Development of Safety Performance Functions for Network Screening of Roadway Departure Crashes in Virginia

http://www.virginiadot.org/vtrc/main/online_reports/pdf/19-r12.pdf

YOUNG-JUN KWEON, Ph.D., P.E.
Senior Research Scientist
Virginia Transportation Research Council

IN-KYU LIM, Ph.D., P.E.
HSIP Program Manager—Data & Analysis
Traffic Engineering Division
Virginia Department of Transportation

Final Report VTRC 19-R12

Standard Title Page - Report on Federally Funded Project

1. Report No.: FHWA/VTRC 19-R12	2. Government Accession No.:	3. Recipient's Catalog No.:
4. Title and Subtitle: Development of Safety Performance Functions for Network Screening of Roadway Departure Crashes in Virginia		5. Report Date: February 2019 6. Performing Organization Code:
7. Author(s): Young-Jun Kweon, Ph.D., P.E., and In-Kyu Lim, Ph.D., P.E.		8. Performing Organization Report No.: VTRC 19-R12
9. Performing Organization and Address: Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAIS): 11. Contract or Grant No.: 108892
12. Sponsoring Agencies' Name and Address: Virginia Department of Transportation 1401 E. Broad Street Richmond, VA 23219	Federal Highway Administration 400 North 8th Street, Room 750 Richmond, VA 23219-4825	13. Type of Report and Period Covered: Final 14. Sponsoring Agency Code:

15. Supplementary Notes:
This is an SPR-B report.

16. Abstract:

Roadway departure (RD) is recognized as one of the eight emphasis areas in the Virginia 2017-2021 Strategic Highway Safety Plan (SHSP), and the Virginia Department of Transportation (VDOT) currently uses counts of RD crashes to identify locations for RD safety improvement. However, identifying locations based on crash counts is subject to bias and inaccuracy, leading to ineffective or erroneous outcomes. The safety performance functions (SPFs) VDOT has been using for statewide network screening might be used for RD safety improvement, but this could lead to undesirable outcomes in that the current SPFs focus on all crash types and RD safety issues are believed to be different from those of other crash types. This study was designed to develop SPFs for statewide network screening for RD safety improvements to overcome this issue. RD SPFs were developed for 16 site types ranging from rural 2-lane segments to urban freeway segments with 8 or more lanes. It should be noted that crashes within 250 feet from an intersection are excluded according to VDOT's RD definition.

Of the 96 RD SPFs (16 site types x 2 severity levels x 3 functional forms) initially investigated, 93 RD SPFs were successfully developed for RD network screening. One site type did not result in statistically significant RD SPFs for fatal and injury crashes, likely because of its small sample size. The study found that the RD SPFs vary in their functional forms of annual average daily traffic (AADT) across the site types. The logarithmic functional form of AADT, regarded as a standard for an SPF, is deemed suitable in general for a typical range of AADT. However, that form could be severely deviated from the true relationship in the data. The study also found that the functional forms of AADT vary by injury severity. The forms are generally similar between the two severity levels, yet there are some cases where the difference is substantial. Accordingly, the functional form of AADT in an SPF for RD crashes should be determined for each site type and by severity level (all RD crashes and fatal and injury RD crashes) separately whenever possible.

Based on the findings, the study recommends that the RD SPFs developed in this study be incorporated in the current VDOT statewide network RD screening procedure. Specifically, the final RD SPFs determined by goodness of fit and prediction capability measures (Tables 11 and 12) are recommended for use. For some site types, more than one final SPF are provided, allowing VDOT to select the most appropriate one for network screening considering the practicality of implementing the RD SPFs. Development of separate SPFs by site type and by severity was desirable to avoid possible inaccurate outcomes of network screening.

17 Key Words: Roadway departure crashes, safety performance function	18. Distribution Statement: No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.

19. Security Classif. (of this report): Unclassified	20. Security Classif. (of this page): Unclassified	21. No. of Pages: 81	22. Price:

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

FINAL REPORT

DEVELOPMENT OF SAFETY PERFORMANCE FUNCTIONS FOR NETWORK SCREENING OF ROADWAY DEPARTURE CRASHES IN VIRGINIA

Young-Jun Kweon, Ph.D., P.E.
Senior Research Scientist
Virginia Transportation Research Council

In-Kyu Lim, Ph.D., P.E.
HSIP Program Manager—Data & Analysis
Traffic Engineering Division
Virginia Department of Transportation

In Cooperation with the U.S. Department of Transportation
Federal Highway Administration

Virginia Transportation Research Council
(A partnership of the Virginia Department of Transportation
and the University of Virginia since 1948)

Charlottesville, Virginia

February 2019
VTRC 19-R12

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Virginia Department of Transportation, the Commonwealth Transportation Board, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. Any inclusion of manufacturer names, trade names, or trademarks is for identification purposes only and is not to be considered an endorsement.

ABSTRACT

Roadway departure (RD) is recognized as one of the eight emphasis areas in the Virginia 2017-2021 Strategic Highway Safety Plan (SHSP), and the Virginia Department of Transportation (VDOT) currently uses counts of RD crashes to identify locations for RD safety improvement. However, identifying locations based on crash counts is subject to bias and inaccuracy, leading to ineffective or erroneous outcomes. The safety performance functions (SPFs) VDOT has been using for statewide network screening might be used for RD safety improvement, but this could lead to undesirable outcomes in that the current SPFs focus on all crash types and RD safety issues are believed to be different from those of other crash types. This study was designed to develop SPFs for statewide network screening for RD safety improvements to overcome this issue. RD SPFs were developed for 16 site types ranging from rural 2-lane segments to urban freeway segments with 8 or more lanes. It should be noted that crashes within 250 feet from an intersection are excluded according to VDOT's RD definition.

Of the 96 RD SPFs (16 site types x 2 severity levels x 3 functional forms) initially investigated, 93 RD SPFs were successfully developed for RD network screening. One site type did not result in statistically significant RD SPFs for fatal and injury crashes, likely because of its small sample size. The study found that the RD SPFs vary in their functional forms of annual average daily traffic (AADT) across the site types. The logarithmic functional form of AADT, regarded as a standard for an SPF, is deemed suitable in general for a typical range of AADT. However, that form could be severely deviated from the true relationship in the data. The study also found that the functional forms of AADT vary by injury severity. The forms are generally similar between the two severity levels, yet there are some cases where the difference is substantial. Accordingly, the functional form of AADT in an SPF for RD crashes should be determined for each site type and by severity level (all RD crashes and fatal and injury RD crashes) separately whenever possible.

Based on the findings, the study recommends that the RD SPFs developed in this study be incorporated in the current VDOT statewide network RD screening procedure. Specifically, the final RD SPFs determined by goodness of fit and prediction capability measures (Tables 11 and 12) are recommended for use. For some site types, more than one final SPF are provided, allowing VDOT to select the most appropriate one for network screening considering the practicality of implementing the RD SPFs. Development of separate SPFs by site type and by severity was desirable to avoid possible inaccurate outcomes of network screening.

FINAL REPORT

DEVELOPMENT OF SAFETY PERFORMANCE FUNCTIONS FOR NETWORK SCREENING OF ROADWAY DEPARTURE CRASHES IN VIRGINIA

Young-Jun Kweon, Ph.D., P.E.
Senior Research Scientist
Virginia Transportation Research Council

In-Kyu Lim, Ph.D., P.E.
HSIP Program Manager—Data & Analysis
Traffic Engineering Division
Virginia Department of Transportation

INTRODUCTION

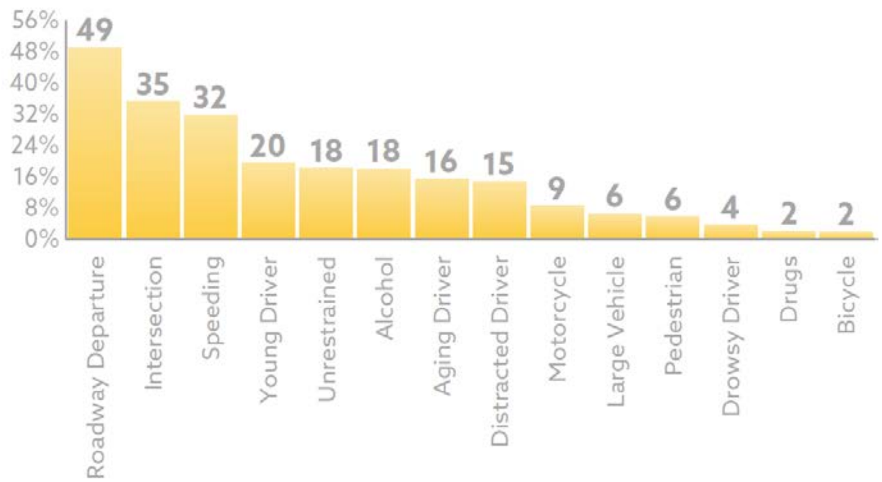
Background

To improve traffic safety in Virginia, the Virginia Department of Transportation (VDOT) works with safety partners such as the Department of Motor Vehicles and Virginia State Police under Virginia's Strategic Highway Safety Plan (SHSP). VDOT focuses its efforts on the SHSP goals in order to maximize the safety benefits that can be achieved with the limited resources available. Within VDOT, the SHSP is used to guide and coordinate safety improvement efforts across divisions, districts, and programs and to ensure their alignment with VDOT's overall safety goals. The 2017-2021 SHSP (VDOT, 2017), the current SHSP, adopted the safety target of reducing deaths and serious injuries caused by traffic crashes by one-half by 2030, corresponding to 2% and 5% annual reductions in fatalities and serious injuries, respectively. To achieve the target, the SHSP identified several areas on which Virginia should concentrate its resources, called "emphasis areas."

The SHSP identified roadway departure (RD) as one of eight emphasis areas based on a data-driven approach. More than 2,000 people were killed and 21,000 seriously injured during RD crashes in Virginia from 2011-2015 (Figure 1a). For the 5 years, RD crashes comprised about 49% of all fatalities and serious injuries, the worst among 14 potential emphasis areas (Figure 1b).

In an effort to make significant safety improvements in Virginia, VDOT has been increasing its efforts to employ a data-driven approach, profoundly changing VDOT's management of the statewide safety program in several ways. Most notably, VDOT has been using safety performance functions (SPFs) to screen the statewide roadway network to identify potential locations for safety improvement projects since 2014.

(a) Annual numbers of fatalities and serious injuries at roadway departure crashes



(b) Five-year percentages of 14 potential emphasis areas in the 2017-2021 SHSP

Figure 1. Contributing Factors for Fatalities and Serious Injuries in Traffic Crashes in 2011-2015. SHSP = Strategic Highway Safety Plan. Source: *Virginia 2017-2021 Strategic Highway Safety Plan* (VDOT, 2017).

To facilitate this statewide network screening, VDOT developed 24 SPFs customized for various road types using Virginia-specific data, hereinafter "VA-SPFs." Details on the development of the SPFs were provided by Hass et al. (2010), Rivera and Garber (2010), and Kweon and Lim (2014). The developed VA-SPFs encompass 98% of about 62,000 miles of interstate, primary, and secondary roads maintained by VDOT. These VA-SPFs enable VDOT to identify locations that have the highest potential to benefit from safety improvement among numerous segments and intersections on the roadway network. VDOT's efforts developing and implementing the VA-SPFs were recognized by the 2015 National Roadway Safety Awards (Federal Highway Administration, 2016) and the 2016 ITE [Institute of Transportation Engineers] Transportation Achievement Awards (Institute of Transportation Engineers, 2016).

Identifying locations with high potential for safety improvement is crucial to maximize limited resources. This is true for RD safety improvement, which is recognized in Strategies 1 and 2 of the RD emphasis area in the SHSP as "identify routes and segments with previous, or the potential for, roadway departure crashes" (VDOT, 2017). In order to implement specific actions effectively, locations that would likely receive the most safety benefit from such actions would need to be identified. SPFs could serve as a useful tool for identification.

It should be noted that the VA-SPFs embedded in VDOT's current network screening procedure are designed to address general safety issues found among common crash types. Applying these SPFs to identify locations for improving RD safety is possible by using the proportion of RD crashes among all crashes calculated from local data. However, the results are valid only if RD crashes occur under driving environments and conditions similar to those under which typical types of crashes occur, such as rear-end crashes. This assumption may not be realistic, and therefore the use of the current VA-SPF network screening may be inappropriate for the RD safety improvement. As an alternative, VDOT continues to rely on a traditional method based on crash frequency for identifying locations for RD safety projects. However, this method has critical shortcomings, likely leading to identifying locations with low potential for safety improvement and/or failing to identify locations with high potential. One of the most critical shortcomings is a failure to account for exposure factors such as traffic volume varying across locations. Identifying locations based only on crash counts tends to be biased toward locations with high traffic volume.

Problem Statement

RD crashes are recognized as one of the eight emphasis areas in the 2017-2021 SHSP that are key to improving highway safety significantly in Virginia. Among the contributing factors identified in the SHSP, RD crashes resulted in the highest number of fatalities and serious injuries in Virginia from 2011-2015. To reduce the occurrence and severity of RD crashes, identifying potential locations for safety improvement is crucial so that appropriate countermeasures can be developed and applied at the identified locations.

VDOT currently uses counts of RD crashes to identify locations for RD safety improvement. However, identifying locations based on crash counts is subject to bias and inaccuracy, leading to ineffective or erroneous outcomes. The existing VA-SPFs VDOT has been using to identify locations for safety improvement could be used for RD safety after some adjustments. However, this could lead to undesirable outcomes in that the VA-SPFs focus on all crash types and RD safety issues are believed to be different from other crash types.

PURPOSE AND SCOPE

The purpose of this study was to develop network screening SPFs to identify potential locations for RD safety improvements. The scope of the study did not include producing a list of RD crash countermeasures or quantifying the effectiveness of such countermeasures. The study was limited to data readily available within VDOT's database system to ensure that the developed RD SPFs could be implemented on the statewide road network without additional data collection.

METHODS

Data Preparation

The research team obtained data from VDOT's Oracle-based roadway management system, Roadway Network System (RNS), which serves as the official repository of VDOT's business data for internal management and reporting. RNS facilitates a relational database that provides universal enterprise data access and links geospatial data and business attributes to the roadway centerlines.

Three subsystems of RNS were merged to produce the study data for 2011-2015: (1) the accident system (RNS_CRASH), (2) the traffic monitoring system (RNS_TMS), and (3) the roadway inventory system (RNS_RDI). These three subsystems are in Oracle databases and were merged using the linear referencing system embedded in RNS_RDI. Structured Query Language (SQL) codes developed in VDOT's Traffic Engineering Division facilitated the merger. The RNS_CRASH database contains more than 80 variables associated with crashes, vehicles, and persons involved in the crashes. The RNS_TMS database contains traffic flow variables such as annual average daily traffic (AADT) and the locations of the traffic counters. The RNS_RDI database contains geometric and locational information on about 62,000 centerline miles of public roadways in Virginia and includes variables such as functional classification, surface width, and number of lanes.

