off-road crash frequency on urban curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-3.994	0.258	-15.482	<0.001
Natural logarithm of AADT	0.428	0.017	24.963	<0.001
Natural logarithm of length	0.834	0.021	39.288	<0.001
Degree of Curvature	0.022	0.001	22.016	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.048	0.026	1.826	0.068
Indicator variable for no shoulder exist (1 indicates no shoulder, 0 indicates has shoulder)	0.085	0.034	2.512	0.012
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.594	0.035	17.129	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.587	0.033	17.912	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.301	0.029	10.309	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.215	0.039	5.494	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.098	0.055	1.784	0.074
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.027	0.056	0.491	0.623
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.035	0.056	0.625	0.532
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.290	0.061	-4.769	<0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.069	0.058	1.201	0.230
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.003	0.057	-0.044	0.965
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.026	0.057	0.466	0.641
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.022	0.058	0.379	0.705
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.027	0.058	0.460	0.646
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.199	0.060	-3.312	0.001
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.076	0.059	-1.281	0.200
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.461	0.276	-1.671	0.095
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.413	0.213	-1.941	0.052
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.080	0.191	0.420	0.675
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.092	0.191	-0.483	0.629
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.124	0.191	0.648	0.517
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.221	0.199	-1.113	0.266
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.547	0.206	-2.659	0.008
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.527	0.200	-2.639	0.008

Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.349	0.199	-1.752	0.080
Overdispersion parameter =1.132, 2 x LL = -47953.767				

Table 22. SPF developed for run-off-road crash frequency on rural curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-4.784	0.206	-23.249	<0.001
Natural logarithm of AADT	0.558	0.016	35.746	<0.001
Natural logarithm of length	0.887	0.026	33.760	<0.001
Degree of Curvature	0.025	0.001	21.312	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.141	0.044	3.190	0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.762	0.032	24.016	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.441	0.036	12.409	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.195	0.035	5.535	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.082	0.047	1.744	0.081
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.049	0.065	0.747	0.455
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.076	0.065	1.170	0.242
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.102	0.065	1.581	0.114
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.341	0.072	-4.740	<0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.050	0.068	0.727	0.467
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.041	0.066	0.617	0.537
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.061	0.068	-0.892	0.372
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.001	0.068	0.011	0.991
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.002	0.069	-0.034	0.973
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.123	0.069	-1.774	0.076
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.271	0.072	-3.751	<0.001
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.436	0.175	-2.488	0.013
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.290	0.152	-1.905	0.057
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.100	0.136	-0.735	0.462
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.112	0.142	-0.789	0.430
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.001	0.136	-0.010	0.992
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.463	0.137	-3.390	0.001
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.601	0.139	-4.324	<0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.541	0.358	-1.512	0.131
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.456	0.151	-3.023	0.003
Overdispersion parameter = 1.207, 2 x LL = -35867.715				

Table 23. SPF developed for hit fixed object crash frequency on urban curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-4.130	0.270	-15.307	<0.001
Natural logarithm of AADT	0.426	0.018	23.437	<0.001
Natural logarithm of length	0.827	0.023	36.760	<0.001
Degree of Curvature	0.022	0.001	21.131	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.050	0.028	1.826	0.068
Indicator variable for no shoulder exist (1 indicates no shoulder, 0 indicates has shoulder)	0.073	0.036	2.036	0.042
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.620	0.037	16.961	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.609	0.034	17.707	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.347	0.031	11.142	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.196	0.041	4.753	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.120	0.059	2.039	0.041
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.068	0.060	1.137	0.255
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.099	0.059	1.668	0.095
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.236	0.065	-3.655	<0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.110	0.061	1.793	0.073
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.038	0.061	0.623	0.533
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.077	0.060	1.284	0.199
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.052	0.061	0.842	0.400
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.056	0.062	0.900	0.368
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.208	0.065	-3.221	0.001
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.066	0.063	-1.046	0.296
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.476	0.285	-1.671	0.095
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.501	0.222	-2.260	0.024
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.011	0.198	0.054	0.957
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.128	0.197	-0.648	0.517
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.062	0.198	0.315	0.753
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.267	0.206	-1.300	0.194
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.622	0.213	-2.914	0.004
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.659	0.208	-3.176	0.001
Indicator for Engineering District 12	-0.468	0.207	-2.262	0.024

(1 indicates yes, 0 indicates no)				
Overdispersion parameter = 1.207, 2 x LL = -44047.139				

Table 24. SPF developed for hit fixed object crash frequency on rural curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-5.021	0.217	-23.092	<0.001
Natural logarithm of AADT	0.567	0.017	34.204	<0.001
Natural logarithm of length	0.877	0.028	31.655	<0.001
Degree of Curvature	0.025	0.001	19.861	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.139	0.047	2.982	0.003
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.758	0.033	22.630	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.404	0.038	10.706	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.213	0.037	5.711	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.076	0.050	1.524	0.128
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.099	0.069	1.432	0.152
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.119	0.070	1.701	0.089
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.126	0.069	1.819	0.069
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.307	0.077	-3.998	<0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.100	0.073	1.379	0.168
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.077	0.070	1.105	0.269
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.019	0.072	-0.262	0.793
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.054	0.072	0.755	0.450
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.058	0.073	0.793	0.428
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.069	0.074	-0.937	0.349
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.213	0.077	-2.778	0.005
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.449	0.185	-2.432	0.015
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.265	0.159	-1.662	0.097
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.120	0.143	-0.837	0.403
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.100	0.149	-0.673	0.501
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.044	0.142	-0.310	0.757
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.487	0.144	-3.391	0.001
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.599	0.146	-4.103	<0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.807	0.418	-1.931	0.053
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.472	0.159	-2.978	0.003
Overdispersion parameter = 1.242, 2 x LL = -32772.721				

Table 25. SPF developed for wet road crash frequency on urban curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-6.225	0.323	-19.267	<0.001
Natural logarithm of AADT	0.627	0.023	27.821	<0.001
Natural logarithm of length	0.826	0.025	32.421	<0.001
Degree of Curvature	0.024	0.001	20.466	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.051	0.032	1.616	0.106
Indicator variable for no shoulder exist (1 indicates no shoulder, 0 indicates has shoulder)	0.074	0.041	1.808	0.071
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.150	0.032	4.742	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.635	0.043	14.694	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.609	0.041	15.005	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.213	0.035	6.159	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.260	0.048	5.399	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.269	0.068	3.962	<0.001
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.092	0.070	1.308	0.191
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.134	0.070	1.924	0.054
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.101	0.074	-1.363	0.173
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.328	0.070	4.696	<0.001
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.098	0.071	1.372	0.170
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.190	0.070	2.724	0.006
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.370	0.069	5.391	<0.001
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.133	0.072	1.832	0.067
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.092	0.075	-1.237	0.216
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.150	0.076	-1.958	0.050
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.685	0.353	-1.940	0.052
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.788	0.264	-2.989	0.003
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.012	0.230	-0.054	0.957
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.095	0.228	-0.418	0.676
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.154	0.229	0.672	0.501
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.203	0.238	-0.852	0.394
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.563	0.247	-2.280	0.023
Indicator for Engineering District 11	-0.649	0.240	-2.705	0.007

(1 indicates yes, 0 indicates no)				
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.659	0.242	-2.721	0.007
Overdispersion parameter = 1.996, 2 x LL = -37877.664				

Table 26. SPF developed for wet road crash frequency on rural curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-6.193	0.272	-22.802	<0.001
Natural logarithm of AADT	0.670	0.021	31.851	<0.001
Natural logarithm of length	0.932	0.035	26.876	<0.001
Degree of Curvature	0.028	0.002	17.954	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.179	0.059	3.015	0.003
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.810	0.042	19.497	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.495	0.047	10.523	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.148	0.046	3.252	0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.091	0.062	1.467	0.142
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.232	0.089	2.618	0.009
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.210	0.090	2.339	0.019
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.298	0.088	3.390	0.001
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.068	0.095	-0.715	0.475
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.305	0.092	3.333	0.001
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.231	0.090	2.579	0.010
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.186	0.091	2.041	0.041
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.361	0.089	4.032	<0.001
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.197	0.093	2.109	0.035
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.065	0.096	-0.673	0.501
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.247	0.101	-2.432	0.015
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.530	0.226	-2.351	0.019
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.702	0.201	-3.494	<0.001
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.290	0.174	-1.671	0.095
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.160	0.180	-0.886	0.376
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.070	0.173	-0.407	0.684
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.504	0.174	-2.894	0.004
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.669	0.177	-3.774	<0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.383	0.432	-0.886	0.375
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.872	0.199	-4.380	<0.001
Overdispersion parameter = 2.229, 2 x LL = -24489.485				