VDOT established a technical definition of an RD crash in 2015 (see Appendix A). This standard definition provides consistency across analyses and was adopted in this study to extract RD crashes from RNS. It should be noted that VDOT's definition excludes crashes within 250 feet from an intersection. As data were extracted from the database, records with missing values for critical variables were removed.

Data Analysis

Generalized Linear Models (GLMs)

GLMs were used with either negative binomial (NB) or Poisson distribution specifications with a segment length being used as an offset. Final estimated models were used to form SPFs for predicting annual crash frequency at segments under given conditions.

Three sets of SPFs were developed for all RD crashes and fatal and injury RD crashes separately: (1) SPFs with only AADT in a logarithmic functional form (Alternative 1), (2) SPFs with only AADT in a customized functional form (Alternative 2), and (3) SPFs with AADT and other predictors in customized functional forms (Alternative 3). Model specifications of the SPFs are presented in Equations 1 through 3:

$$N_{SPF,i} = exp[\beta_0 + \beta_1 \times \ln(AADT_i) + \ln(Length_i)] \quad \text{[Eq. 1]}$$

$$N_{SPF,i} = exp[\beta_0 + \beta_1 \times f(AADT_i) + \ln(Length_i)] \quad \text{[Eq. 2]}$$

$$N_{SPF,i} = exp\begin{bmatrix}\beta_0 + \beta_1 \times g(AADT_i) + \beta_2 \times h(X1_i)\\ +\beta_2 \times k(X2_i) + \cdots + \ln(Length_i)\end{bmatrix} \qquad \text{[Eq. 3]}$$

where

i = segment index

$N_{SPF,i}$ = predicted number of RD crashes at segment i

$\beta_0, \beta_1, ...$ = SPF coefficients to be estimated

$Length_i$ = length of segment i

$X1_i, X2_i, ...$ = predictors of segment i (e.g., shoulder width, pavement roughness, and surface type)

$f(\cdot), g(\cdot), h(\cdot), k(\cdot), ...$ = functional forms to be customized.

Equation 1 is considered to be a standard form of an SPF and is used in the *Highway Safety Manual* (American Association of State Highway and Transportation Officials, 2010) and SafetyAnalyst (Federal Highway Administration, 2010).

Moreover, separate SPFs were developed for each of 16 site types listed in Table 1. Thus, a total of 96 final RD SPFs (i.e., 16 site types x 2 severity levels [all RD crashes versus fatal and injury RD crashes] x 3 functional forms [Eqs. 1-3]) would be developed in the end if a large enough sample size existed for each site type and estimated coefficients of an SPF were statistically significant; RD SPFs for fatal and injury RD crashes for Site Type 107 were not developed in the end because of a small sample size.

Table 1. Sixteen Site Types for RD SPF Development

Site Type Code	Site Type Description
101	Rural 2-lane segments
102	Rural multilane undivided segments
103	Rural multilane divided segments
104	Rural freeway segments–4 lanes
105	Rural freeway segments–6+ lanes
106	Rural freeway segments within an interchange area–4 lanes
107	Rural freeway segments within an interchange area–6+ lanes
151	Urban 2-lane arterial segments
152	Urban multilane undivided arterial segments
153	Urban multilane divided arterial segments
155	Urban freeway segments–4 lanes
156	Urban freeway segments–6+ lanes
157	Urban freeway segments–8+ lanes
158	Urban freeway segments within an interchange area–4 lanes
159	Urban freeway segments within an interchange area–6 lanes
160	Urban freeway segments within an interchange area–8+ lanes

RD = roadway departure; SPF = safety performance function.

Model Selection and Validation

As for Alternative 2 (Eq. 2) and Alternative 3 (Eq. 3) SPFs, several competing models were developed and the best model was selected based on (1) Akaike information criteria (AIC) corrected (AICc), (2) k-fold cross-validation, and (3) model parsimony. AIC is often used in selecting the best performing model among models in comparison, and a model with a lower AIC value is better. However, when the models contain a different number of variables, AIC values would not be ideal for comparing model performance because including more variables in a model tends to lower its AIC value. AICc addresses this concern by imposing a larger penalty for additional variables. When the number of variables is identical across the competing models, AIC and AICc values are identical. Further, as the sample size increases, AICc converges to AIC. In cases where a sample size is large enough compared to the number of parameters to be estimated, the correction could be negligible. Since there were cases where competing models had different numbers of variables, AICc was used for all model comparisons in this study.

Since the RD SPFs developed in this study are primarily for predicting crash frequencies (for the past, current, and future years), k-fold cross-validation is used for assessing their prediction performance. The k-fold cross-validation is frequently used in developing a predictive model and has advantages over the conventional validation technique partitioning data into two sets, one for training and the other for testing, especially when the data are not large enough to be partitioned into the two sets without compromising model estimation and/or prediction assessment. In the k-fold cross-validation, the data are randomly partitioned into k datasets, with one dataset for testing and the remaining k-1 datasets for training. The cross-validation process is repeated k times with each of the partitioned k datasets being used exactly once for testing. The resulting k sets of validation results are then averaged to measure the prediction performance of the model. Model parsimony is also used to select the best model, and it means that a model with a smaller number of variables is preferred. Although AICc accounts for this aspect with a higher penalty for a larger number of variables, on some occasions where AICc values are quite similar among competing models, a model with fewer variables is determined to be better.

The best RD SPF is selected in each alternative for each site type in terms of the measures described. This means three best RD SPFs (one for each alternative) would be available for each site type. The final RD SPFs are then determined from among the three alternatives based on AICc and k-fold cross-validation error rate. For fair comparisons, a random seed was fixed across the alternatives for calculating the k-fold cross-validation error rate.

RESULTS AND DISCUSSION

Study Data

A set of final study datasets was prepared by merging several database tables from the three subsystems (RNS_CRASH, RNS_TMS, and RNS_RDI) of VDOT's RNS using SQL codes developed for this study; RNS_CORE, the roadway inventory system, was used as the backbone for merging these tables. A total of 965,714 merged records were included in the final datasets after records with invalid or missing values were removed. The datasets corresponded to more than 190,000 road segments in 16 site types. Table 2 provides the names and descriptions of the variables analyzed; descriptive statistics (e.g., mean and standard deviation) for the variables are presented by site type in Tables B1 through B16 in Appendix B.

Data Analysis

Data analysis was performed using the software R 3.1.1. Developed SPFs are presented for all RD crashes and for fatal and injury RD crashes separately.

All RD Crashes

Three sets of SPFs, Alternatives 1 through 3, were developed for all RD crashes: (1) SPFs with only AADT in a logarithmic functional form (Alternative 1 corresponding to Eq. 1); (2) SPFs with only AADT in a customized functional form (Alternative 2 corresponding to Eq. 2); and (3) SPFs with AADT and other predictors in customized functional forms (Alternative 3 corresponding to Eq. 3). For Alternatives 2 and 3, many SPFs with different functional forms and for Alternative 3 different predictors were estimated; the best SPFs based on AICc and 5-fold cross-validation error rate are presented.

Alternative 1: SPFs With Only AADT in a Logarithmic Functional Form for All RD Crashes

SPFs were developed through a GLM with a log-transformed AADT being the only predictor. The developed SPFs are shown in Table 3 in a functional form; they are presented in Table C1 in Appendix C in a statistical tabular form. The coefficient estimate of *ln(AADT)* is statistically significant at 0.05 for all 16 site types, and the NB dispersion estimate is provided for the application of the empirical Bayes (EB) method. The log-transformed AADT form in the SPF guarantees that the predicted number of crashes is non-decreasing with an increasing AADT and is deemed a standard form of AADT entering into an SPF used in the *Highway Safety Manual* and SafetyAnalyst.

Figure 2 visualizes the developed SPFs of 2 site types for all RD crashes: Site Type 101 (rural 2-lane segments), and Site Type 156 (urban freeway segments-6+ lanes). It should be noted that each circle in the graphs corresponds to a roadway segment (with its AADT and annual RD crash count per mile in a particular year) and that the predicted annual number of crashes for each site shown by the SPF curve (solid line) was calculated setting the length of the segment at 1 mile so that the SPF curve is presented to reveal its functional form; however, when the SPF is applied for network screening, actual values for the length of segments on the network should be used. It should also be noted that for visual clarity, the figure does not show all data points. For example, in Figure 2(a), there are points with more than 9 crashes per mile. In this case, the 95th percentile prediction limit represented by the gray band is so narrow that it is almost invisible in Figure 2(a).

Table 2. Name and Description of Variables

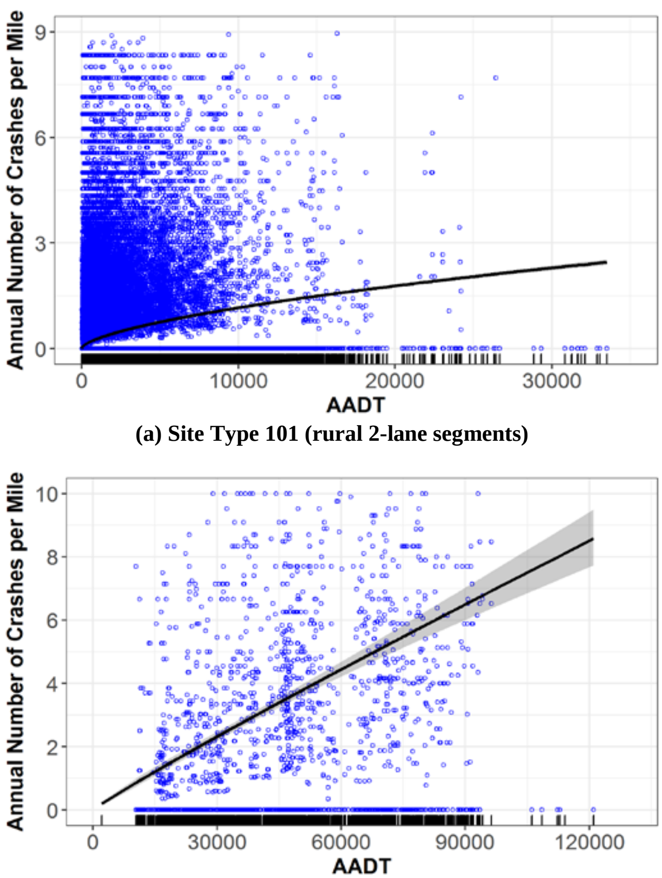
Variable Type	Variable Name	Variable Description
Dependent Variable	All RD Crashes	Annual Number of All Roadway Departure Crashes (crashes per year)
	Fatal & Injury RD Crashes	Annual Number of Fatal and Injury Roadway Departure Crashes (crashes per year)
Offset	Length	Segment Length (mile)
Explanatory Variable (also called predictor variables)	AADT	Annual Average Daily Traffic (number of vehicles per day)
	SurfaceWidth	Road Surface Width (feet)
	LaneWidth	Lane Width (feet): SurfaceWidth / Number of Lane
	LtShldWidth	Left Shoulder Width (feet)
	RtShldWidth	Right Shoulder Width (feet)
	ShoulderWidth	Average Shoulder Width (feet): (RtShldWidth + LtShldWidth) / 2
	MedianWidthMax	Maximum Median Width Within Segment (feet)
	MedianWidthMin	Minimum Median Width Within Segment (feet)
	MedianWidth	Average Median Width (feet): (MedianWidthMin + MediaWidthMax) / 2
	MedLtShldWidth	Median Left Shoulder Width (feet)
	MedRtShldWidth	Median Right Shoulder Width (feet)
	MedShldWidth	Average Median Shoulder Width (feet): (MedRtShldWidth + MedLtShldWidth) / 2
	MedMedShldWidth	Median-Median Shoulder Width (feet): MedianWidth + MedShldWidth
	PaveConditionV	Pavement Condition Value (0-5)
	PaveRoughness	Pavement Roughness[a]
	SurfaceType3456C[b]	Road Surface Type 3, 4, 5, 6, or C (Untreated, Light Bituminous, Heavy Bituminous, Plant Mix, or Cold Mix)
	SurfaceType8[b]	Road Surface Type 8 (Portland Cement Concrete)
	CurbGutter2[b]	Curb and Gutter Type 2 (Right Side)
	CurbGutter3[b]	Curb and Gutter Type 3 (Left Side)
	CurbGutter4[b]	Curb and Gutter Type 4 (Median)
	CurbGutter5[b]	Curb and Gutter Type 5 (Left and Right Sides)
	CurbGutter8[b]	Curb and Gutter Type 8 (Left Side, Right Side, and Median)
	CurbGutter25[b]	Curb and Gutter Type 2 or 5
	CurbGutter1235[b]	Curb and Gutter Type 1, 2, 3, or 5

[a] Non-negative integer value ranging from 0 to 807 in the study data.
[b] Indicator variable equaling 1 if the condition stated in the description is satisfied. For example, SurfaceType8 = 1 if the surface type of a segment is portland cement concrete pavement.

Table 3. SPFs With Only AADT in a Logarithmic Functional Form for All RD Crashes (2011-2015)[a]

Site Type	SPF	NB Dispersion
101	$N_{SPF} = exp[-5.570 + 0.621 \times \ln(AADT) + \ln(Length)]$	1.425
102	$N_{SPF} = exp[-3.982 + 0.380 \times \ln(AADT) + \ln(Length)]$	1.676
103	$N_{SPF} = exp[-6.287 + 0.663 \times \ln(AADT) + \ln(Length)]$	2.158
104	$N_{SPF} = exp[-4.476 + 0.493 \times \ln(AADT) + \ln(Length)]$	5.761
105	$N_{SPF} = exp[-12.08 + 1.212 \times \ln(AADT) + \ln(Length)]$	7.441
106	$N_{SPF} = exp[-2.955 + 0.383 \times \ln(AADT) + \ln(Length)]$	1.813
107	$N_{SPF} = exp[-10.88 + 1.141 \times \ln(AADT) + \ln(Length)]$	8.362
151	$N_{SPF} = exp[-6.373 + 0.692 \times \ln(AADT) + \ln(Length)]$	0.559
152	$N_{SPF} = exp[-4.782 + 0.487 \times \ln(AADT) + \ln(Length)]$	1.459
153	$N_{SPF} = exp[-5.275 + 0.534 \times \ln(AADT) + \ln(Length)]$	1.189
155	$N_{SPF} = exp[-5.574 + 0.616 \times \ln(AADT) + \ln(Length)]$	2.145
156	$N_{SPF} = exp[-8.818 + 0.937 \times \ln(AADT) + \ln(Length)]$	2.376
157	$N_{SPF} = exp[-8.183 + 0.861 \times \ln(AADT) + \ln(Length)]$	2.814
158	$N_{SPF} = exp[-4.592 + 0.564 \times \ln(AADT) + \ln(Length)]$	1.390
159	$N_{SPF} = exp[-4.386 + 0.567 \times \ln(AADT) + \ln(Length)]$	1.932
160	$N_{SPF} = exp[-1.596 + 0.300 \times \ln(AADT) + \ln(Length)]$	2.004

SPF = safety performance function; AADT = annual average daily traffic; RD = roadway departure; NB = negative binomial.
[a] Crashes occurring within 250 feet from an intersection are excluded.



(a) Site Type 101 (rural 2-lane segments)

(b) Site Type 156 (urban freeway segments–6+ lanes)

Figure 2. SPFs With Only AADT in a Logarithmic Functional Form for All RD Crashes (Site Types 101 and 156). A circle represents a segment; a solid line represents an SPF with the segment length of 1 mile and a corresponding AADT; and the gray band surrounding the solid line represents the 95th percentile mean prediction limit. The graphs were created for illustration purposes and may not show the entire range of data points. SPF = safety performance function; AADT = annual average daily traffic; RD = roadway departure.

Alternative 2: SPFs With Only AADT in a Customized Functional Form for All RD Crashes

SPFs were next developed using only AADT, but with its functional form customized to try to improve the prediction accuracy. The form was customized for each of 16 site types separately. The developed SPFs are shown in Table 4 in a functional form and are presented in Table C2 in Appendix C in a statistical tabular form. The coefficient estimates of AADT variables are statistically significant at 0.05 for all 16 site types and the NB dispersion estimate is provided for the application of EB method. It should be noted that, unlike the SPFs shown in Table 3, those in Table 4 do not guarantee non-decreasing number of crashes with an increasing AADT since the functional form for AADT is not constrained by the logarithm function.

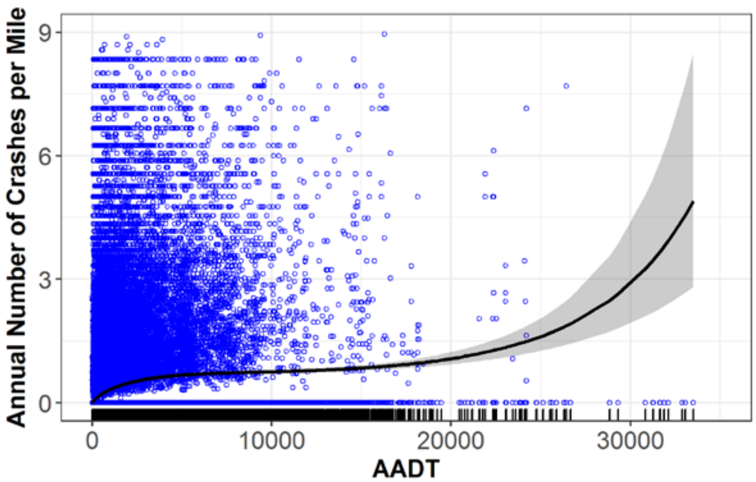
Figure 3 visualizes the developed SPFs of 2 site types for all RD crashes: Site Type 101 (rural 2-lane segments), and Site Type 156 (urban freeway segments–6+ lanes). Each circle in the graphs corresponds to a roadway segment, and the predicted annual number of crashes for each site shown by the SPF curve (solid line) is for the segment length of 1 mile. It should also be noted that for visual clarity the figure does not show all data points. As seen in Figure 3(b), the predicted number of all RD crashes increases until AADT reaches at around 70,000 vehicles per day and then decreases as AADT further increases.

Table 4. SPFs With Only AADT in a Customized Functional Form for All RD Crashes (2011-2015)[a]

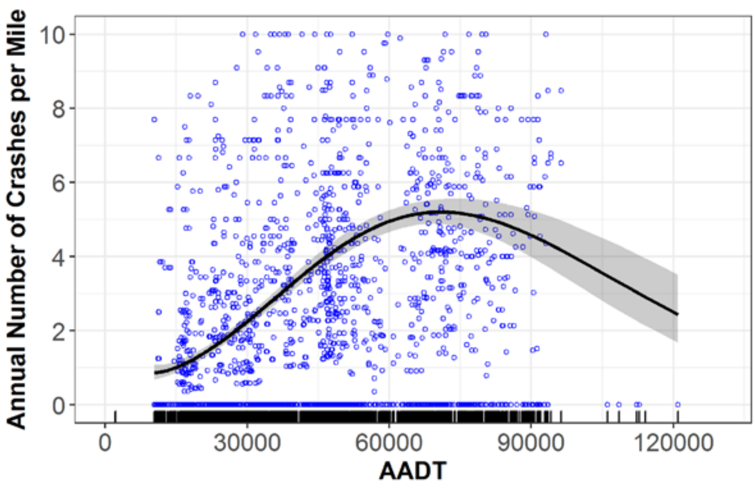
Site Type	SPF	NB Dispersion
101	$N_{SPF} = exp[-7.577 - 0.0001315 \times AADT + 0.000000004135 \times AADT^2 + 1.132 \times \ln(AADT) - 0.0264 \times (\ln(AADT))^2 + \ln(Length)]$	1.489
102	$N_{SPF} = exp[-1.029 + 0.00004868 \times AADT + \ln(Length)]$	1.767
103	$N_{SPF} = exp[-10.16 - 0.00005996 \times AADT + 0.0000000006292 \times AADT^2 + 1.148 \times \ln(AADT) + \ln(Length)]$	2.184
104	$N_{SPF} = exp[-116.5 + 0.0002406 \times AADT + 27.01 \times \ln(AADT) - 1.584 \times (\ln(AADT))^2 + \ln(Length)]$	6.120
105	$N_{SPF} = exp[-12.08 + 1.212 \times \ln(AADT) + \ln(Length)]$	7.441
106	$N_{SPF} = exp[-2.955 + 0.3828 \times \ln(AADT) + \ln(Length)]$	1.813
107	$N_{SPF} = exp[0.00975 + 0.00002792 \times AADT + \ln(Length)]$	9.863
151	$N_{SPF} = exp[-8.939 - 0.0001376 \times AADT + 0.000000001541 \times AADT^2 + 1.095 \times \ln(AADT) + \ln(Length)]$	0.634
152	$N_{SPF} = exp[8.378 - 0.0001526 \times AADT + 0.000000001076 \times AADT^2 - 3.522 \times \ln(AADT) + 0.298 \times (\ln(AADT))^2 + \ln(Length)]$	1.489
153	$N_{SPF} = exp[-5.275 + 0.534 \times \ln(AADT) + \ln(Length)]$	1.189
155	$N_{SPF} = exp[-2.688 + 0.0000117 \times AADT + 0.299 \times \ln(AADT) + \ln(Length)]$	2.164
156	$N_{SPF} = exp[120.4 - 0.0000977 \times AADT - 26.96 \times \ln(AADT)) + 1.517 \times (\ln(AADT))^2 + \ln(Length)]$	2.456
157	$N_{SPF} = exp[-4512 + 0.0031 \times AADT - 0.000000005780 \times AADT^2 + 934.3 \times \ln(AADT) - 48.99 \times (\ln(AADT))^2 + \ln(Length)]$	2.913
158	$N_{SPF} = exp\left[6.862 - 57.99 \times \left({}^{1}/_{\ln(AADT)}\right) + \ln(Length)\right]$	1.392
159	$N_{SPF} = exp[0.280 + 0.00004962 \times AADT - 0.0000000003678 \times AADT^2 + \ln(Length)]$	1.993
160	$N_{SPF} = exp[224.0 - 0.000674 \times AADT + 0.000000002322 \times AADT^2 + 23.44 \times \ln(AADT) + \ln(Length)]$	2.225

AADT = annual average daily traffic; RD = roadway departure; SPF = safety performance function; NB = negative binomial.

[a] Crashes occurring within 250 feet from an intersection are excluded.



(a) Site Type 101 (rural 2-lane segments)



(b) Site Type 156 (urban freeway segments–6+ lanes)

Figure 3. SPFs With Only AADT in a Customized Functional Form for All RD Crashes (Site Types 101 and 156). A circle represents a segment; a solid line represents an SPF with the segment length of 1 mile and a corresponding AADT; and the gray band surrounding the solid line represents the 95th percentile mean prediction limit. The graphs were created for illustration purposes and may not show the entire range of data points. SPF = safety performance function; AADT = annual average daily traffic; RD = roadway departure.

Figure 3 illustrates some of the challenges of using a customized functional form. Although model fit with the customized form may be improved over the logarithmic form, sometimes counterintuitive results could be obtained. Model trends in areas with sparse data may be suspect, such as the changes seen in the higher AADT ranges in Figures 3(a) and 3(b), which could be attributed to unaccounted factors related to safer driving conditions (e.g., better safety features and road geometry) at sites carrying more traffic. For example, segments carrying a certain range of AADTs might typically be equipped with better safety features and more forgiving geometric design as compared to those carrying other AADTs. In those cases, the sites are expected to have smaller numbers of RD crashes, resulting in sagging in an SPF shape for that AADT range. It should be noted that although these unusual shapes are uncommon, they have been found in the past (e.g., SPFs for encroachment counts by Hutchinson and Kennedy [1966] and Cooper [1980]).

Alternative 3: SPFs With AADT and Other Predictors in Customized Functional Forms for All RD Crashes

SPFs were developed with all available predictors such as AADT, lane width, and shoulder width, and the predictors were customized in their functional forms for each site type. The developed SPFs are shown in Table 5 in a functional form; they are presented in Table C3 in Appendix C in a statistical tabular form. The coefficient estimates of predictor variables included in the table are statistically significant at 0.05, and the NB dispersion estimate is provided for the application of the EB method. Unlike the SPFs shown in Table 3, those in Table 5 do not guarantee a non-decreasing number of crashes with an increasing AADT since the functional form for AADT is not constrained at the logarithm. Since the SPFs were developed for predictions under actual conditions, not for interpretation or prediction in hypothetical conditions, the estimated coefficients should not be interpreted as partial effects on RD crash frequency. For example, the coefficient estimate of CurbGutter25 in the SPF for Site Type 101, -0.9298, should not be interpreted as a decrease in the annual number of all RD crashes by 0.9298 when a road segment has curb and gutter installed on the right side (Curb Gutter Type = 2) or both the left and right sides (Curb Gutter Type = 5) while all other conditions are unchanged.

Figure 4 visualizes the developed SPFs for 2 site types for all RD crashes: Site Type 101 (rural 2-lane segments) and Site Type 156 (urban freeway segments–6+ lanes). Each circle in the graphs corresponds to a roadway segment, and the predicted annual number of crashes for each site shown by the SPF curve (solid line) is for the segment length of 1 mile. Predictors other than AADT are set at their average values for an illustration. It should also be noted that for visual clarity of the SPFs the figure does not show all data points.

Fatal and Injury RD Crashes

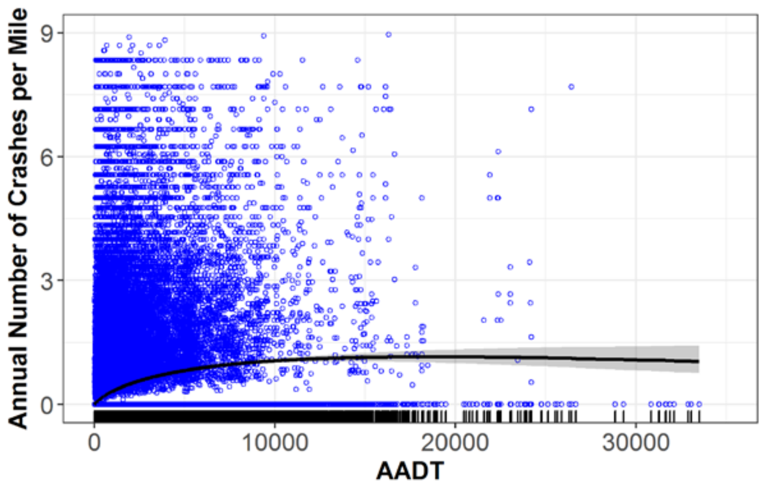
Three sets of SPFs, Alternatives 1 through 3, were developed for fatal and injury RD crashes: (1) SPFs with only AADT in a logarithmic functional form (Alternative 1 corresponding to Equation 1); (2) SPFs with only AADT in a customized functional form (Alternative 2 corresponding to Equation 2); and (3) SPFs with AADT and other predictors in customized functional forms (Alternative 3 corresponding to Equation 3). For Alternatives 2 and 3, many SPFs with different functional forms and for Alternative 3 different predictors were estimated, and the best SPFs based on AICc and 5-fold cross-validation error rate are presented. It should be noted that the SPFs for fatal and injury RD crashes were not developed for Site Type 107 (rural freeway segments with 6 or more lanes within an interchange area) because a statistically significant estimation of the corresponding GLMs was not successful. This was probably due to a small sample size of 115 observations corresponding to 23 segments.