Table 27. SPF developed for head on crash frequency on urban curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-11.430	1.125	-10.158	<0.001
Natural logarithm of AADT	0.882	0.051	17.150	<0.001
Natural logarithm of length	0.757	0.052	14.445	<0.001
Degree of Curvature	0.023	0.003	8.500	<0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.145	0.068	2.137	0.033
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.369	0.096	3.820	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.497	0.091	5.438	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.436	0.096	4.524	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	-0.105	0.137	-0.763	0.446
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.492	0.152	-3.233	0.001
Indicator for year 2013 (1 indicates yes, 0 indicates no)	-0.255	0.143	-1.777	0.076
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.628	0.162	-3.863	<0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	-0.023	0.141	-0.164	0.870
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.277	0.147	-1.884	0.060
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.041	0.135	0.300	0.764
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.135	0.134	1.007	0.314
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.126	0.145	-0.865	0.387
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.162	0.144	-1.126	0.260
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.207	0.148	-1.399	0.162
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	0.697	1.236	0.564	0.573
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	1.240	1.035	1.198	0.231
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	1.727	1.007	1.715	0.086
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	1.413	1.006	1.405	0.160
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	1.536	1.007	1.525	0.127
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	0.895	1.027	0.872	0.383
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	1.135	1.026	1.107	0.268
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	1.417	1.013	1.398	0.162
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	1.051	1.022	1.028	0.304
Overdispersion parameter = 2.173, 2 x LL = -10455.106				

Table 28. SPF developed for head on crash frequency on rural curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-11.736	0.928	-12.640	<0.001
Natural logarithm of AADT	0.993	0.060	16.425	<0.001
Natural logarithm of length	0.969	0.091	10.605	<0.001
Degree of Curvature	0.033	0.004	8.193	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.262	0.114	2.291	0.022
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.586	0.127	4.630	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.239	0.119	2.018	0.044
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.317	0.229	1.387	0.166
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.019	0.250	-0.075	0.940
Indicator for year 2013 (1 indicates yes, 0 indicates no)	-0.056	0.252	-0.221	0.825
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.377	0.277	-1.359	0.174
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.449	0.232	1.936	0.053
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.179	0.261	-0.685	0.493
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.391	0.230	1.697	0.090
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.531	0.226	2.356	0.019
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.117	0.265	-0.440	0.660
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.074	0.256	-0.289	0.773
Indicator for year 2021 (1 indicates yes, 0 indicates no)	0.290	0.237	1.224	0.221
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.115	0.925	-0.125	0.901
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	0.172	0.786	0.219	0.827
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.781	0.723	1.079	0.281
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.852	0.732	1.163	0.245
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.945	0.721	1.310	0.190
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	0.473	0.728	0.651	0.515
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	0.476	0.729	0.653	0.514
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	0.650	1.279	0.508	0.611
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	0.848	0.750	1.131	0.258
Overdispersion parameter = 1.772, 2 x LL = -4418.707				

Table 29. SPF developed for sideswipe crash frequency on urban curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-9.419	0.833	-11.306	<0.001
Natural logarithm of AADT	0.810	0.067	12.097	<0.001
Natural logarithm of length	0.872	0.071	12.299	<0.001
Degree of Curvature	0.033	0.003	11.966	<0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.283	0.087	3.243	0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.334	0.125	2.675	0.007
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.497	0.112	4.432	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.253	0.095	2.666	0.008
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.010	0.195	0.049	0.961
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.100	0.200	-0.497	0.619
Indicator for year 2013 (1 indicates yes, 0 indicates no)	-0.128	0.203	-0.632	0.528
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.078	0.203	-0.384	0.701
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.433	0.185	2.340	0.019
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.015	0.200	-0.076	0.939
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.026	0.198	0.131	0.896
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.342	0.187	1.832	0.067
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.044	0.207	-0.211	0.833
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.021	0.202	-0.104	0.917
Indicator for year 2021 (1 indicates yes, 0 indicates no)	0.117	0.198	0.591	0.555
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.057	0.682	-0.084	0.933
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.816	0.567	-1.439	0.150
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.533	0.490	-1.088	0.277
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.721	0.486	-1.484	0.138
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.610	0.490	-1.245	0.213
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.763	0.524	-1.456	0.145
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-1.105	0.557	-1.985	0.047
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.768	0.509	-1.508	0.132
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-1.163	0.540	-2.153	0.031
Overdispersion parameter = 3.986, 2 x LL = -6694.870				

Table 30. SPF developed for sideswipe crash frequency on rural curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-10.716	0.920	-11.651	<0.001
Natural logarithm of AADT	0.939	0.077	12.146	<0.001
Natural logarithm of length	0.984	0.119	8.267	<0.001
Degree of Curvature	0.039	0.005	8.443	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.781	0.137	5.707	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.766	0.150	5.090	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.270	0.160	1.688	0.091
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.297	0.181	1.642	0.101
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.042	0.294	0.143	0.886
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.504	0.343	-1.472	0.141
Indicator for year 2013 (1 indicates yes, 0 indicates no)	-0.281	0.322	-0.874	0.382
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.173	0.289	0.598	0.550
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.223	0.293	0.759	0.448
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.239	0.284	0.840	0.401
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.167	0.292	0.571	0.568
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.043	0.303	0.142	0.888
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.219	0.293	0.750	0.454
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.104	0.310	-0.336	0.737
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.172	0.319	-0.540	0.589
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-1.163	0.790	-1.472	0.141
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-1.194	0.652	-1.832	0.067
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.482	0.537	-0.899	0.369
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.341	0.558	-0.611	0.541
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.194	0.532	-0.364	0.716
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-1.086	0.552	-1.969	0.049
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-1.123	0.562	-1.997	0.046
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	1.498	0.739	2.027	0.043
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.708	0.598	-1.184	0.236
Overdispersion parameter = 3.115, 2 x LL = -2988.510				

Table 31. SPF developed for run-off-road fatal + injury crash frequency on urban curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-4.383	0.348	-12.604	<0.001
Natural logarithm of AADT	0.408	0.024	16.724	<0.001
Natural logarithm of length	0.796	0.030	26.668	<0.001
Degree of Curvature	0.020	0.001	14.007	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.562	0.048	11.660	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.486	0.047	10.387	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.311	0.042	7.484	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.134	0.056	2.387	0.017
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.045	0.075	0.593	0.553
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.010	0.076	-0.127	0.899
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.001	0.076	0.011	0.992
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.372	0.085	-4.380	<0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.032	0.079	0.409	0.682
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.151	0.080	-1.892	0.058
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.108	0.079	-1.369	0.171
Indicator for year 2018 (1 indicates yes, 0 indicates no)	-0.215	0.083	-2.596	0.009
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.232	0.084	-2.759	0.006
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.317	0.084	-3.765	<0.001
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.216	0.083	-2.604	0.009
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.675	0.381	-1.772	0.076
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.497	0.278	-1.789	0.074
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.081	0.247	-0.329	0.742
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.259	0.245	-1.054	0.292
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.114	0.247	-0.461	0.645
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.427	0.259	-1.652	0.099
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.515	0.265	-1.940	0.052
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.562	0.259	-2.173	0.030
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.398	0.258	-1.545	0.122
Overdispersion parameter = 0.978, 2 x LL = -26971.051				