Table 5. SPFs With AADT and Other Predictors in Customized Functional Forms for All RD Crashes[a]

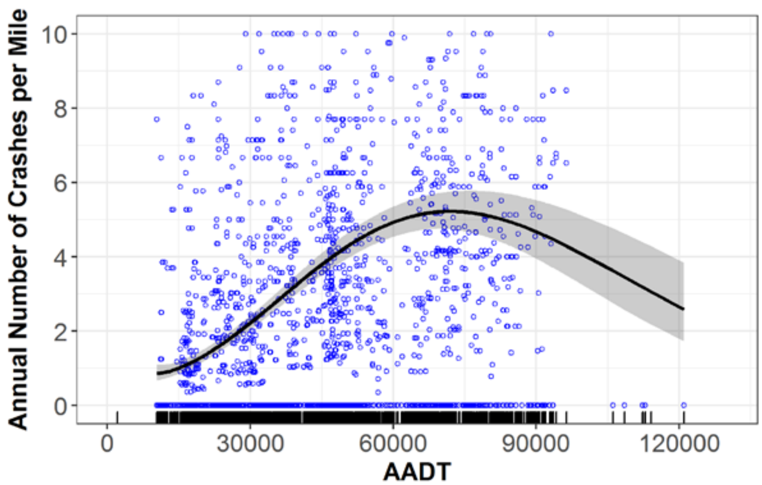
Site Type	SPF	NB Dispersion
101	$N_{SPF} = exp[-8.156 - 0.00002166 \times AADT + 1.507 \times \ln(AADT) - 0.0559 \times (\ln(AADT))^2 - 0.1055 \times LaneWidth + 0.001708 \times LaneWidth^2 - 0.0899 \times ShouldWidth + 0.1792 \times \ln(MedShldWidth + 0.1) + 0.0003766 \times PaveRoughness + 0.0868 \times PaveConditionV + 0.8408 \times SurfaceType3456C - 0.9298 \times CurbGutter25 + \ln(Length)]$	1.669
102	$N_{SPF} = exp[-1.124 + 0.00005441 \times AADT + 0.1109 \times \ln(ShouldWidth + 0.1) + \ln(Length)]$	1.825

103	$N_{SPF} = exp[-17.35 - 0.00005328 \times AADT + 0.000000000594 \times AADT^2 + 1.083 \times \ln(AADT) + 1.954 \times LaneWidth - 0.1575 \times LaneWidth^2 + 0.003863 \times\times LaneWidth^3 + 0.01474 \times ShouldWidth + 0.002398 \times MedianWidth + 0.6016 \times CurvGutter2 + \ln(Length)]$	2.345
104	$N_{SPF} = exp[-89.99 + 0.0001847 \times AADT + 20.91 \times \ln(AADT) - 1.220 \times (\ln(AADT))^2 - 0.1769 \times ShldWidth + 0.00145 \times PaveRoughness + 0.1962 \times SurfaceType8 - 0.7225 \times CurbGutter3 - 2.466 \times CurbGutter5 + \ln(Length)]$	6.263
105	$N_{SPF} = exp[81.28 + 0.0005263 \times AADT - 0.000000002963 \times AADT^2 - 8.911 \times \ln(AADT) + 0.01433 \times MedianWidth - 0.0001073 \times MedianWidth^2 + 0.0000002034 \times MedianWidth^3 - 2.633 \times MedShldWidth + 0.6729 \times MedShldWidth^2 - 0.05471 \times MedShldWidth^3 + 0.001874 \times PaveRoughness + \ln(Length)]$	15.25
106	$N_{SPF} = exp[-2.577 + 0.3822 \times \ln(AADT) - 0.01093 \times MedMedShldWidth + 0.00008258 \times MedMedShldWidth^2 - 0.0000001682 \times MedMedShldWidth^3 + \ln(Length)]$	1.892
107	$N_{SPF} = exp[-3.105 + 0.00002078 \times AADT + 0.6813 \times ShouldWidth + \ln(Length)]$	58.87
151	$N_{SPF} = exp[-6.943 - 0.0001273 \times AADT + 0.00000000132 \times AADT^2 + 1.096 \times \ln(AADT) - 0.2318 \times LaneWidth + 0.007097 \times LaneWidth^2 - 0.00007274 \times LaneWidth^3 - 0.04005 \times ShouldWidth - 0.006363 \times ShouldWidth^2 + 0.02965 \times MedMedShldWidth - 0.0003478 \times MedMedShldWidth^2 + 0.0000009662 \times MedMedShldWidth^3 + \ln(Length)]$	1.000
152	$N_{SPF} = exp[-9.912 - 0.0001707 \times AADT + 0.000000001269 \times AADT^2 - 3.745 \times \ln(AADT) + 0.3171 \times (\ln(AADT))^2 - 0.08115 \times LaneWidth - 0.002821 \times PaveRoughness + 0.00002085 \times PaveRoughness^2 - 0.0000000229 \times PaveRoughness^3 - 0.4084 \times SurfaceType8 + \ln(Length)]$	1.701
153	$N_{SPF} = exp\left[3.876 - 38.65 \times {}^{1}/_{\ln(AADT)} - 0.03119 \times SurfaceWidth + 0.000544 \times SurfaceWidth^2 - 0.000002717 \times SurfaceWidth^3 + 0.070 \times MedShldWidth + 0.00001909 \times MedShldWidth^2 + 0.0008224 \times PaveConditionV - 0.08842 \times PaveConditionV^2 + 0.4608 \times CurbGutter4 + 0.3745 \times CurbGutter1235 + \ln(Length)\right]$	1.287
155	$N_{SPF} = exp[-2.084 + 0.427 \times \ln(AADT) - 0.07736 \times LaneWidth - 0.157 \times ShouldWidth + 0.254 \times MedShldWidth - 0.03199 \times MedShldWidth^2 - 0.005274 \times MedWidthMin - 0.005608 \times PaveRoughness + 0.00009753 \times PaveRoughness^2 - 0.0000002868 \times PaveRoughness^3 + \ln(Length)]$	2.656
156	$N_{SPF} = exp[117.9 - 0.00009494 \times AADT - 26.47 \times \ln(AADT) + 1.489 \times (\ln(AADT))^2 - 0.02006 \times RtShldWidth + 0.429 \times MedShldWidth - 0.160 \times MedShldWidth^2 + 0.01764 \times MedShldWidth^3 - 0.001506 \times MedianWidth + \ln(Length)]$	2.607
157	$N_{SPF} = exp[-4130 + 0.0028 \times AADT - 0.000000005251 \times AADT^2 + 853.9 \times \ln(AADT) - 44.71 \times (\ln(AADT))^2 + 0.02258 \times SurfaceWidth + 0.539 \times RtShldWidth - 0.1002 \times RtShldWidth^2 + 0.004581 \times RtShldWidth^3 - 0.04658 \times \ln(MedianWidthMin + 0.1) + 0.004733 \times PaveRoughness + \ln(Length)]$	3.415
158	$N_{SPF} = exp[-3.268 + 0.487 \times \ln(AADT) - 0.08212 \times ShouldWidth - 0.001258 \times MedianWidth - 0.01702 \times PaveRoughness + 0.0002358 \times PaveRoughness^2 - 0.0000007403 \times PaveRoughness^3 + \ln(Length)]$	1.512
159	$N_{SPF} = exp[0.372 + 0.00005197 \times AADT - 0.0000000003957 \times AADT^2 + 0.04464 \times \ln(RtShldWidth) - 0.0503 \times \ln(MedianWidthMin) + \ln(Length)]$	2.061
160	$N_{SPF} = exp[-206.4 - 0.0006678 \times AADT + 0.000000002393 \times AADT^2 - 0.03889 \times MedRtShldWidth - 0.004824 \times MedianWidthMin + \ln(Length)]$	2.921

AADT = annual average daily traffic; RD = roadway departure; SPF = safety performance function; NB = negative binomial.
[a] Crashes occurring within 250 feet from an intersection are excluded.



a) Site Type 101 (rural 2-lane segments)



(b) Site Type 156 (urban freeway segments–6+ lanes)

Figure 4. SPFs With AADT and Other Predictors in Customized Functional Forms for All RD Crashes (Site Types 101 and 156). A circle represents a segment; a solid line represents an SPF with the segment length of 1 mile and a corresponding AADT; and the gray band surrounding the solid line represents the 95th percentile mean prediction limit. Predictors other than AADT are set at their average values. The graphs were created for illustration purposes and may not show the entire range of data points. SPF = safety performance function; AADT = annual average daily traffic; RD = roadway departure.

Alternative 1: SPFs With Only AADT in a Logarithmic Functional Form for Fatal and Injury RD Crashes

SPFs were developed through a GLM with log-transformed AADT being the only predictor. The developed SPFs are shown in Table 6 in a functional form; they are presented in Table C4 in Appendix C in a statistical tabular form. The coefficient estimate of *ln(AADT)* is statistically significant at 0.05 for all site types excluding Site Type 107, and the NB dispersion estimate is provided for the application of EB method. The SPF functional form guarantees that the predicted number of crashes is non-decreasing with an increasing AADT.

Table 6. SPFs With Only AADT in a Logarithmic Functional Form for Fatal and Injury RD Crashes (2011-2015)[a]

Site Type	SPF	NB Dispersion
101	$N_{SPF} = exp[-6.501 + 0.643 \times \ln(AADT) + \ln(Length)]$	1.404
102	$N_{SPF} = exp[-5.123 + 0.421 \times \ln(AADT) + \ln(Length)]$	1.188
103	$N_{SPF} = exp[-6.929 + 0.647 \times \ln(AADT) + \ln(Length)]$	2.012
104	$N_{SPF} = exp[-5.886 + 0.532 \times \ln(AADT) + \ln(Length)]$	6.119
105	$N_{SPF} = exp[-12.70 + 1.156 \times \ln(AADT) + \ln(Length)]$	7.639
106	$N_{SPF} = exp[-5.791 + 0.562 \times \ln(AADT) + \ln(Length)]$	2.848
107	NA	
151	$N_{SPF} = exp[-7.500 + 0.716 \times \ln(AADT) + \ln(Length)]$	0.667
152	$N_{SPF} = exp[-6.700 + 0.599 \times \ln(AADT) + \ln(Length)]$	1.005
153	$N_{SPF} = exp[-5.908 + 0.510 \times \ln(AADT) + \ln(Length)]$	1.106
155	$N_{SPF} = exp[-7.256 + 0.672 \times \ln(AADT) + \ln(Length)]$	2.522
156	$N_{SPF} = exp[-9.279 + 0.878 \times \ln(AADT) + \ln(Length)]$	4.121
157	$N_{SPF} = exp[-8.260 + 0.775 \times \ln(AADT) + \ln(Length)]$	2.474
158	$N_{SPF} = exp[-3.910 + 0.379 \times \ln(AADT) + \ln(Length)]$	1.986
159	$N_{SPF} = exp[-5.479 + 0.561 \times \ln(AADT) + \ln(Length)]$	1.685
160	$N_{SPF} = exp[-5.507 + 0.553 \times \ln(AADT) + \ln(Length)]$	2.026

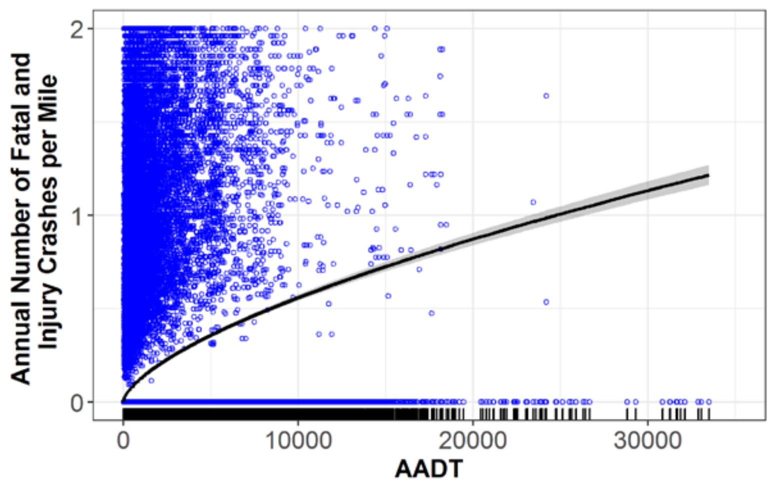
AADT = annual average daily traffic; RD = roadway departure; SPF = safety performance function; NB = negative binomial; NA = not available (a statistically significant SPF was not developed).
[a] Crashes occurring within 250 feet from an intersection are excluded.

Figure 5 visualizes the developed SPFs of 2 site types for fatal and injury RD crashes: Site Type 101 (rural 2-lane segments) and Site Type 156 (urban freeway segments–6+ lanes). Each circle in the graphs corresponds to a roadway segment, and the predicted annual number of fatal and injury crashes for each site shown by the SPF curve (solid line) was calculated setting the length of the segment at 1 mile so that the SPF curve is presented to reveal its functional form; however, when the SPF is applied for network screening, actual values for the length of segments on the network should be used. It should also be noted that for visual clarity of the SPFs the figure does not show all data points.

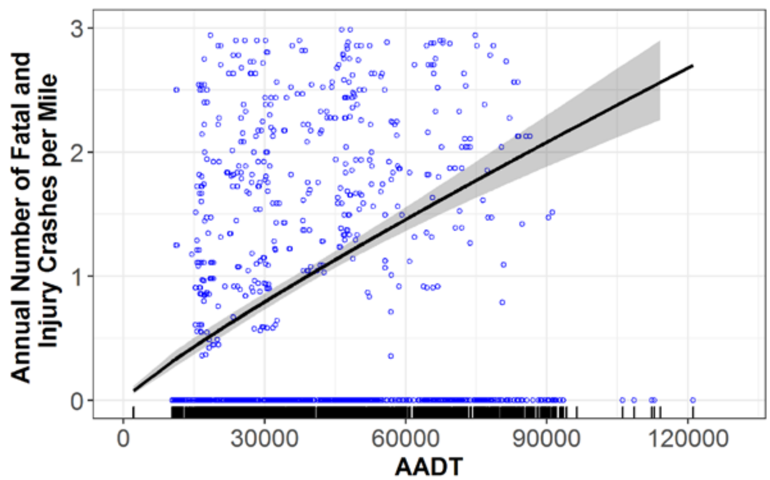
Alternative 2: SPFs With Only AADT in a Customized Functional Form for Fatal and Injury RD Crashes

SPFs were developed using only AADT but with its functional form customized to enhance the prediction accuracy. The form was customized for each site type. The developed SPFs are shown in Table 7 in a functional form; they are presented in Table C5 in Appendix C in a statistical tabular form. The coefficient estimates of AADT variables are statistically significant at 0.05, and the NB dispersion estimate is provided for the application of the EB method. Unlike the SPFs shown in Table 6, those in Table 7 do not guarantee a non-decreasing number of fatal and injury crashes with an increasing AADT because the functional form was not constrained at the logarithm.

Figure 6 visualizes the developed SPFs for fatal and injury RD crashes for 2 site types: Site Type 101 (rural 2-lane segments) and Site Type 156 (urban freeway segments–6+ lanes). Each circle in the graphs corresponds to a roadway segment, and the predicted annual number of fatal and injury crashes for each site shown by the SPF curve (solid line) is for the segment length of 1 mile. It should also be noted that for visual clarity the figure does not show all data points of the SPFs.



(a) Site Type 101 (rural 2-lane segments)



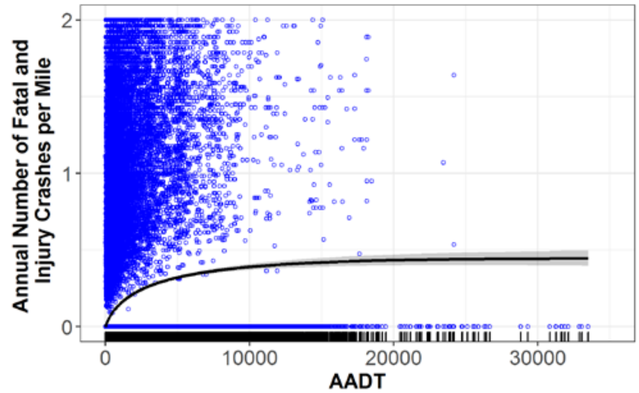
(b) Site Type 156 (urban freeway segments–6+ lanes)

Figure 5. SPFs With Only AADT in a Logarithmic Functional Form for Fatal and Injury RD Crashes (Site Types 101 and 156). A circle represents a segment; a solid line represents an SPF with the segment length of 1 mile and a corresponding AADT; and the gray band surrounding the solid line represents the 95th percentile mean prediction limit. The graphs were created for illustration purposes and may not show the entire range of data points. SPF = safety performance function; AADT = annual average daily traffic; RD = roadway departure.

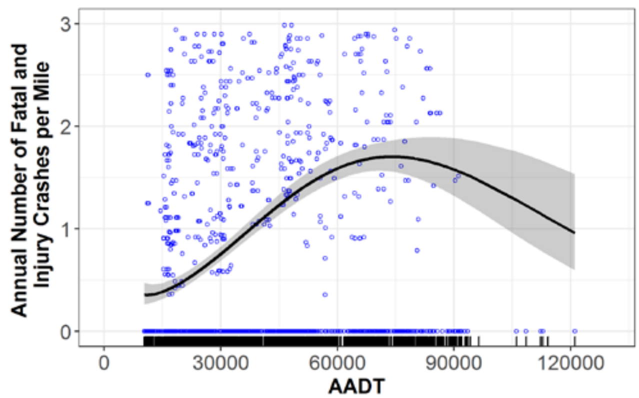
Table 7. SPFs With Only AADT in a Customized Functional Form for Fatal and Injury RD Crashes (2011-2015)[a]

Site Type	SPF	NB Dispersion
101	$N_{SPF} = exp[-10.510 + 1.859 \times \ln(AADT) - 0.0891 \times (\ln(AADT))^2 + \ln(Length)]$	1.475
102	$N_{SPF} = exp[-5.123 + 0.4209 \times \ln(AADT) + Length]$	1.188
103	$N_{SPF} = exp[-1.773 + 0.00008576 \times AADT - 0.000000001071 \times AADT^2 + \ln(Length)]$	1.979
104	$N_{SPF} = exp[-97.65 + 0.0002187 \times AADT + 22.50 \times \ln(AADT) - 1.327 \times (\ln(AADT))^2 + \ln(Length)]$	6.517
105	$N_{SPF} = exp[-1.779 + 0.00003091 \times AADT + \ln(Length)]$	9.973
106	$N_{SPF} = exp[-5.791 + 0.5615 \times \ln(AADT) + \ln(Length)]$	2.848
107	NA	
151	$N_{SPF} = exp[-10.48 - 0.0001414 \times AADT + 0.000000001482 \times AADT^2 + 1.174 \times \ln(AADT) + \ln(Length)]$	0.772
152	$N_{SPF} = exp[-11.60 - 0.00003927 \times AADT + 1.181 \times \ln(AADT) + \ln(Length)]$	1.029
153	$N_{SPF} = exp[-24.15 + 0.00001830 \times AADT + 4.591 \times \ln(AADT) - 0.2296 \times (\ln(AADT))^2 + \ln(Length)]$	1.106
155	$N_{SPF} = exp[-7.256 + 0.6716 \times \ln(AADT) + \ln(Length)]$	2.522
156	$N_{SPF} = exp[115.7 - 0.00008705 \times AADT - 25.84 \times \ln(AADT) + 1.440 \times (\ln(AADT))^2 + \ln(Length)]$	4.430
157	$N_{SPF} = exp[-5223 + 0.003713 \times AADT - 0.000000007087 \times AADT^2 + 1085 \times \ln(AADT) - 57.11 \times (\ln(AADT))^2 + \ln(Length)]$	2.639
158	$N_{SPF} = exp[-3.910 + 0.3787 \times \ln(AADT) + \ln(Length)]$	1.986
159	$N_{SPF} = exp[-0.9671 + 0.00005399 \times AADT - 0.0000000004117 \times AADT^2 + \ln(Length)]$	1.746
160	$N_{SPF} = exp[-9.152 + 0.0004125 \times AADT - 0.000000005561 \times AADT^2 + 0.0000000000000242 \times AADT^3 + \ln(Length)]$	2.456

AADT = annual average daily traffic; RD = roadway departure; SPF = safety performance function; NB = negative binomial; NA = not available (a statistically significant SPF was not developed).
[a] Crashes occurring within 250 feet from an intersection are excluded.



(a) Site Type 101 (rural 2-lane segments)



(b) Site Type 156 (urban freeway segments–6+ lanes)

Figure 6. SPFs With Only AADT in a Customized Functional Form for Fatal and Injury RD Crashes (Site Types 101 and 156). A circle represents a segment; a solid line represents an SPF with the segment length of 1 mile and a corresponding AADT; and the gray band surrounding the solid line represents the 95th percentile mean prediction limit. The graphs were created for illustration purposes and may not show the entire range of data points. SPF = safety performance function; AADT = annual average daily traffic; RD = roadway departure.

Alternative 3: SPFs With AADT and Other Predictors in Customized Functional Forms for Fatal and Injury RD Crashes

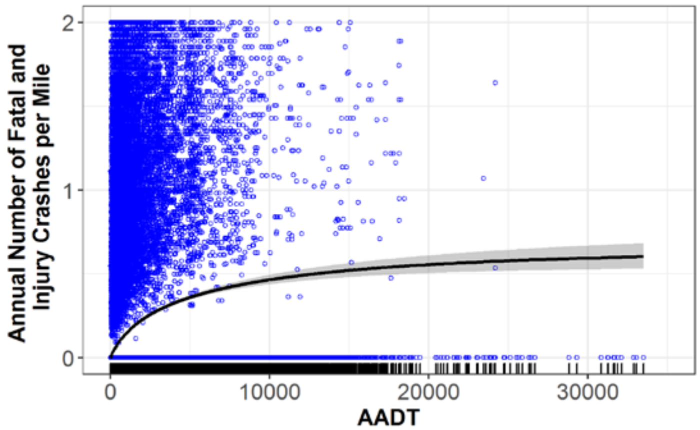
SPFs were developed with all available predictors such as AADT, lane width, and shoulder width, and the predictors were customized in their functional forms for each site type. The developed SPFs are shown in Table 8 in a functional form; they are presented in Table C6 in Appendix C in a statistical tabular form. The coefficient estimates of predictor variables presented in the table are statistically significant at 0.05, and the NB dispersion estimate is provided for the application of the EB method. Unlike the SPFs shown in Table 6, those in Table 8 do not guarantee a non-decreasing number of fatal and injury crashes with an increasing AADT because the functional form for AADT was not constrained at the logarithm. Since the SPFs were developed for predictions under actual conditions, the estimated coefficients should not be interpreted as partial effects on RD crash frequency. For example, the coefficient estimate of CurbGutter25 in the SPF for Site Type 101, -1.261, should not be interpreted as a decrease in the annual number of fatal and injury RD crashes by 1.264 when a road segment has curb and gutter installed on the right side (Curb Gutter Type = 2) or both the left and right sides (Curb Gutter Type = 5) while all other conditions are unchanged.

Table 8. SPFs With AADT and Other Predictors in Customized Functional Forms for Fatal and Injury RD Crashes (2011-2015)[a]

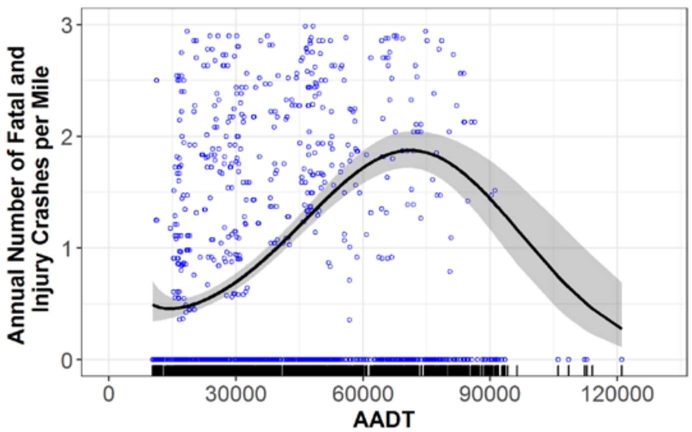
Site Type	SPF	NB Dispersion
101	$N_{SPF} = exp[-10.84 + 1.806 \times \ln(AADT) - 0.08105 \times (\ln(AADT))^2 - 0.04642 \times LaneWidth - 0.07232 \times ShouldWidth + 0.00103 \times PaveRoughness + 0.09519 \times PaveConditionV + 0.9889 \times SurfaceType3456C - 1.261 \times CurbGutter25 + \ln(Length)]$	1.611
102	$N_{SPF} = exp[-5.463 + 0.4545 \times \ln(AADT) + 0.1002 \times \ln(ShouldWidth + 0.1) + \ln(Length)]$	1.196
103	$N_{SPF} = exp[-18.54 + 0.6585 \times \ln(AADT) + 0.00315 \times MedianWidth + 2.8610 \times LaneWidth - 0.2223 \times LaneWidth^2 + 0.0052 \times LaneWidth^3 + \ln(Length)]$	2.279
104	$N_{SPF} = exp[-0.1339 + 0.0000361 \times AADT - 0.2517 \times ShouldWidth + 0.001269 \times PaveRoughness + 0.2234 \times SurfaceType8 - 1.324 \times CurbGutter3 - 3.127 \times CurbGutter5 + \ln(Length)]$	6.432
105	$N_{SPF} = exp[-1.761 + 0.00003812 \times AADT - 0.002263 \times MedianWidth + \ln(Length)]$	12.31
106	$N_{SPF} = exp[-5.791 + 0.5694 \times \ln(AADT) + 0.005554 \times MedMedShldWidth - 0.00001836 \times MedMedShldWidth^2 + \ln(Length)]$	3.176
107	NA	
151	$N_{SPF} = exp[-9.215 - 0.0001341 \times AADT + 0.000000001348 \times AADT^2 + 1.166 \times \ln(AADT) - 0.09387 \times LaneWidth - 0.06141 \times ShouldWidth + 0.009289 \times MedMedShldWidth + 0.001069 \times PaveRoughness + \ln(Length)]$	0.885
152	$N_{SPF} = exp[-10.48 - 0.00004045 \times AADT + 1.129 \times \ln(AADT) - 0.06322 \times LaneWidth + 0.01850 \times MedMedShldWidth + 0.001460 \times PaveRoughness - 0.5082 \times SurfaceType8 + \ln(Length)]$	1.161
153	$N_{SPF} = exp[-14.64 + 2.337 \times \ln(AADT) - 0.1017 \times (\ln(AADT))^2 + 0.009654 \times SurfaceWidth - 0.03884 \times MedShldWidth + 0.002971 \times MedianWidth + 0.0008097 \times PaveRoughness + 0.3443 \times CurbGutter1235 + 0.01078 \times ShouldWidth + \ln(Length)]$	1.265
155	$N_{SPF} = exp[-6.027 + 0.6271 \times \ln(AADT) - 0.1753 \times ShouldWidth + 0.1205 \times \ln(MedShldWidth + 0.1) + 0.001160 \times PaveRoughness + \ln(Length)]$	3.161
156	$N_{SPF} = exp[14.86 + 0.0001533 \times AADT - 0.0000000008949 \times AADT^2 - 1.844 \times \ln(AADT) + 0.01654 \times RtShldWidth - 0.001653 \times MedianWidth + \ln(Length)]$	4.669
157	$N_{SPF} = exp[-5003 + 0.003491 \times AADT - 0.000000006577 \times AADT^2 + 1040 \times \ln(AADT) - 54.62 \times (\ln(AADT))^2 + 0.02962 \times SurfaceWidth - 1.026 \times LaneWidth - 0.04650 \times RtShldWidth - 0.05173 \times MedRtShldWidth + 0.007284 \times PaveRoughness - 0.7532 \times CurbGutter25 + \ln(Length)]$	3.067
158	$N_{SPF} = exp[-2.611 + 0.2568 \times \ln(AADT) - 0.02825 \times PaveRoughness + 0.0004077 \times PaveRoughness^2 - 0.00000133 \times PaveRoughness^3 + \ln(Length)]$	2.283
159	$N_{SPF} = exp[-0.8092 + 0.00005263 \times AADT - 0.0000000003973 \times AADT^2 - 0.003862 \times MedianWidthMin + \ln(Length)]$	1.807
160	$N_{SPF} = exp[-9.446 + 0.0004275 \times AADT - 0.000000005804 \times AADT^2 + 0.0000000000000253 \times AADT^3 - 0.06962 \times \ln(MedRtShldWidth + 0.1) + \ln(Length)]$	2.535

AADT = annual average daily traffic; RD = roadway departure; SPF = safety performance function; NB = negative binomial; NA = not available (a statistically significant SPF was not developed).
[a] Crashes occurring within 250 feet from an intersection are excluded.

Figure 7 visualizes the SPFs for fatal and injury RD crashes for 2 site types: Site Type 101 (rural 2-lane segments) and Site Type 156 (urban freeway segments–6+ lanes). Each circle in the graphs corresponds to a roadway segment, and the predicted annual number of fatal and injury crashes for each site by the SPF curve (solid line) is for the segment length of 1 mile. Predictors other than AADT are set at their average values for an illustration purpose. It should also be noted that for visual clarity the figure does not show all data points of the SPFs.



(a) Site Type 101 (rural 2-lane segments)



(b) Site Type 156 (urban freeway segments–6+ lanes)

Figure 7. SPFs With AADT and Other Predictors in Customized Functional Forms for Fatal and Injury RD Crashes (Site Types 101 and 156). A circle represents a segment; a solid line represents an SPF with the segment length of 1 mile and a corresponding AADT; and the gray band surrounding the solid line represents the 95th percentile mean prediction limit. Predictors other than AADT are set at their average values. The graphs were created for illustration purposes and may not show the entire range of data points. SPF = safety performance function; AADT = annual average daily traffic; RD = roadway departure.

Final SPF Selection and Validation

For all RD crashes and fatal and injury RD crashes, three sets of SPFs (Alternatives 1 through 3) were developed separately, and they were presented in separate sections earlier in the report. It should be noted that many SPFs with different functional forms and for Alternative 3 different predictors were developed for Alternatives 2 and 3. The SPFs reported in Tables 4, 5, 7, and 8 were those with the best performance in terms of AICc and 5-fold cross-validation error rate in each alternative for each site type.

Tables 9 and 10 show AICc and error rate values for the SPFs performing the best in each alternative. It should be noted that the error rates reported in the tables were calculated while the random seed for performing 5-fold cross-validation was fixed at 1 for all the SPFs so that fair comparisons across the three alternatives were possible. When the random seed was not fixed, the same SPF produced a slightly different error rate value because of the randomness involved in splitting the data into 5 datasets for cross-validation.