Table 32. SPF developed for run-off-road fatal + injury crash frequency on urban curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-5.115	0.277	-18.481	<0.001
Natural logarithm of AADT	0.524	0.021	24.500	<0.001
Natural logarithm of length	0.855	0.036	23.804	<0.001
Degree of Curvature	0.021	0.002	12.280	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.141	0.061	2.318	0.020
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.749	0.043	17.458	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.497	0.048	10.296	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.192	0.047	4.064	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.032	0.085	0.376	0.707
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.018	0.086	-0.212	0.832
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.036	0.085	0.424	0.672
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.432	0.096	-4.485	<0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	-0.107	0.092	-1.166	0.244
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.096	0.088	-1.097	0.273
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.143	0.090	-1.588	0.112
Indicator for year 2018 (1 indicates yes, 0 indicates no)	-0.265	0.094	-2.818	0.005
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.209	0.094	-2.231	0.026
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.239	0.093	-2.577	0.010
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.472	0.100	-4.736	<0.001
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.485	0.232	-2.089	0.037
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.254	0.199	-1.274	0.203
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.128	0.179	-0.715	0.475
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.189	0.188	-1.007	0.314
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.074	0.178	-0.414	0.679
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.567	0.180	-3.143	0.002
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.647	0.184	-3.527	<0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.557	0.490	-1.138	0.255
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.460	0.199	-2.312	0.021
Overdispersion parameter = 1.052, 2 x LL = -21234.216				

Table 33. SPF developed for hit fixed object fatal + injury crash frequency on urban curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-4.610	0.367	-12.562	<0.001
Natural logarithm of AADT	0.421	0.026	15.957	<0.001
Natural logarithm of length	0.803	0.032	24.994	<0.001
Degree of Curvature	0.020	0.002	13.157	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.580	0.052	11.238	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.481	0.050	9.590	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.360	0.045	8.011	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.102	0.061	1.680	0.093
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.081	0.082	0.988	0.323
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.044	0.082	0.537	0.591
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.066	0.082	0.804	0.422
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.310	0.091	-3.394	0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.096	0.085	1.133	0.257
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.114	0.087	-1.314	0.189
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.051	0.085	-0.598	0.550
Indicator for year 2018 (1 indicates yes, 0 indicates no)	-0.186	0.090	-2.065	0.039
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.213	0.092	-2.330	0.020
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.328	0.093	-3.542	<0.001
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.191	0.090	-2.116	0.034
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.703	0.395	-1.783	0.075
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.632	0.289	-2.186	0.029
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.189	0.254	-0.743	0.457
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.340	0.252	-1.348	0.178
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.213	0.254	-0.837	0.403
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.474	0.267	-1.778	0.075
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.528	0.273	-1.935	0.053
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.689	0.267	-2.578	0.010
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.538	0.267	-2.017	0.044
Overdispersion parameter = 1.003, 2 x LL = -24053.547				

Table 34. SPF developed for hit fixed object fatal + injury crash frequency on rural curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-5.398	0.296	-18.227	<0.001
Natural logarithm of AADT	0.544	0.023	23.193	<0.001
Natural logarithm of length	0.837	0.038	21.746	<0.001
Degree of Curvature	0.020	0.002	10.469	<0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	-0.097	0.044	-2.185	0.029
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.723	0.046	15.706	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.428	0.053	8.127	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.219	0.051	4.293	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.104	0.092	1.131	0.258
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.012	0.094	0.124	0.902
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.068	0.093	0.732	0.464
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.396	0.105	-3.764	<0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	-0.025	0.099	-0.249	0.803
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.060	0.096	-0.628	0.530
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.078	0.098	-0.794	0.427
Indicator for year 2018 (1 indicates yes, 0 indicates no)	-0.171	0.101	-1.692	0.091
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.122	0.101	-1.206	0.228
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.170	0.100	-1.696	0.090
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.379	0.107	-3.534	<0.001
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.409	0.250	-1.636	0.102
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.197	0.214	-0.921	0.357
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.082	0.194	-0.420	0.674
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.138	0.203	-0.681	0.496
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.073	0.193	-0.378	0.706
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.491	0.196	-2.511	0.012
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.591	0.199	-2.973	0.003
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.850	0.614	-1.385	0.166
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.413	0.215	-1.920	0.055
Overdispersion parameter = 0.953, 2 x LL = -18716.559				

Table 35. SPF developed for wet road fatal + injury crash frequency on urban curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-7.643	0.486	-15.734	<0.001
Natural logarithm of AADT	0.681	0.034	20.032	<0.001
Natural logarithm of length	0.786	0.037	21.431	<0.001
Degree of Curvature	0.023	0.002	13.214	<0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.200	0.046	4.353	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.570	0.063	9.045	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.487	0.061	8.012	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.179	0.050	3.566	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.202	0.072	2.819	0.005
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.243	0.095	2.557	0.011
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.040	0.099	0.404	0.687
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.027	0.100	0.266	0.790
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.186	0.106	-1.751	0.080
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.314	0.097	3.225	0.001
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.004	0.102	0.039	0.969
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.046	0.101	0.459	0.646
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.276	0.097	2.833	0.005
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.151	0.109	-1.389	0.165
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.336	0.112	-3.005	0.003
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.404	0.116	-3.492	<0.001
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-1.062	0.627	-1.694	0.090
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.585	0.394	-1.485	0.137
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.159	0.346	0.459	0.646
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.057	0.344	0.165	0.869
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.234	0.345	0.678	0.498
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.140	0.360	-0.388	0.698
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.223	0.367	-0.608	0.543
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.354	0.358	-0.987	0.323
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.354	0.362	-0.977	0.329

Overdispersion parameter = 2.224, 2 x LL = -19856.303

Table 36. SPF developed for wet road fatal + injury crash frequency on rural curve sections

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-6.832	0.376	-18.171	<0.001
Natural logarithm of AADT	0.689	0.031	22.523	<0.001
Natural logarithm of length	0.913	0.051	18.073	<0.001
Degree of Curvature	0.023	0.002	9.155	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.758	0.060	12.640	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.549	0.069	7.934	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.232	0.123	1.891	0.059
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.127	0.126	1.003	0.316
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.191	0.124	1.538	0.124
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.195	0.137	-1.424	0.154
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.141	0.131	1.080	0.280
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.101	0.127	0.797	0.426
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.071	0.130	0.548	0.583
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.080	0.131	0.611	0.541
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.086	0.137	-0.626	0.531
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.233	0.140	-1.668	0.095
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.459	0.150	-3.059	0.002
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.336	0.314	-1.070	0.285
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.676	0.288	-2.344	0.019
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.250	0.250	-0.999	0.318
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.141	0.260	-0.541	0.589
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.105	0.249	-0.424	0.672
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.479	0.251	-1.904	0.057
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.543	0.255	-2.132	0.033
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.351	0.651	-0.539	0.590
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.855	0.289	-2.957	0.003
Overdispersion parameter = 2.275, 2 x LL = -12601.706				

APPENDIX C: SUMMARY OF SPFS DEVELOPED FOR CURVE SECTIONS AND ADJACENT

TANGENTS ON TWO-LANE DIVIDED ROADS

Table 37. SPF developed for total crash frequency on urban curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-6.809	0.146	-46.714	<0.001
Natural logarithm of AADT	0.801	0.010	82.220	<0.001
Natural logarithm of length	0.295	0.010	28.277	<0.001
Degree of Curvature	0.010	0.001	18.275	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	-0.037	0.014	-2.710	0.007
Indicator variable for no shoulder exist (1 indicates no shoulder, 0 indicates has shoulder)	0.131	0.017	7.640	<0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.082	0.014	5.892	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.348	0.021	16.252	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.195	0.020	9.594	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.119	0.023	5.151	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.094	0.029	3.200	0.001
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.005	0.030	0.170	0.865
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.023	0.030	0.773	0.439
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.012	0.030	0.410	0.682
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.056	0.031	1.812	0.070
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.086	0.030	2.891	0.004
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.090	0.030	3.004	0.003
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.052	0.031	1.701	0.089
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.037	0.031	1.197	0.231
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.208	0.032	-6.593	<0.001
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.061	0.031	-1.965	0.049
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.394	0.176	-2.240	0.025
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.235	0.123	-1.911	0.056
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.246	0.111	2.211	0.027
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.015	0.111	0.139	0.889
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.159	0.111	1.425	0.154
Indicator for Engineering District 9	-0.090	0.116	-0.779	0.436