Table 9. AICc and 5-Fold Cross-Validation Error Rates of SPFs for All RD Crashes (2011-2015)

Site Type	Alternative 1[a]		Alternative 2[b]		Alternative 3[c]	
	AICc[d]	Error Rate[e]	AICc[d]	Error Rate[e]	AICc[d]	Error Rate[e]
101	197,045	0.1419	196,312	0.1436	194,568	0.1383
102	2,200	0.1433	2,197	0.1424	2,183	0.1434
103	23,844	0.4547	23,830	0.4537	23,732	0.4461
104	9,864	3.8206	9,840	3.7349	9,797	3.7407
105	1,129	7.1096	1,129	7.1096	1,073	7.2748
106	3,441	0.9597	3,441	0.9597	3,436	0.9522
107	319	1.6131	317	1.6010	314	1.3560
151	109,496	0.0661	108,334	0.0652	110,089	0.0638
152	14,960	0.1248	14,928	0.1246	14,866	0.1229
153	52,573	0.2530	52,573	0.2530	52,184	0.2581
155	7,016	2.8239	7,012	2.8197	6,883	2.5617
156	7,058	4.3495	7,007	4.4985	6,976	4.6553
157	4,763	3.5065	4,756	3.3949	4,691	3.1543
158	4,141	1.3372	4,141	1.3128	4,119	1.2605
159	5,488	2.7302	5,478	2.6575	5,466	2.5961
160	2,743	3.0941	2,719	2.5789	2,674	2.1429

[a] SPFs with only AADT in a logarithmic functional form (Table 3).
[b] SPFs with only AADT in a customized functional form (Table 4).
[c] SPFs with AADT and other predictors in customized functional forms (Table 5).
[d] Akaike information criteria corrected.
[e] Error rate based on 5-fold cross-validation predictions (random seed fixed at 1).

Table 10. AICc and 5-Fold Cross-Validation Error Rates of SPFs for Fatal and Injury RD Crashes (2011-2015)

Site Type	Alternative 1[a]		Alternative 2[b]		Alternative 3[c]	
	AICc[d]	Error Rate[e]	AICc[d]	Error Rate[e]	AICc[d]	Error Rate[e]
101	113,703	0.0556	113,291	0.0554	112,595	0.0549
102	1,253	0.0655	1,253	0.0655	1,249	0.0660
103	14,456	0.1729	14,493	0.1732	14,373	0.1700
104	6,281	1.0599	6,271	1.0487	6,257	1.0560
105	699	1.5412	693	1.4709	691	1.4679
106	1,796	0.2403	1,796	0.2403	1,793	0.2391
107	NA	NA	NA	NA	NA	NA
151	53,418	0.0197	52,819	0.0195	52,257	0.0193
152	8,087	0.0517	8,061	0.0517	8,036	0.0513
153	28,569	0.0877	28,556	0.0878	28,344	0.0858
155	4,056	0.5980	4,056	0.5980	4,006	0.5746
156	4,147	0.8553	4,126	0.8556	4,111	0.8547
157	2,914	0.9405	2,910	0.9228	2,875	0.9036
158	2,058	0.2642	2,058	0.2642	2,046	0.2631
159	3,028	0.5758	3,023	0.5708	3,014	0.5753
160	1,574	0.6194	1,563	0.5802	1,559	0.5842

NA = not available (a statistically significant SPF was not developed).
[a] SPFs with only AADT in a logarithmic functional form (Table 6).
[b] SPFs with only AADT in a customized functional form (Table 7).
[c] SPFs with AADT and other predictors in customized functional forms (Table 8).
[d] Akaike information criteria corrected.
[e] Error rate based on 5-fold cross-validation predictions (random seed fixed at 1).

The best performing SPF for each site type can be determined by comparing the three alternative SPFs based on AICc and error rate. Lower AICc and error rate values indicate better SPF model fit. For example, Alternative 3 (SPF with AADT and other predictors) performs the best for Site Type 101 for all RD crashes (Table 9) since its AICc and error rate values are the smallest among the three alternative for the site type. However, applying this SPF for network screening requires input values for nine variables included in the SPF: AADT, LaneWidth, ShouldWidth, MedShldWidth, PaveRoughness, PaveConditionV, SurfaceType3456C, CurbGutter25, and Length.

The error rates varied across the site types. This variation was expected partly because raw crash rates (per mile) vary. For example, raw crash rates are 0.21 and 2.38 crashes per mile per year for Site Types 101 and 105, respectively (see Tables B1 and B5 in Appendix B). The variation also hints how different the level of variation in crash counts being explained by the SPFs is across the site types. For example, the dispersion parameter is one of the statistics that suggests how much variation remains unexplained after including all variables in the SPFs (e.g., 1.425 and 8.362 for Site Types 101 and 105, respectively).

Although the input values for all variables included in the SPFs developed were available in VDOT's RNS database for the study data years (2011-2015), the values except for AADT and Length may not be available for a specific year that network screening targets. When a value for any of these variables in a developed SPF is not available, network screening using the SPF is not feasible. Thus, for ease of implementation, the best SPF with only AADT was chosen between Alternatives 1 and 2 for each site type. In addition, if Alternative 3 was found to perform better than the best SPF with only AADT as a variable, it was also provided in case input values for all variables of Alternative 3 SPF are available. Thus, the Alternative 3 SPF if provided is the overall best SPF for the site type and if not provided performs worse than Alternatives 1 and 2.

Tables 11 and 12 present the final SPFs for all RD crashes and fatal and injury RD crashes, respectively. For each site type, the best SPF with only AADT is provided. For some site types, the SPF with AADT and other predictors (the overall best SPF) is also provided. For the site types with the overall best SPFs, these SPFs should produce the most accurate prediction of annual crash count under given conditions resulting in the most accurate outcomes of network screening. For example, Site Type 101 in Table 11 lists two SPFs, one with only AADT and the other with AADT and other predictors. This means that when input values for all predictors included in Alternative 3 (SPF with AADT and other predictors) are available in VDOT's RNS database, the SPF with AADT and other predictors would produce the most accurate outcomes for network screening of that site type. However, when values in any of the predictors other than AADT and segment length are not available in the database, the SPF with only AADT should be used for network screening.

Table 11. Final SPFs for All RD Crashes

Site Type	SPF With Only AADT	SPF With AADT and Other Predictors
101	Alternative 1 (Table 3)	Alternative 3 (Table 5)
102	Alternative 2 (Table 4)	NA
103	Alternative 2 (Table 4)	Alternative 3 (Table 5)
104	Alternative 2 (Table 4)	NA
105	Alternative 1 (Table 3)	NA
106	Alternative 1 (Table 3)	Alternative 3 (Table 5)
107	Alternative 2 (Table 4)	Alternative 3 (Table 5)
151	Alternative 2 (Table 4)	Alternative 3 (Table 5)
152	Alternative 2 (Table 4)	Alternative 3 (Table 5)
153	Alternative 1 (Table 3)	NA
155	Alternative 2 (Table 4)	Alternative 3 (Table 5)
156	Alternative 1 (Table 3)	NA
157	Alternative 2 (Table 4)	Alternative 3 (Table 5)
158	Alternative 2 (Table 4)	Alternative 3 (Table 5)
159	Alternative 2 (Table 4)	Alternative 3 (Table 5)
160	Alternative 2 (Table 4)	Alternative 3 (Table 5)

SPF = safety performance function; RD = roadway departure; AADT = annual average daily traffic; NA = not applicable.

Table 12. Final SPFs for Fatal and Injury RD Crashes

Site Type	SPF With Only AADT	SPF With AADT and Other Predictors
101	Alternative 2 (Table 7)	Alternative 3 (Table 8)
102	Alternative 1 (Table 6)	NA
103	Alternative 1 (Table 6)	Alternative 3 (Table 8)
104	Alternative 2 (Table 7)	NA
105	Alternative 2 (Table 7)	Alternative 3 (Table 8)
106	Alternative 1 (Table 6)	Alternative 3 (Table 8)
107[a]	NA	NA
151	Alternative 2 (Table 7)	Alternative 3 (Table 8)
152	Alternative 2 (Table 7)	Alternative 3 (Table 8)
153	Alternative 1 (Table 6)	Alternative 3 (Table 8)
155	Alternative 1 (Table 6)	Alternative 3 (Table 8)
156	Alternative 1 (Table 6)	Alternative 3 (Table 8)
157	Alternative 2 (Table 7)	Alternative 3 (Table 8)
158	Alternative 1 (Table 6)	Alternative 3 (Table 8)
159	Alternative 2 (Table 7)	NA
160	Alternative 2 (Table 7)	NA

SPF = safety performance function; RD = roadway departure; AADT = annual average daily traffic; NA = not applicable.

[a] A statistically significant SPF was not developed. For network screening, either an average crash rate (i.e., average annual number of fatal and injury RD crashes per mile) for this site type or the SPFs of all RD crashes for the site type could be used.

It should be noted that Site Type 107 for fatal and injury RD crashes does not have a statistically significant SPF, most likely because of the small sample size for the site type. Without an SPF for this site type, network screening for fatal and injury RD crashes could still be performed in one of two ways: (1) an average crash rate per mile, and (2) SPFs developed for all RD crashes. For the first way, an annual average number of fatal and injury RD crashes per mile is calculated for the site type in a target year and used as a threshold for assessing individual sites (potentially safe at or below the threshold and potentially unsafe above the threshold).

Confidence intervals could be constructed using variance calculated for the site type, and an upper limit at a desired confidence level (e.g., 95% upper limit of the confidence interval) could be used as a fine-tuned threshold. The second way is to apply a fatal and injury crash proportion to the outcomes from applying the SPFs developed for all RD crashes for network screening for fatal and injury RD crashes.

CONCLUSIONS

- *SPFs for RD crashes vary in their functional forms of AADT across the site types*. The logarithmic functional form of AADT, regarded a standard for an SPF, is deemed suitable in general for a typical range of AADTs. However, that form could be severely deviated from the true relationships in the data. For example, the customized functional forms of AADT of Site Type 156 (urban freeway segments with 6 or more lanes) indicate that annual RD crashes (all RD crashes and fatal and injury RD crashes) are expected to increase until a certain level of AADT and to start decreasing after that level whereas the logarithmic form of AADT predicts increasing RD crashes over the entire range of AADTs. This implies that the SPF with *ln*(AADT) would identify sites where safety benefits are not expected to be promising, especially for sites with a larger AADT. Thus, the functional form of AADT in an SPF for RD crashes should be customized for each site type.

- *SPFs for RD crashes vary in their functional forms of AADT by injury severity*. The forms appear generally similar between all RD crashes and fatal and injury RD crashes. However, there are some cases where the difference is substantial. For example, for Site Type 103 (rural multilane divided segments), all RD crashes are expected to increase for the entire range of AADTs as AADT increases whereas fatal and injury RD crashes are expected to increase until AADT reaches around 40,000 vehicles per day and then decrease afterward. This means that if a severity proportion (proportion of fatal and injury RD crashes among all RD crashes) is applied to the SPFs developed for all RD crashes to identify sites for addressing safety issues involving fatal and injury RD crashes, identified sites are not expected to be cost-effective in safety improvement, especially sites with a larger AADT. Thus, the functional form of AADT in an SPF for RD crashes should be customized separately for all RD crashes versus fatal and injury RD crashes.

RECOMMENDATIONS

1. *VDOT's Traffic Engineering Division (TED) should implement the final RD SPFs developed in this study by incorporating them into the current VDOT network screening procedure*. The final RD SPFs are provided by severity level (all RD crashes versus fatal and injury RD crashes) and site type (see Tables 11 and 12). Thus, they should be incorporated and implemented accordingly. It should be noted that when the RD SPFs are implemented for network screening for target years outside the study data years (2011-2015), they should be adjusted by a calibration factor corresponding to each target year.

2. *VDOT's TED should choose the most appropriate final RD SPF when more than one final SPF are provided by considering the practicality of their use for RD network screening.* For some site types, two final SPFs are provided (see Tables 11 and 12), one with only AADT and the other with AADT and other predictors. In such cases, the SPF with AADT and other predictors is the overall best SPF that provides the most accurate outcomes for network screening, based on the data used in this study. However, the SPF with only AADT should be used if data for some predictors in the SPF are not available. Likewise, the level of comfort with the directionality of model parameters and trends with AADT changes should also be considered when Alternatives 2 and 3 are examined. It should be noted that the SPF with only AADT also provides acceptably accurate outcomes for network screening.

IMPLEMENTATION AND BENEFITS

Implementation

With regard to Recommendations 1 and 2, VDOT's TED will integrate the developed RD SPFs into the current VDOT statewide network screening process, determining locations for priority consideration for safety improvement projects. Currently, the network screening is performed annually based on total and fatal and injury potential safety improvement (PSI) values, producing the top 100 intersections and 100 miles of segments, provided to the VDOT districts each January. With the developed RD SPFs to be incorporated in the current statewide network screening process, priority sites specific to RD safety improvement would be generated. The enhanced list of priority sites including both the RD priority list and the overall priority list generated by the existing VA-SPFs would be provided to the districts. These new SPFs will be incorporated into the next annual screening performed by TED following the publication of this report.

Benefits

Implementing the study recommendations will lead to more accurate identification of locations with higher than expected RD crash frequencies under existing conditions during network screening.

The benefit of implementing Recommendation 1 is improved identification of locations with higher than expected RD crash frequencies. This will allow for better investment of safety funds to address RD safety concerns. The RD SPFs developed will be useful not only for identifying locations for RD safety improvement projects but also for evaluating effectiveness of RD crash countermeasures, likely leading to better informed decisions on countermeasures to be deployed at locations for future RD safety projects.

The benefit of implementing Recommendation 2 is that immediate implementation of Recommendation 1 is allowed for by accounting for data availability limitations.

ACKNOWLEDGMENTS

The authors thank the members of the technical review panel for this study for their guidance and support during the study: Justice Appiah, Virginia Transportation Research Council; Anne Booker, VDOT's Southwest Region; and Mark Cole and Tracy Turpin, VDOT's TED. It should be noted that Young-Jun Kweon, a coauthor of this report, is now employed with the National Highway Traffic Safety Administration (NHTSA). He worked on this report while employed previously by VDOT. Neither NHTSA nor the U.S. Department of Transportation is responsible for the content of this report and makes no claims, promises, or guarantees about the accuracy, completeness, or adequacy of its contents.

REFERENCES

American Association of State Highway and Transportation Officials. *Highway Safety Manual, 1st Edition*. Washington, DC, 2010.

Cooper, P. Analysis of Roadside Encroachments—Single-Vehicle Run-off-Road Accident Data Analysis for Five Provinces. *B.C. Research*, March 1980.

Federal Highway Administration. *SafetyAnalyst™: Software Tools for Safety Management of Specific Highway Sites.* FHWA-HRT-10-063. Washington, DC, 2010.

Federal Highway Administration. *2015 National Roadway Safety Awards*. 2016. https://safety.fhwa.dot.gov/roadwaysafetyawards/2015/#va2. Accessed January 30, 2019.

Hass, P., Gosse, C., and Garber, N.J. *Development of Safety Performance Functions for Two-Lane Roads Maintained by the Virginia Department of Transportation.* VTRC 10-R25. Virginia Transportation Research Council, Charlottesville, 2010.

Hutchinson, J.W., and Kennedy, T.W. *Medians of Divided Highways—Frequency and Nature of Vehicle Encroachments.* Engineering Experiment Station Bulletin 487. University of Illinois, Champaign, June 1966.

Institute of Transportation Engineers. *2016 ITE Transportation Achievement Awards*. https://www.ite.org/pub/?id=d752ad01-9ca8-04c5-2d71-bd521b248636. Accessed January 30, 2019.