Variable	Coefficient	Standard Error	t-statistic	P-value
(1 indicates yes, 0 indicates no)				
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.264	0.118	-2.245	0.025
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.180	0.115	-1.558	0.119
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.274	0.117	-2.343	0.019
Overdispersion parameter = 0.827, 2 x LL = -131672.249				

Table 38. SPF developed for total crash frequency on rural curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-6.211	0.135	-45.983	<0.001
Natural logarithm of AADT	0.732	0.010	71.494	<0.001
Natural logarithm of length	0.380	0.016	24.332	<0.001
Degree of Curvature	0.015	0.001	19.481	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.083	0.028	2.977	0.003
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.083	0.019	4.356	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.562	0.021	26.836	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.265	0.024	11.005	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.105	0.022	4.806	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.081	0.031	2.614	0.009
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.094	0.042	2.217	0.027
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.098	0.043	2.282	0.023
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.069	0.043	1.607	0.108
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.072	0.043	1.672	0.095
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.087	0.045	1.942	0.052
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.104	0.043	2.437	0.015
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.013	0.044	0.298	0.765
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.078	0.044	1.776	0.076
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.024	0.045	0.534	0.593
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.081	0.045	-1.798	0.072
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.136	0.046	-2.949	0.003
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.359	0.119	-3.008	0.003
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.363	0.102	-3.563	<0.001
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.016	0.090	-0.175	0.861
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.042	0.092	-0.454	0.650
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.001	0.089	-0.011	0.991
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.338	0.090	-3.749	<0.001
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.499	0.092	-5.447	<0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.174	0.203	-0.855	0.393

Variable	Coefficient	Standard Error	t-statistic	P-value
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.358	0.099	-3.597	<0.001
Overdispersion parameter = 0.729, 2 x LL = -68417.188				

Table 39. SPF developed for fatal + injury crash frequency on urban curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-7.905	0.192	-41.272	<0.001
Natural logarithm of AADT	0.854	0.013	64.902	<0.001
Natural logarithm of length	0.273	0.013	20.307	<0.001
Degree of Curvature	0.009	0.001	12.434	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	-0.098	0.018	-5.464	<0.001
Indicator variable for no shoulder exist (1 indicates no shoulder, 0 indicates has shoulder)	0.156	0.022	7.066	<0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.064	0.018	3.564	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.303	0.028	10.802	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.091	0.027	3.347	0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.111	0.030	3.659	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.026	0.037	0.702	0.483
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.030	0.037	-0.793	0.428
Indicator for year 2013 (1 indicates yes, 0 indicates no)	-0.024	0.038	-0.639	0.523
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.052	0.038	-1.371	0.170
Indicator for year 2015 (1 indicates yes, 0 indicates no)	-0.018	0.039	-0.458	0.647
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.022	0.038	-0.573	0.566
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.023	0.038	0.614	0.539
Indicator for year 2018 (1 indicates yes, 0 indicates no)	-0.103	0.039	-2.605	0.009
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.107	0.040	-2.679	0.007
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.323	0.041	-7.880	<0.001
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.221	0.041	-5.430	<0.001
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.424	0.236	-1.800	0.072
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.244	0.159	-1.536	0.124
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.256	0.143	1.782	0.075
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.006	0.143	-0.041	0.967
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.080	0.144	0.556	0.578
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.144	0.150	-0.957	0.339
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.194	0.152	-1.276	0.202
Indicator for Engineering District 11	-0.167	0.149	-1.120	0.263

Variable	Coefficient	Standard Error	t-statistic	P-value
(1 indicates yes, 0 indicates no)				
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.207	0.151	-1.368	0.171
Overdispersion parameter = 0.911, 2 x LL = -87184.374				

Table 40. SPF developed for fatal + injury crash frequency on rural curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-6.474	0.171	-37.896	<0.001
Natural logarithm of AADT	0.722	0.014	52.651	<0.001
Natural logarithm of length	0.376	0.021	18.123	<0.001
Degree of Curvature	0.012	0.001	11.071	<0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.046	0.025	1.828	0.068
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.538	0.027	19.657	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.295	0.032	9.189	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.075	0.029	2.633	0.008
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.070	0.041	1.694	0.090
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.099	0.054	1.828	0.068
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.082	0.055	1.498	0.134
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.057	0.055	1.034	0.301
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.013	0.056	0.226	0.821
Indicator for year 2015 (1 indicates yes, 0 indicates no)	-0.029	0.059	-0.486	0.627
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.003	0.056	0.051	0.959
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.073	0.058	-1.260	0.208
Indicator for year 2018 (1 indicates yes, 0 indicates no)	-0.115	0.059	-1.953	0.051
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.112	0.060	-1.882	0.060
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.186	0.059	-3.126	0.002
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.320	0.062	-5.152	<0.001
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.538	0.152	-3.531	<0.001
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.429	0.126	-3.412	0.001
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.164	0.110	-1.485	0.138
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.239	0.114	-2.093	0.036
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.191	0.110	-1.738	0.082
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.504	0.111	-4.531	<0.001
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.643	0.113	-5.680	<0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.515	0.290	-1.774	0.076
Indicator for Engineering District 12	-0.462	0.124	-3.727	<0.001

(1 indicates yes, 0 indicates no)				
Overdispersion parameter = 0.670, 2 x LL = -43351.261				

Table 41. SPF developed for PDO crash frequency on urban curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-7.138	0.185	-38.675	<0.001
Natural logarithm of AADT	0.751	0.012	61.155	<0.001
Natural logarithm of length	0.318	0.013	24.333	<0.001
Degree of Curvature	0.011	0.001	15.584	<0.001
Indicator variable for no shoulder exist (1 indicates no shoulder, 0 indicates has shoulder)	0.111	0.021	5.352	<0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.095	0.017	5.464	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.369	0.026	13.992	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.266	0.025	10.607	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.133	0.029	4.674	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.156	0.037	4.187	<0.001
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.040	0.038	1.050	0.294
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.065	0.038	1.705	0.088
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.083	0.038	2.153	0.031
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.131	0.039	3.338	0.001
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.191	0.038	5.067	<0.001
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.157	0.038	4.147	<0.001
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.197	0.038	5.138	<0.001
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.177	0.039	4.539	<0.001
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.088	0.040	-2.199	0.028
Indicator for year 2021 (1 indicates yes, 0 indicates no)	0.096	0.039	2.448	0.014
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.347	0.222	-1.567	0.117
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.206	0.157	-1.317	0.188
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.265	0.142	1.873	0.061
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.069	0.141	0.491	0.623
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.255	0.142	1.797	0.072
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.005	0.147	-0.034	0.973
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.281	0.150	-1.869	0.062
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.141	0.147	-0.963	0.335
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.294	0.149	-1.970	0.049

Overdispersion parameter = 0.876, 2 x LL = -91110.927

Table 42. SPF developed for PDO crash frequency on rural curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-7.257	0.190	-38.109	<0.001
Natural logarithm of AADT	0.727	0.014	52.969	<0.001
Natural logarithm of length	0.378	0.021	18.132	<0.001
Degree of Curvature	0.017	0.001	17.302	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.129	0.038	3.425	0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.098	0.025	3.842	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.564	0.028	20.356	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.235	0.032	7.328	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.123	0.029	4.226	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.091	0.041	2.213	0.027
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.082	0.058	1.397	0.163
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.111	0.059	1.883	0.060
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.082	0.059	1.394	0.163
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.130	0.059	2.210	0.027
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.201	0.060	3.347	0.001
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.197	0.058	3.427	0.001
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.093	0.060	1.557	0.120
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.257	0.058	4.398	<0.001
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.154	0.060	2.548	0.011
Indicator for year 2020 (1 indicates yes, 0 indicates no)	0.020	0.061	0.322	0.747
Indicator for year 2021 (1 indicates yes, 0 indicates no)	0.036	0.061	0.587	0.557
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.137	0.170	-0.802	0.423
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.249	0.149	-1.666	0.096
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.213	0.133	1.605	0.108
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.222	0.135	1.637	0.102
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.264	0.132	2.003	0.045
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.089	0.133	-0.670	0.503
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.267	0.135	-1.979	0.048
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	0.193	0.267	0.725	0.468

Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.180	0.145	-1.241	0.215
Overdispersion parameter = 0.9147, 2 x LL = -44777.293				

Table 43. SPF developed for run-off-road crash frequency on urban curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-4.550	0.185	-24.579	<0.001
Natural logarithm of AADT	0.438	0.012	35.861	<0.001
Natural logarithm of length	0.307	0.014	21.672	<0.001
Degree of Curvature	0.012	0.001	17.475	<0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.116	0.018	6.416	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.594	0.026	23.154	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.401	0.024	16.525	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.298	0.020	14.848	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.107	0.029	3.656	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.147	0.039	3.817	<0.001
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.029	0.039	0.746	0.455
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.033	0.040	0.824	0.410
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.001	0.040	-0.028	0.978
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.008	0.041	0.196	0.845
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.003	0.040	-0.077	0.939
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.031	0.040	0.785	0.432
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.020	0.041	0.485	0.628
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.007	0.041	0.165	0.869
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.203	0.042	-4.788	<0.001
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.076	0.042	-1.827	0.068
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.527	0.212	-2.483	0.013
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.464	0.155	-2.992	0.003
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.067	0.139	0.481	0.630
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.098	0.138	-0.707	0.479
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.033	0.139	0.239	0.811
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.192	0.144	-1.337	0.181
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.659	0.149	-4.409	<0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.444	0.145	-3.072	0.002
Indicator for Engineering District 12	-0.426	0.145	-2.931	0.003

(1 indicates yes, 0 indicates no)				
Overdispersion parameter = 0.857, 2 x LL = -82444.671				

Table 44. SPF developed for run-off-road crash frequency on rural curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-5.228	0.153	-34.104	<0.001
Natural logarithm of AADT	0.561	0.012	48.315	<0.001
Natural logarithm of length	0.402	0.018	21.827	<0.001
Degree of Curvature	0.016	0.001	17.994	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.093	0.032	2.898	0.004
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.108	0.022	4.903	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.738	0.024	30.705	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.313	0.027	11.574	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.228	0.026	8.904	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.077	0.049	1.568	0.117
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.135	0.049	2.751	0.006
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.079	0.049	1.595	0.111
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.060	0.050	1.191	0.234
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.038	0.052	0.729	0.466
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.064	0.050	1.296	0.195
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.034	0.051	-0.659	0.510
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.027	0.051	0.533	0.594
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.015	0.052	0.280	0.779
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.083	0.052	-1.594	0.111
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.181	0.054	-3.365	0.001
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.412	0.133	-3.097	0.002
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.433	0.115	-3.777	<0.001
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.099	0.101	-0.977	0.329
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.168	0.105	-1.604	0.109
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.102	0.101	-1.019	0.308
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.456	0.101	-4.499	<0.001
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.672	0.104	-6.491	<0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.569	0.258	-2.207	0.027
Indicator for Engineering District 12	-0.505	0.113	-4.481	<0.001

(1 indicates yes, 0 indicates no)				
Overdispersion parameter = 0.908, 2 x LL = -56340.978				

Table 45. SPF developed for hit fixed object crash frequency on urban curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-4.587	0.198	-23.189	<0.001
Natural logarithm of AADT	0.414	0.013	32.661	<0.001
Natural logarithm of length	0.298	0.015	19.737	<0.001
Degree of Curvature	0.012	0.001	16.464	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	-0.008	0.019	-0.431	0.666
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.621	0.027	22.952	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.424	0.026	16.594	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.347	0.021	16.221	<0.001
Indicator variable for sideroad warning exist (1 indicates no shoulder, 0 indicates has shoulder)	0.080	0.031	2.596	0.009
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.168	0.041	4.092	<0.001
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.055	0.042	1.302	0.193
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.071	0.042	1.699	0.089
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.038	0.043	0.898	0.369
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.047	0.044	1.074	0.283
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.016	0.043	0.385	0.700
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.063	0.042	1.490	0.136
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.040	0.043	0.914	0.361
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.028	0.044	0.638	0.524
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.219	0.045	-4.821	<0.001
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.095	0.045	-2.117	0.034
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.384	0.223	-1.723	0.085
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.399	0.168	-2.378	0.017
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.140	0.151	0.928	0.353
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	<0.001	0.150	0.001	1.000
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.111	0.151	0.731	0.465
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.103	0.156	-0.659	0.510
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.605	0.162	-3.727	<0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.393	0.157	-2.499	0.012
Indicator for Engineering District 12	-0.392	0.158	-2.482	0.013

(1 indicates yes, 0 indicates no)				
Overdispersion parameter = 0.930, 2 x LL = -76169.266				

Table 46. SPF developed for hit fixed object crash frequency on rural curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-5.404	0.162	-33.374	<0.001
Natural logarithm of AADT	0.564	0.012	45.928	<0.001
Natural logarithm of length	0.400	0.019	20.567	<0.001
Degree of Curvature	0.015	0.001	16.712	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.092	0.034	2.729	0.006
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.098	0.023	4.221	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.738	0.025	29.204	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.285	0.029	9.944	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.245	0.027	9.042	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.092	0.052	1.764	0.078
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.141	0.052	2.711	0.007
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.092	0.052	1.758	0.079
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.073	0.053	1.378	0.168
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.061	0.055	1.099	0.272
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.069	0.053	1.308	0.191
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.019	0.054	-0.348	0.728
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.058	0.054	1.068	0.286
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.044	0.055	0.804	0.422
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.068	0.055	-1.225	0.221
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.157	0.057	-2.756	0.006
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.409	0.140	-2.915	0.004
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.441	0.121	-3.649	<0.001
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.091	0.106	-0.857	0.391
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.139	0.110	-1.261	0.207
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.117	0.106	-1.109	0.267
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.457	0.107	-4.274	<0.001
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.668	0.109	-6.124	<0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.613	0.278	-2.207	0.027
Indicator for Engineering District 12	-0.517	0.119	-4.345	<0.001

(1 indicates yes, 0 indicates no)				
Overdispersion parameter = 0.913, 2 x LL = -51690.736				

Table 47. SPF developed for wet road crash frequency on urban curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-6.794	0.223	-30.496	<0.001
Natural logarithm of AADT	0.651	0.015	42.290	<0.001
Natural logarithm of length	0.300	0.017	18.058	<0.001
Degree of Curvature	0.014	0.001	17.467	<0.001
Indicator variable for no shoulder exist (1 indicates no shoulder, 0 indicates has shoulder)	0.055	0.026	2.099	0.036
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.219	0.021	10.276	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.593	0.031	18.974	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.391	0.030	13.245	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.220	0.023	9.482	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.116	0.035	3.280	0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.312	0.046	6.780	<0.001
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.097	0.048	2.039	0.041
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.155	0.047	3.263	0.001
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.200	0.048	4.216	<0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.192	0.049	3.920	<0.001
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.063	0.049	1.291	0.197
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.163	0.048	3.400	0.001
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.277	0.048	5.803	<0.001
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.132	0.050	2.674	0.007
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.121	0.051	-2.366	0.018
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.151	0.052	-2.900	0.004
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.900	0.276	-3.266	0.001
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.821	0.186	-4.424	<0.001
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.006	0.161	-0.036	0.971
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.151	0.161	-0.941	0.347
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.034	0.161	0.211	0.833
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.174	0.168	-1.039	0.299
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.695	0.174	-3.985	<0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.536	0.168	-3.183	0.001

Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.744	0.172	-4.333	<0.001
Overdispersion parameter = 1.354, 2 x LL = -68703.625				