Rivera, G., and Garber, N.J. *Safety Performance Functions for Intersections on Highways Maintained by the Virginia Department of Transportation.* VTRC 11-CR1. Virginia Transportation Research Council, Charlottesville, 2010.

Virginia Department of Transportation. *Virginia 2017-2021 Strategic Highway Safety Plan*. Richmond, 2017.

APPENDIX A

VDOT'S TECHNICAL DEFINITION OF ROADWAY DEPARTURE

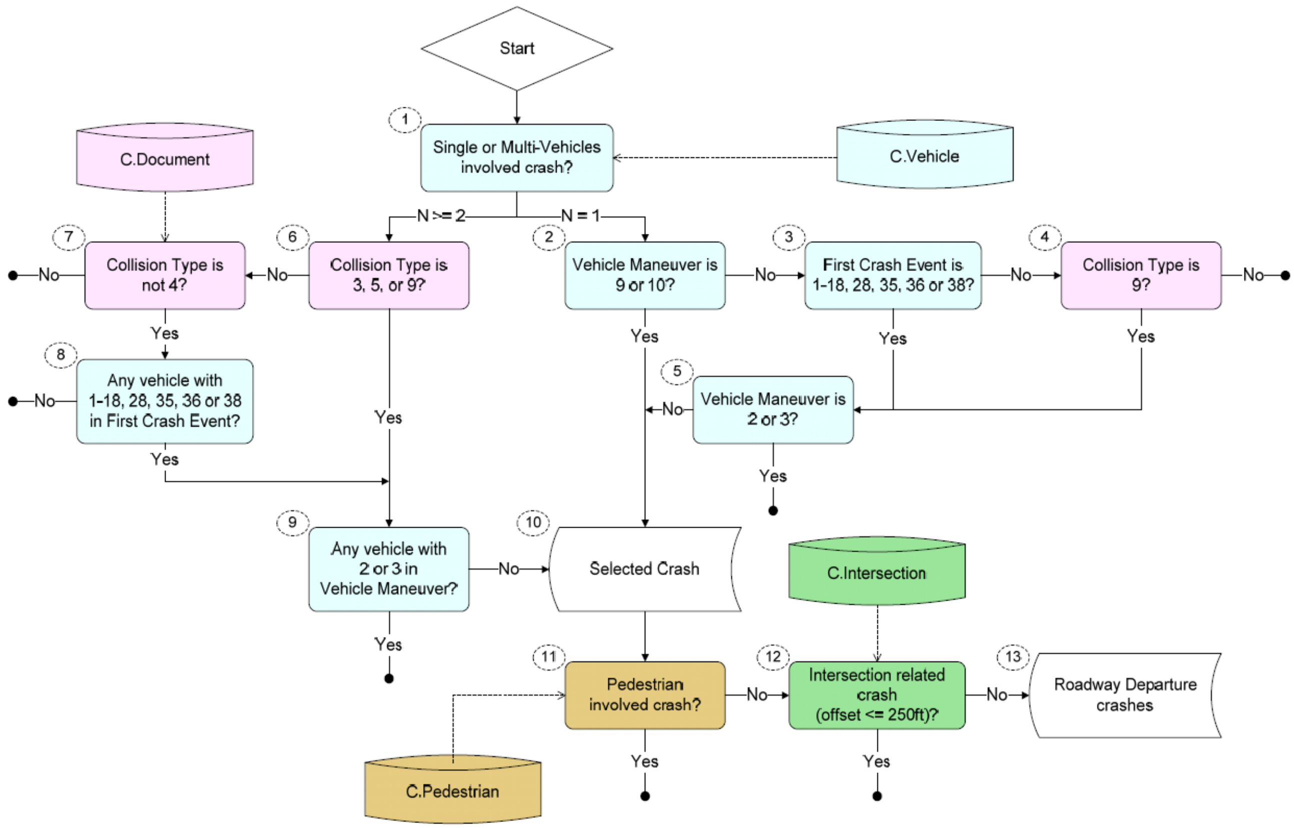


Figure A1. VDOT's Technical Definition of Roadway Departure Crashes. The definition is shown in a flowchart based on VDOT's Oracle database, RNS.

APPENDIX B

DESCRIPTIVE STATISTICS OF FINAL STUDY DATA BY SITE TYPE

Descriptive statistics (e.g., mean and standard deviation) of the variables analyzed for SPF development are presented by site type in Tables B1 through B16. Variable descriptions are provided in Table 2 in the body of the report. It should be noted that variables listed are not necessarily included in the final SPFs developed, but they all were attempted in developing the SPFs. Crashes occurring within 250 feet from an intersection are excluded according to VDOT's RD definition.

Table B1. Descriptive Statistics for Site Type 101 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	383,213	0.110	0.430	0	22
Fatal & Injury RD Crashes		0.050	0.250	0	13
Length		0.520	0.670	0.01	18.29
AADT		1,116	1,929	1	33,506
SurfaceWidth		19.02	5.010	16	86
RtShldWidth		3.470	1.920	0	24
LtShldWidth		3.460	1.910	0	29
MedRtShldWidth		0.000	0.120	0	8
MedLtShldWidth		0.000	0.120	0	8
MedianWidthMin		0.040	1.340	0	105
MedianWidthMax		0.110	3.950	0	400
PaveRoughness		17.72	42.71	0	586
PaveConditionV		0.040	0.390	0	5
ShoulderWidth		3.470	1.900	0	24
MedShldWidth		0.000	0.120	0	8
MedianWidth		0.080	2.520	0	220
MedMedShldWidth		0.080	2.570	0	228
LaneWidth		9.510	2.500	8	13
SurfaceType3456C		Yes: 381,721		No: 1,492	
CurbGutter25		Yes: 22,122		No: 361,091	

Table B2. Descriptive Statistics for Site Type 102 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	3,774	0.120	0.430	0	5
Fatal & Injury RD Crashes		0.060	0.280	0	4
Length		0.200	0.320	0.01	3.83
AADT		9,426	5,315	29	29,600
SurfaceWidth		45.86	4.810	24	70
RtShldWidth		2.680	3.150	0	12
LtShldWidth		2.610	3.120	0	12
MedianWidthMin		0.150	2.780	0	54
MedianWidthMax		0.150	2.780	0	54
PaveRoughness		99.86	49.46	0	399
ShoulderWidth		2.640	3.060	0	12
MedianWidth		0.150	2.780	0	54
MedMedShldWidth		0.150	2.780	0	54
LaneWidth		11.41	1.080	8	17
SurfaceType8		Yes: 30		No: 3,744	
CurbGutter2		Yes: 100		No: 3,674	

Table B3. Descriptive Statistics for Site Type 103 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	21,527	0.310	0.820	0	15
Fatal & Injury RD Crashes		0.140	0.470	0	7
Length		0.350	0.450	0.01	8.59
AADT		11,607	7,676	88	80,000
SurfaceWidth		47.37	4.360	12	96
RtShldWidth		7.230	2.640	0	12
LtShldWidth		7.210	2.870	0	60
MedRtShldWidth		3.000	2.280	0	12
MedLtShldWidth		3.010	2.270	0	12
MedianWidthMin		31.58	21.01	0	120
MedianWidthMax		55.72	59.30	0	460
PaveRoughness		86.77	31.15	0	316
PaveConditionV		0.010	0.220	0	5
ShoulderWidth		7.220	2.620	0	33
MedShldWidth		3.010	2.270	0	12
MedianWidth		43.65	35.39	0	249
MedMedShldWidth		46.66	35.93	0	249
LaneWidth		11.77	0.850	8	23
CurbGutter2		Yes: 180		No: 21,347	

Table B4. Descriptive Statistics for Site Type 104 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	3,002	2.340	2.870	0	24
Fatal & Injury RD Crashes		0.850	1.280	0	10
Length		1.730	1.610	0.01	8.54
AADT		17,419	6,239	3,657	35,884
SurfaceWidth		24.12	1.220	24	40
RtShldWidth		4.740	5.100	0	12
LtShldWidth		5.310	4.940	0	14
MedRtShldWidth		1.590	2.110	0	18
MedLtShldWidth		1.800	2.020	0	10
MedianWidthMin		56.04	25.03	0	200
MedianWidthMax		171.3	137.8	0	640
PaveRoughness		35.82	41.73	0	268
ShoulderWidth		5.020	0.810	0	7
MedShldWidth		1.690	0.840	0	9
MedianWidth		113.7	74.37	0	355
MedMedShldWidth		115.4	74.41	0	356.5
LaneWidth		12.06	0.610	12	20
SurfaceType8		Yes: 255		No: 2,747	
CurbGutter3		Yes: 25		No: 2,977	
CurbGutter5		Yes: 30		No: 2,972	

Table B5. Descriptive Statistics for Site Type 105 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	275	4.120	4.290	0	21
Fatal & Injury RD Crashes		1.260	1.660	0	9
Length		1.730	1.410	0.02	6.5
AADT		44,375	16,189	13,892	71,811
SurfaceWidth		36.44	2.250	36	48
RtShldWidth		4.910	5.220	0	12
LtShldWidth		5.270	5.000	0	10
MedRtShldWidth		4.360	4.910	0	12
MedLtShldWidth		3.240	3.780	0	10
MedianWidthMin		63.76	34.83	0	146
MedianWidthMax		252.7	155.7	0	600
PaveRoughness		37.95	44.25	0	117
ShoulderWidth		5.090	0.290	5	6
MedShldWidth		3.800	1.580	1.5	6
MedianWidth		158.3	90.25	0	363
MedMedShldWidth		162.1	90.90	1.5	369
LaneWidth		12.00	0.000	12	12

Table B6. Descriptive Statistics for Site Type 106 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	1,614	0.650	1.000	0	9
Fatal & Injury RD Crashes		0.220	0.500	0	3
Length		0.310	0.160	0.01	1.31
AADT		17,795	6,255	3,583	35,884
SurfaceWidth		23.98	0.440	16	24
RtShldWidth		4.730	5.060	0	12
LtShldWidth		5.390	4.900	0	10
MedRtShldWidth		1.570	2.060	0	18
MedLtShldWidth		1.830	2.000	0	10
MedianWidthMin		57.10	22.04	0	120
MedianWidthMax		177.7	147.4	0	640
PaveRoughness		36.10	40.39	0	159
ShoulderWidth		5.060	0.540	0	7
MedShldWidth		1.700	0.790	0	9
MedianWidth		117.4	78.45	0	355
MedMedShldWidth		119.1	78.42	1.5	356.5
LaneWidth		11.99	0.220	8	12
SurfaceType8		Yes: 85		No: 1,529	
CurbGutter3		Yes: 10		No: 1,604	

Table B7. Descriptive Statistics for Site Type 107 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	115	1.230	1.450	0	7
Fatal & Injury RD Crashes		0.250	0.490	0	2
Length		0.290	0.130	0.05	0.63
AADT		46,283	13,914	23,234	71,811
SurfaceWidth		36.00	0.000	36	36
RtShldWidth		4.430	5.090	0	12
LtShldWidth		5.650	4.980	0	10
MedRtShldWidth		3.960	4.780	0	12
MedLtShldWidth		4.220	4.320	0	10
MedianWidthMin		61.65	33.66	0	146
MedianWidthMax		273.4	142.4	0	580
PaveRoughness		38.43	45.02	0	117
ShoulderWidth		5.040	0.200	5	6
MedShldWidth		4.090	1.400	1.5	6
MedianWidth		167.5	87.13	0	363
MedMedShldWidth		171.6	87.55	1.5	369
LaneWidth		12.00	0.000	12	12

Table B8. Descriptive Statistics for Site Type 151 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	448,618	0.040	0.280	0	19
Fatal & Injury RD Crashes		0.020	0.150	0	9
Length		0.130	0.160	0.01	14.15
AADT		2,327	4,059	2	79,136
SurfaceWidth		25.40	7.210	16	94
RtShldWidth		2.180	2.520	0	61
LtShldWidth		2.170	2.490	0	42
MedRtShldWidth		0.000	0.120	0	6
MedLtShldWidth		0.000	0.120	0	6
MedianWidthMin		0.170	2.630	0	200
MedianWidthMax		0.300	4.800	0	600
PaveRoughness		8.020	35.33	0	769
PaveConditionV		0.110	0.620	0	5
ShoulderWidth		2.180	2.480	0	42
MedShldWidth		0.000	0.120	0	6
MedianWidth		0.240	3.400	0	303
MedMedShldWidth		0.240	3.450	0	306
LaneWidth		12.70	3.610	8	25
CurbGutter8		Yes: 400		No: 448,218	

Table B9. Descriptive Statistics for Site Type 152 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	25,144	0.110	0.380	0	6
Fatal & Injury RD Crashes		0.050	0.240	0	5
Length		0.120	0.130	0.01	2.41
AADT		14,963	10,073	50	75,287
SurfaceWidth		47.04	6.270	20	88
RtShldWidth		0.930	2.350	0	23
LtShldWidth		0.880	2.270	0	17
MedianWidthMin		0.140	1.770	0	74
MedianWidthMax		0.370	2.970	0	74
PaveRoughness		73.98	88.59	0	807
PaveConditionV		0.270	0.940	0	5
ShoulderWidth		0.900	2.220	0	20
MedianWidth		0.250	2.260	0	74
MedMedShldWidth		0.250	2.260	0	74
LaneWidth		11.69	1.480	8	22
CurbGutter5		Yes: 20,229		No: 4,915	
SurfaceType8		Yes: 455		No: 24,689	

Table B10. Descriptive Statistics for Site Type 153 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	67,309	0.170	0.590	0	24
Fatal & Injury RD Crashes		0.070	0.320	0	10
Length		0.150	0.210	0.01	4.4
AADT		24,868	17,083	51	140,708
SurfaceWidth		51.85	11.23	16	120
RtShldWidth		3.270	4.120	0	30
LtShldWidth		3.170	4.040	0	30
MedRtShldWidth		1.180	2.140	0	30
MedLtShldWidth		1.150	2.060	0	12
MedianWidthMin		13.36	18.29	0	220
MedianWidthMax		24.51	32.49	0	460
PaveRoughness		83.80	72.31	0	563
PaveConditionV		0.170	0.780	0	5
ShoulderWidth		3.220	3.950	0	30
MedShldWidth		1.170	2.040	0	16.5
MedianWidth		18.93	23.04	0	250
MedMedShldWidth		20.10	24.05	0	252
LaneWidth		11.950	1.160	8	25.5
CurbGutter4		Yes: 358		No: 66,951	
CurbGutter1235		Yes: 65,660		No: 1,649	