Table 48. SPF developed for wet road crash frequency on rural curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-6.676	0.205	-32.495	<0.001
Natural logarithm of AADT	0.676	0.016	42.708	<0.001
Natural logarithm of length	0.441	0.025	17.968	<0.001
Degree of Curvature	0.016	0.001	13.830	<0.001
Indicator for posted speed limit of greater than or equal to 40 mph (1 indicates yes, 0 indicates no)	0.130	0.044	2.982	0.003
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.094	0.029	3.196	0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.791	0.032	24.949	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.348	0.036	9.549	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.197	0.034	5.873	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.220	0.068	3.253	0.001
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.219	0.068	3.210	0.001
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.263	0.067	3.915	<0.001
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.257	0.068	3.778	<0.001
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.252	0.071	3.576	<0.001
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.238	0.068	3.503	<0.001
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.130	0.070	1.848	0.065
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.397	0.068	5.867	<0.001
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.166	0.071	2.327	0.020
Indicator for year 2020 (1 indicates yes, 0 indicates no)	0.005	0.072	0.069	0.945
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.168	0.076	-2.226	0.026
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.486	0.175	-2.784	0.005
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.744	0.154	-4.848	<0.001
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.246	0.132	-1.867	0.062
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.228	0.136	-1.674	0.094
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.169	0.131	-1.295	0.195
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.437	0.132	-3.321	0.001
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.695	0.135	-5.166	<0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.328	0.312	-1.050	0.294
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.910	0.152	-5.986	<0.001

Overdispersion parameter = 1.653, 2 x LL = -38575.925

Table 49. SPF developed for head on crash frequency on urban curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-11.107	0.540	-20.581	<0.001
Natural logarithm of AADT	0.922	0.035	26.471	<0.001
Natural logarithm of length	0.250	0.034	7.325	<0.001
Degree of Curvature	0.014	0.002	8.225	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.263	0.072	3.650	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.244	0.068	3.599	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.285	0.072	3.975	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	-0.053	0.096	-0.548	0.584
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.166	0.099	-1.686	0.092
Indicator for year 2013 (1 indicates yes, 0 indicates no)	-0.193	0.100	-1.930	0.054
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.087	0.099	-0.884	0.377
Indicator for year 2015 (1 indicates yes, 0 indicates no)	-0.067	0.102	-0.663	0.507
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.026	0.096	0.269	0.788
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.079	0.095	0.834	0.404
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.051	0.097	0.528	0.598
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.073	0.102	-0.711	0.477
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.130	0.101	-1.283	0.200
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.133	0.103	-1.293	0.196
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.919	0.832	-1.105	0.269
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	0.031	0.462	0.067	0.947
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.591	0.424	1.395	0.163
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.261	0.423	0.618	0.537
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.346	0.424	0.816	0.415
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.124	0.446	-0.279	0.780
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.056	0.447	-0.125	0.901
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	0.365	0.432	0.845	0.398
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.003	0.443	-0.007	0.994
Overdispersion parameter = 1.930, 2 x LL = -20091.017				

Table 50. SPF developed for head on crash frequency on rural curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-12.123	0.676	-17.945	<0.001
Natural logarithm of AADT	0.997	0.046	21.735	<0.001
Natural logarithm of length	0.434	0.065	6.652	<0.001
Degree of Curvature	0.021	0.003	6.640	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.247	0.088	2.786	0.005
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.426	0.101	4.215	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.209	0.089	2.343	0.019
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.224	0.181	1.237	0.216
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.088	0.198	-0.447	0.655
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.213	0.184	1.163	0.245
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.122	0.189	0.645	0.519
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.337	0.185	1.821	0.069
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.132	0.200	-0.662	0.508
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.152	0.188	0.808	0.419
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.543	0.175	3.108	0.002
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.017	0.199	0.086	0.932
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.041	0.198	-0.208	0.835
Indicator for year 2021 (1 indicates yes, 0 indicates no)	0.352	0.182	1.940	0.052
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.675	0.770	-0.877	0.380
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.054	0.568	-0.096	0.924
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.648	0.510	1.271	0.204
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.616	0.516	1.194	0.232
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.644	0.509	1.266	0.206
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	0.239	0.515	0.465	0.642
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	0.264	0.516	0.512	0.608
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	0.665	0.891	0.747	0.455
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	0.674	0.533	1.265	0.206
Overdispersion parameter = 1.107, 2 x LL = -6899.489				

Table 51. SPF developed for sideswipe crash frequency on urban curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-10.542	0.641	-16.448	<0.001
Natural logarithm of AADT	0.837	0.047	17.737	<0.001
Natural logarithm of length	0.384	0.047	8.107	<0.001
Degree of Curvature	0.022	0.002	10.335	<0.001
Indicator variable for no shoulder exist (1 indicates no shoulder, 0 indicates has shoulder)	0.155	0.072	2.142	0.032
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.353	0.060	5.887	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.297	0.093	3.197	0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.321	0.083	3.859	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.246	0.065	3.791	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.055	0.134	0.414	0.679
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.093	0.139	-0.669	0.504
Indicator for year 2013 (1 indicates yes, 0 indicates no)	-0.184	0.143	-1.286	0.198
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.228	0.131	1.736	0.083
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.200	0.136	1.477	0.140
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.097	0.135	0.716	0.474
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.121	0.134	0.899	0.369
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.127	0.136	0.935	0.350
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.062	0.145	-0.428	0.668
Indicator for year 2020 (1 indicates yes, 0 indicates no)	0.047	0.138	0.344	0.731
Indicator for year 2021 (1 indicates yes, 0 indicates no)	0.161	0.136	1.184	0.237
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.043	0.637	-0.068	0.946
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.646	0.496	-1.302	0.193
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.062	0.433	-0.144	0.886
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.247	0.431	-0.572	0.567
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.244	0.434	-0.562	0.574
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.473	0.460	-1.030	0.303
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.756	0.479	-1.581	0.114
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.161	0.444	-0.363	0.717
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.649	0.465	-1.395	0.163
Overdispersion parameter = 2.682, 2 x LL = -12429.627				

Table 52. SPF developed for sideswipe crash frequency on rural curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-11.584	0.719	-16.108	<0.001
Natural logarithm of AADT	0.973	0.058	16.855	<0.001
Natural logarithm of length	0.536	0.086	6.247	<0.001
Degree of Curvature	0.029	0.003	8.398	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.668	0.107	6.269	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.791	0.117	6.739	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.240	0.227	1.058	0.290
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.273	0.259	-1.052	0.293
Indicator for year 2013 (1 indicates yes, 0 indicates no)	-0.249	0.258	-0.965	0.335
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.372	0.224	1.662	0.097
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.137	0.242	0.566	0.572
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.483	0.218	2.215	0.027
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.121	0.238	0.508	0.612
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.180	0.236	0.761	0.447
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.239	0.235	1.016	0.309
Indicator for year 2020 (1 indicates yes, 0 indicates no)	0.173	0.235	0.735	0.462
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.096	0.252	-0.381	0.703
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-1.245	0.750	-1.661	0.097
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.825	0.558	-1.478	0.139
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.102	0.474	-0.215	0.830
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.055	0.483	0.113	0.910
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.120	0.470	0.256	0.798
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.748	0.484	-1.544	0.123
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.825	0.492	-1.675	0.094
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	1.276	0.696	1.833	0.067
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.473	0.522	-0.905	0.365
Overdispersion parameter = 2.587, 2 x LL = -4725.348				

Table 53. SPF developed for run-off-road fatal + injury crash frequency on urban curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-5.133	0.252	-20.342	<0.001
Natural logarithm of AADT	0.440	0.017	25.198	<0.001
Natural logarithm of length	0.297	0.020	14.909	<0.001
Degree of Curvature	0.011	0.001	10.824	<0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.084	0.026	3.270	0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.543	0.036	15.283	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.333	0.034	9.648	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.275	0.028	9.759	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.085	0.041	2.059	0.039
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.054	0.053	1.019	0.308
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.019	0.053	0.352	0.725
Indicator for year 2013 (1 indicates yes, 0 indicates no)	-0.019	0.054	-0.349	0.727
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.099	0.055	-1.781	0.075
Indicator for year 2015 (1 indicates yes, 0 indicates no)	-0.107	0.057	-1.859	0.063
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.115	0.056	-2.060	0.039
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.062	0.055	-1.129	0.259
Indicator for year 2018 (1 indicates yes, 0 indicates no)	-0.183	0.058	-3.168	0.002
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.215	0.059	-3.641	<0.001
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.315	0.059	-5.332	<0.001
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.228	0.059	-3.895	<0.001
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.631	0.293	-2.154	0.031
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.510	0.205	-2.484	0.013
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.030	0.182	-0.167	0.867
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.229	0.181	-1.264	0.206
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.170	0.182	-0.935	0.350
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.329	0.190	-1.728	0.084
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.624	0.197	-3.173	0.002
Indicator for Engineering District 11	-0.470	0.190	-2.472	0.013

(1 indicates yes, 0 indicates no)				
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.451	0.191	-2.361	0.018
Overdispersion parameter = 0.810, 2 x LL = -47855.745				

Table 54. SPF developed for run-off-road fatal + injury crash frequency on rural curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-5.359	0.195	-27.468	<0.001
Natural logarithm of AADT	0.532	0.016	33.668	<0.001
Natural logarithm of length	0.374	0.025	14.963	<0.001
Degree of Curvature	0.011	0.001	9.094	<0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.053	0.030	1.765	0.078
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.721	0.032	22.444	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.349	0.037	9.529	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.224	0.035	6.449	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.059	0.064	0.928	0.354
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.089	0.064	1.379	0.168
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.048	0.064	0.740	0.459
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.018	0.066	-0.268	0.789
Indicator for year 2015 (1 indicates yes, 0 indicates no)	-0.075	0.070	-1.083	0.279
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.056	0.066	-0.843	0.399
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.102	0.068	-1.506	0.132
Indicator for year 2018 (1 indicates yes, 0 indicates no)	-0.211	0.071	-2.985	0.003
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.111	0.070	-1.583	0.113
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.202	0.070	-2.879	0.004
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.409	0.075	-5.467	<0.001
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.565	0.167	-3.376	0.001
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.520	0.141	-3.693	<0.001
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.310	0.124	-2.507	0.012
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.416	0.129	-3.218	0.001
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.331	0.123	-2.691	0.007
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.674	0.124	-5.420	<0.001
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.847	0.128	-6.642	<0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-1.240	0.432	-2.871	0.004
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.668	0.140	-4.763	<0.001
Overdispersion parameter = 0.775, 2 x LL = -34213.302				

Table 55. SPF developed for hit fixed object fatal + injury crash frequency on urban curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-5.338	0.273	-19.554	<0.001
Natural logarithm of AADT	0.434	0.019	23.113	<0.001
Natural logarithm of length	0.298	0.022	13.832	<0.001
Degree of Curvature	0.011	0.001	10.384	<0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.076	0.028	2.774	0.006
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.560	0.038	14.670	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.343	0.037	9.312	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.333	0.030	11.089	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.090	0.057	1.578	0.115
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.062	0.058	1.076	0.282
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.042	0.058	0.729	0.466
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.051	0.060	-0.846	0.398
Indicator for year 2015 (1 indicates yes, 0 indicates no)	-0.033	0.062	-0.539	0.590
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.085	0.060	-1.406	0.160
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.023	0.060	-0.388	0.698
Indicator for year 2018 (1 indicates yes, 0 indicates no)	-0.148	0.063	-2.368	0.018
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.195	0.064	-3.044	0.002
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.318	0.065	-4.911	<0.001
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.235	0.064	-3.660	<0.001
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.503	0.307	-1.637	0.102
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.543	0.223	-2.431	0.015
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.020	0.197	-0.102	0.918
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.186	0.196	-0.948	0.343
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.143	0.198	-0.723	0.469
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.273	0.206	-1.325	0.185
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.562	0.213	-2.640	0.008
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.455	0.206	-2.211	0.027
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.464	0.208	-2.232	0.026
Overdispersion parameter = 0.869, 2 x LL = -42841.169				

Table 56. SPF developed for hit fixed object fatal + injury crash frequency on rural curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-5.624	0.209	-26.883	<0.001
Natural logarithm of AADT	0.544	0.017	32.201	<0.001
Natural logarithm of length	0.367	0.027	13.677	<0.001
Degree of Curvature	0.010	0.001	7.364	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.706	0.035	20.431	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.307	0.040	7.680	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.244	0.038	6.517	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.092	0.069	1.335	0.182
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.075	0.070	1.074	0.283
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.061	0.070	0.877	0.381
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.017	0.072	-0.239	0.811
Indicator for year 2015 (1 indicates yes, 0 indicates no)	-0.047	0.075	-0.621	0.535
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.051	0.072	-0.706	0.480
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.087	0.074	-1.185	0.236
Indicator for year 2018 (1 indicates yes, 0 indicates no)	-0.177	0.076	-2.313	0.021
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.066	0.075	-0.883	0.377
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.179	0.076	-2.369	0.018
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.361	0.080	-4.493	<0.001
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.541	0.180	-3.007	0.003
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.518	0.151	-3.425	0.001
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.292	0.132	-2.203	0.028
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.395	0.139	-2.853	0.004
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.348	0.132	-2.637	0.008
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.642	0.133	-4.811	<0.001
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.857	0.137	-6.251	<0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-1.469	0.522	-2.815	0.005
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.680	0.151	-4.495	<0.001
Overdispersion parameter = 0.773, 2 x LL = -30336.043				

Table 57. SPF developed for wet road fatal + injury crash frequency on urban curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-8.479	0.338	-25.118	<0.001
Natural logarithm of AADT	0.726	0.023	31.427	<0.001
Natural logarithm of length	0.275	0.024	11.574	<0.001
Degree of Curvature	0.013	0.001	10.651	<0.001
Indicator variable for no shoulder exist (1 indicates no shoulder, 0 indicates has shoulder)	0.109	0.037	2.920	0.004
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.256	0.031	8.350	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.538	0.045	11.947	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.295	0.044	6.746	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.167	0.033	5.049	<0.001
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.104	0.052	2.009	0.044
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.247	0.064	3.852	<0.001
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.072	0.066	1.083	0.279
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.087	0.067	1.306	0.191
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.091	0.067	1.358	0.174
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.125	0.069	1.823	0.068
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.008	0.069	-0.113	0.910
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.070	0.068	1.029	0.303
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.176	0.067	2.621	0.009
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.061	0.072	-0.856	0.392
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.294	0.074	-3.951	<0.001
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.357	0.077	-4.643	<0.001
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.717	0.427	-1.679	0.093
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.565	0.280	-2.019	0.044
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.222	0.246	0.901	0.367
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.053	0.245	0.218	0.828
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.175	0.246	0.710	0.478
Indicator for Engineering District 9	-0.052	0.257	-0.202	0.840

(1 indicates yes, 0 indicates no)				
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.328	0.263	-1.247	0.212
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.238	0.255	-0.933	0.351
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.364	0.260	-1.402	0.161
Overdispersion parameter = 1.560, 2 x LL = -37784.203				

Table 58. SPF developed for wet road fatal + injury crash frequency on rural curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-7.172	0.280	-25.570	<0.001
Natural logarithm of AADT	0.689	0.023	29.816	<0.001
Natural logarithm of length	0.402	0.036	11.258	<0.001
Degree of Curvature	0.010	0.002	5.209	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.754	0.046	16.560	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.394	0.054	7.310	<0.001
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.103	0.048	2.145	0.032
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.266	0.094	2.834	0.005
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.177	0.096	1.840	0.066
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.254	0.094	2.691	0.007
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.212	0.096	2.199	0.028
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.108	0.102	1.064	0.287
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.129	0.097	1.326	0.185
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.039	0.100	0.386	0.699
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.162	0.099	1.632	0.103
Indicator for year 2019 (1 indicates yes, 0 indicates no)	0.001	0.104	0.012	0.990
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.165	0.106	-1.558	0.119
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.483	0.117	-4.145	<0.001
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.596	0.234	-2.549	0.011
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.854	0.203	-4.202	<0.001
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.460	0.172	-2.672	0.008
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.452	0.180	-2.515	0.012
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.433	0.171	-2.529	0.011
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.629	0.173	-3.640	<0.001
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.818	0.177	-4.629	<0.001
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	-0.938	0.545	-1.721	0.085
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-1.126	0.207	-5.450	<0.001
Overdispersion parameter = 1.745, 2 x LL = -20279.735				

Table 59. SPF developed for head on fatal + injury crash frequency on urban curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-11.813	0.654	-18.075	<0.001
Natural logarithm of AADT	0.961	0.042	22.820	<0.001
Natural logarithm of length	0.288	0.040	7.194	<0.001
Degree of Curvature	0.014	0.002	6.729	<0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.287	0.053	5.395	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.204	0.085	2.393	0.017
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.220	0.080	2.751	0.006
Indicator variable for sideroad warning exist (1 indicates yes, 0 indicates no)	0.361	0.083	4.355	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	-0.120	0.112	-1.066	0.287
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.100	0.112	-0.891	0.373
Indicator for year 2013 (1 indicates yes, 0 indicates no)	-0.274	0.118	-2.323	0.020
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.120	0.115	-1.047	0.295
Indicator for year 2015 (1 indicates yes, 0 indicates no)	-0.100	0.118	-0.848	0.397
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.044	0.113	-0.391	0.696
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.082	0.109	0.747	0.455
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.015	0.113	0.134	0.894
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.150	0.120	-1.251	0.211
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.271	0.121	-2.231	0.026
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.191	0.121	-1.582	0.114
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.462	0.878	-0.527	0.599
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	0.010	0.557	0.018	0.986
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.635	0.511	1.243	0.214
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.319	0.510	0.625	0.532
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.359	0.512	0.702	0.482
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.095	0.537	-0.177	0.859
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.026	0.539	-0.047	0.962
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	0.312	0.520	0.599	0.549
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	0.202	0.530	0.381	0.703

Overdispersion parameter = 1.548, 2 x LL = -15130.591				

Table 60. SPF developed for head on fatal + injury crash frequency on rural curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-12.488	0.775	-16.113	<0.001
Natural logarithm of AADT	1.061	0.055	19.399	<0.001
Natural logarithm of length	0.570	0.077	7.408	<0.001
Degree of Curvature	0.021	0.004	5.076	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.370	0.101	3.673	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.398	0.122	3.268	0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.363	0.205	1.770	0.077
Indicator for year 2012 (1 indicates yes, 0 indicates no)	0.011	0.226	0.048	0.961
Indicator for year 2013 (1 indicates yes, 0 indicates no)	0.229	0.214	1.070	0.285
Indicator for year 2014 (1 indicates yes, 0 indicates no)	-0.081	0.232	-0.348	0.728
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.339	0.216	1.568	0.117
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.156	0.236	-0.661	0.508
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.148	0.220	0.671	0.502
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.450	0.207	2.170	0.030
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.063	0.238	-0.266	0.790
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.054	0.232	-0.234	0.815
Indicator for year 2021 (1 indicates yes, 0 indicates no)	0.402	0.210	1.920	0.055
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-0.841	0.917	-0.917	0.359
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	0.156	0.641	0.244	0.808
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.623	0.587	1.060	0.289
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.632	0.595	1.062	0.288
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.545	0.586	0.929	0.353
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	0.248	0.593	0.418	0.676
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	0.255	0.594	0.429	0.668
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	0.410	1.163	0.352	0.725
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	0.738	0.611	1.208	0.227
Overdispersion parameter = 0.708, 2 x LL = -5192.128				

Table 61. SPF developed for sideswipe fatal + injury crash frequency on urban curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-11.990	0.990	-12.110	<0.001
Natural logarithm of AADT	0.895	0.067	13.271	<0.001
Natural logarithm of length	0.412	0.064	6.417	<0.001
Degree of Curvature	0.021	0.003	7.027	<0.001
Indicator for adjacent curve within 250 ft exist (1 indicates yes, 0 indicates no)	0.401	0.083	4.827	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.299	0.131	2.281	0.023
Indicator variable for curve warning exist (1 indicates yes, 0 indicates no)	0.155	0.088	1.767	0.077
Indicator for year 2011 (1 indicates yes, 0 indicates no)	-0.042	0.192	-0.216	0.829
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.166	0.199	-0.835	0.404
Indicator for year 2013 (1 indicates yes, 0 indicates no)	-0.127	0.198	-0.642	0.521
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.364	0.179	2.030	0.042
Indicator for year 2015 (1 indicates yes, 0 indicates no)	0.404	0.182	2.220	0.026
Indicator for year 2016 (1 indicates yes, 0 indicates no)	-0.057	0.198	-0.290	0.772
Indicator for year 2017 (1 indicates yes, 0 indicates no)	0.167	0.187	0.893	0.372
Indicator for year 2018 (1 indicates yes, 0 indicates no)	0.030	0.196	0.155	0.877
Indicator for year 2019 (1 indicates yes, 0 indicates no)	-0.003	0.201	-0.013	0.990
Indicator for year 2020 (1 indicates yes, 0 indicates no)	0.167	0.189	0.886	0.375
Indicator for year 2021 (1 indicates yes, 0 indicates no)	0.310	0.185	1.673	0.094
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-18.530	5003.000	-0.004	0.997
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-0.407	0.819	-0.497	0.620
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	0.374	0.729	0.513	0.608
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	0.203	0.727	0.279	0.780
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	0.118	0.730	0.161	0.872
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-0.055	0.763	-0.072	0.943
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-0.170	0.774	-0.220	0.826
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	0.033	0.746	0.044	0.965
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.239	0.770	-0.310	0.756

Overdispersion parameter = 3.488, 2 x LL = -7205.076

Table 62. SPF developed for sideswipe fatal + injury crash frequency on rural curve sections and adjacent tangents

Variable	Coefficient	Standard Error	t-statistic	P-value
Constant	-11.770	0.890	-13.222	<0.001
Natural logarithm of AADT	1.019	0.078	13.128	<0.001
Natural logarithm of length	0.623	0.113	5.501	<0.001
Degree of Curvature	0.029	0.005	6.033	<0.001
Indicator variable for chevron mark exist (1 indicates yes, 0 indicates no)	0.707	0.138	5.126	<0.001
Indicator variable for arrow mark exist (1 indicates yes, 0 indicates no)	0.718	0.157	4.586	<0.001
Indicator for year 2011 (1 indicates yes, 0 indicates no)	0.256	0.270	0.947	0.344
Indicator for year 2012 (1 indicates yes, 0 indicates no)	-0.182	0.304	-0.599	0.549
Indicator for year 2013 (1 indicates yes, 0 indicates no)	-0.239	0.309	-0.774	0.439
Indicator for year 2014 (1 indicates yes, 0 indicates no)	0.116	0.284	0.409	0.683
Indicator for year 2015 (1 indicates yes, 0 indicates no)	-0.094	0.309	-0.303	0.762
Indicator for year 2016 (1 indicates yes, 0 indicates no)	0.347	0.269	1.292	0.196
Indicator for year 2017 (1 indicates yes, 0 indicates no)	-0.176	0.308	-0.571	0.568
Indicator for year 2018 (1 indicates yes, 0 indicates no)	-0.596	0.354	-1.684	0.092
Indicator for year 2019 (1 indicates yes, 0 indicates no)	<0.001	0.300	-0.001	1.000
Indicator for year 2020 (1 indicates yes, 0 indicates no)	-0.036	0.296	-0.121	0.904
Indicator for year 2021 (1 indicates yes, 0 indicates no)	-0.531	0.345	-1.541	0.123
Indicator for Engineering District 2 (1 indicates yes, 0 indicates no)	-1.442	0.876	-1.646	0.100
Indicator for Engineering District 4 (1 indicates yes, 0 indicates no)	-1.205	0.657	-1.835	0.067
Indicator for Engineering District 5 (1 indicates yes, 0 indicates no)	-0.398	0.523	-0.761	0.447
Indicator for Engineering District 6 (1 indicates yes, 0 indicates no)	-0.379	0.543	-0.698	0.485
Indicator for Engineering District 8 (1 indicates yes, 0 indicates no)	-0.353	0.521	-0.679	0.497
Indicator for Engineering District 9 (1 indicates yes, 0 indicates no)	-1.084	0.542	-2.000	0.046
Indicator for Engineering District 10 (1 indicates yes, 0 indicates no)	-1.021	0.547	-1.867	0.062
Indicator for Engineering District 11 (1 indicates yes, 0 indicates no)	1.205	0.776	1.553	0.121
Indicator for Engineering District 12 (1 indicates yes, 0 indicates no)	-0.628	0.584	-1.074	0.283

Overdispersion parameter = 1.590, 2 x LL = -2916.855