Table B11. Descriptive Statistics for Site Type 155 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	2,513	1.330	1.940	0	19
Fatal & Injury RD Crashes		0.460	0.860	0	8
Length		0.740	0.830	0.01	5.56
AADT		28,435	14,024	3,992	102,219
SurfaceWidth		24.26	1.860	22	52
RtShldWidth		5.720	5.040	0	12
LtShldWidth		4.570	5.010	0	12
MedRtShldWidth		2.320	3.250	0	18
MedLtShldWidth		1.660	2.450	0	10
MedianWidthMin		38.11	28.17	0	200
MedianWidthMax		86.29	90.06	0	610
PaveRoughness		52.15	61.28	0	307
ShoulderWidth		5.140	1.520	0	10
MedShldWidth		1.990	1.490	0	9
MedianWidth		62.20	54.43	0	334
MedMedShldWidth		64.19	54.46	0	335.5
LaneWidth		12.13	0.930	11	26
CurbGutter1235		Yes: 2,498		No: 15	

Table B12. Descriptive Statistics for Site Type 156 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	2,291	1.850	2.960	0	28
Fatal & Injury RD Crashes		0.660	1.220	0	10
Length		0.600	0.710	0.01	4.2
AADT		46,377	21,528	2,168	121,041
SurfaceWidth		36.32	2.060	24	57
RtShldWidth		5.550	5.160	0	12
LtShldWidth		4.520	5.150	0	14
MedRtShldWidth		3.480	4.180	0	12
MedLtShldWidth		2.630	3.620	0	10
MedianWidthMin		39.70	39.21	0	180
MedianWidthMax		76.77	98.74	0	580
PaveRoughness		60.64	60.36	0	256
ShoulderWidth		5.040	1.060	0	11
MedShldWidth		3.060	1.750	0	6
MedianWidth		58.24	64.49	0	363
MedMedShldWidth		61.29	65.16	0	368
LaneWidth		12.11	0.690	8	19
CurbGutter1235		Yes: 2,286		No: 5	

Table B13. Descriptive Statistics for Site Type 157 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	1,528	1.680	2.130	0	18
Fatal & Injury RD Crashes		0.620	1.060	0	11
Length		0.440	0.460	0.01	2.45
AADT		73,567	20,336	29,593	121,041
SurfaceWidth		49.69	4.710	36	72
RtShldWidth		4.720	5.070	0	12
LtShldWidth		4.520	5.110	0	16
MedRtShldWidth		2.780	3.990	0	12
MedLtShldWidth		2.230	3.630	0	30
MedianWidthMin		32.59	47.01	0	200
MedianWidthMax		48.61	77.49	0	540
PaveRoughness		51.83	53.66	0	290
PaveConditionV		0.020	0.270	0	4.8
ShoulderWidth		4.620	1.830	0	10
MedShldWidth		2.500	2.040	0	15
MedianWidth		40.60	56.36	0	285.5
MedMedShldWidth		43.11	57.15	0	288.5
LaneWidth		11.99	0.170	9	12
SurfaceType8		Yes: 463		No: 1,065	
CurbGutter2		Yes: 120		No: 1,408	
CurbGutter25		Yes: 135		No: 1,393	

Table B14. Descriptive Statistics for Site Type 158 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	1,883	0.710	1.200	0	12
Fatal & Injury RD Crashes		0.220	0.540	0	5
Length		0.240	0.200	0.01	1.57
AADT		29,085	16,418	3,660	122,682
SurfaceWidth		24.20	1.630	18	41
RtShldWidth		5.040	5.140	0	12
LtShldWidth		4.850	5.030	0	12
MedRtShldWidth		2.050	2.840	0	10
MedLtShldWidth		2.310	3.010	0	10
MedianWidthMin		38.43	28.78	0	160
MedianWidthMax		83.36	96.28	0	610
PaveRoughness		53.68	62.43	0	267
ShoulderWidth		4.950	1.180	0	10
MedShldWidth		2.180	1.380	0	5
MedianWidth		60.90	56.86	0	334
MedMedShldWidth		63.08	56.74	0	335.5
LaneWidth		12.10	0.820	9	20.5

Table B15. Descriptive Statistics for Site Type 159 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	1,952	1.290	2.020	0	20
Fatal & Injury RD Crashes		0.410	0.840	0	11
Length		0.250	0.260	0.01	2.21
AADT		50,046	20,610	10,931	93,477
SurfaceWidth		36.13	1.230	24	45
RtShldWidth		4.650	5.110	0	12
LtShldWidth		5.180	5.180	0	14
MedRtShldWidth		2.800	3.760	0	12
MedLtShldWidth		2.930	3.700	0	10
MedianWidthMin		35.66	34.95	0	200
MedianWidthMax		70.13	102.3	0	580
PaveRoughness		50.60	56.54	0	268
ShoulderWidth		4.920	1.260	0	11
MedShldWidth		2.870	1.690	0	6
MedianWidth		52.89	65.29	0	363
MedMedShldWidth		55.76	65.85	0	368
LaneWidth		12.04	0.410	8	15
SurfaceType8		Yes: 432		No: 1,520	

Table B16. Descriptive Statistics for Site Type 160 (2011-2015)

Variables	Nobs	Mean	Std. Dev.	Min.	Max.
All RD Crashes	956	1.260	1.740	0	11
Fatal & Injury RD Crashes		0.440	0.820	0	6
Length		0.250	0.300	0.01	2.05
AADT		71,294	17,602	30,645	121,041
SurfaceWidth		48.97	3.400	36	60
RtShldWidth		4.080	4.980	0	12
LtShldWidth		6.000	5.030	0	16
MedRtShldWidth		2.030	3.530	0	12
MedLtShldWidth		3.050	3.590	0	10
MedianWidthMin		36.79	52.97	0	200
MedianWidthMax		49.54	73.33	0	400
PaveRoughness		42.47	54.96	0	168
ShoulderWidth		5.040	1.050	0	10
MedShldWidth		2.540	1.800	0	6
MedianWidth		43.16	58.71	0	215.5
MedMedShldWidth		45.71	59.60	0	215.5
LaneWidth		11.98	0.240	9	12
CurbGutter1235		Yes: 951		No: 5	

APPENDIX C

ESTIMATED GLM MODELS FOR ROADWAY DEPARTURE CRASHES

All Roadway Departure (RD) Crashes

Developed NB models with only AADT in logarithmic functional form for all RD crashes are presented in Table C1.

Table C1. Estimated NB Models With Only AADT in Logarithmic Functional Form for All RD Crashes (2011-2015)

Site Type	Variable	Coefficient	Std. Err.	p-value	NB Dispersion	No. Obs.
101	Intercept	-5.57E+00	2.90E-02	2.00E-16	1.425	383,213
	ln(AADT)	6.21E-01	4.20E-03	2.00E-16		
102	Intercept	-3.98E+00	8.40E-01	2.11E-06	1.676	3,774
	ln(AADT)	3.80E-01	9.23E-02	3.91E-05		
103	Intercept	-6.29E+00	2.28E-01	2.00E-16	2.158	21,527
	ln(AADT)	6.63E-01	2.43E-02	2.00E-16		
104	Intercept	-4.48E+00	3.70E-01	2.00E-16	5.761	3,002
	ln(AADT)	4.93E-01	3.80E-02	2.00E-16		
105	Intercept	-1.21E+01	1.28E+00	2.00E-16	7.441	275
	ln(AADT)	1.21E+00	1.19E-01	2.00E-16		
106	Intercept	-2.96E+00	8.79E-01	7.69E-04	1.813	1,614
	ln(AADT)	3.83E-01	9.01E-02	2.14E-05		
107	Intercept	-1.09E+01	3.59E+00	2.40E-03	8.362	115
	ln(AADT)	1.14E+00	3.31E-01	5.69E-04		
151	Intercept	-6.37E+00	5.18E-02	2.00E-16	0.559	448,618
	ln(AADT)	6.92E-01	6.31E-03	2.00E-16		
152	Intercept	-4.78E+00	2.92E-01	2.00E-16	1.459	25,144
	ln(AADT)	4.87E-01	3.04E-02	2.00E-16		
153	Intercept	-5.27E+00	1.65E-01	2.00E-16	1.189	67,309
	ln(AADT)	5.34E-01	1.63E-02	2.00E-16		
155	Intercept	-5.57E+00	5.41E-01	2.00E-16	2.145	2,513
	ln(AADT)	6.16E-01	5.31E-02	2.00E-16		
156	Intercept	-8.82E+00	5.17E-01	2.00E-16	2.376	2,291
	ln(AADT)	9.37E-01	4.82E-02	2.00E-16		
157	Intercept	-8.18E+00	1.08E+00	4.25E-14	2.814	1,528
	ln(AADT)	8.61E-01	9.69E-02	2.00E-16		
158	Intercept	-4.59E+00	6.78E-01	1.23E-11	1.390	1,883
	ln(AADT)	5.64E-01	6.62E-02	2.00E-16		
159	Intercept	-4.39E+00	6.30E-01	3.42E-12	1.932	1,952
	ln(AADT)	5.67E-01	5.84E-02	2.00E-16		
160	Intercept	-1.60E+00	1.55E+00	3.03E-01	2.004	956
	ln(AADT)	3.00E-01	1.39E-01	3.11E-02		

Note: Crashes occurring within 250 feet from an intersection are excluded.

Using the results in the table, the predicted annual number of all crashes can be calculated using the following equation:

$$N_{SPF} = \exp[\alpha + \beta \times \ln(AADT) + \ln(Length)]$$

where

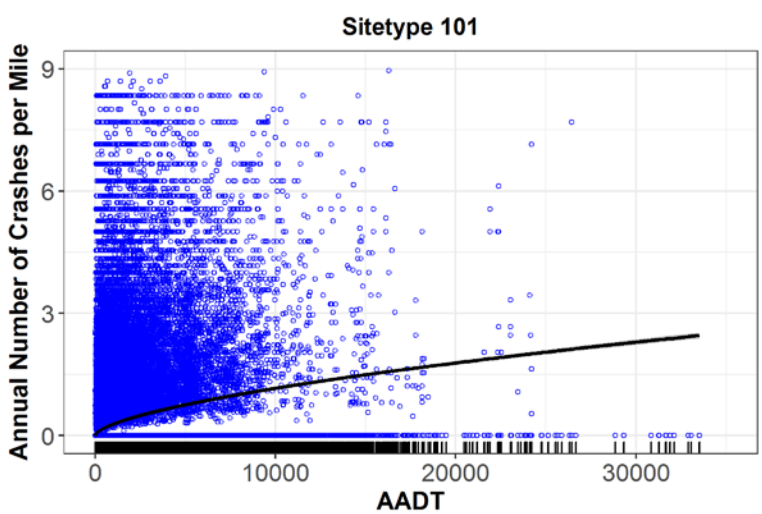
N_{spf} = annual number of crashes by SPF (crashes per year)
$AADT$ = annual average daily traffic (vehicles per day)
$Length$ = segment length (miles)
α, β = coefficient estimates of SPF.

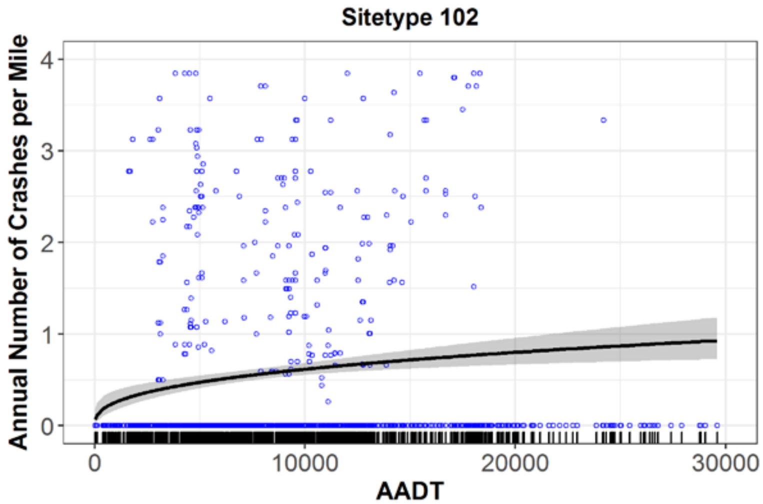
For the example of Site Type 101, the predicted annual number of crashes is calculated by the following equation:

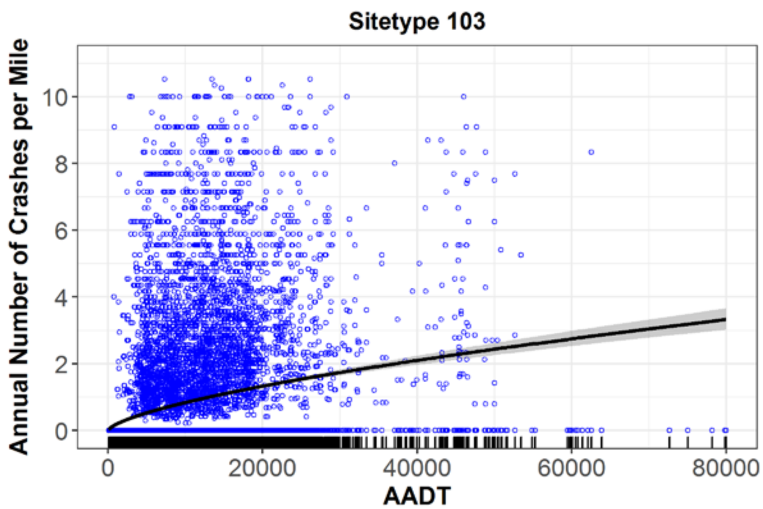
$$N_{SPF} = exp[-5.570 + 0.621 \times \ln(AADT) + \ln(Length)]$$
$$= e^{-5.570} \times AADT^{0.621} \times Length$$

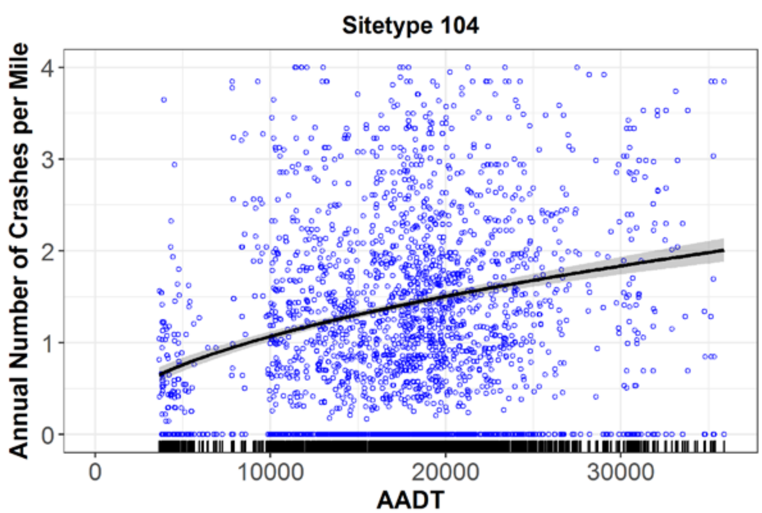
The models shown in Table C1 are presented in a functional form in Table 3 in the body of the report.

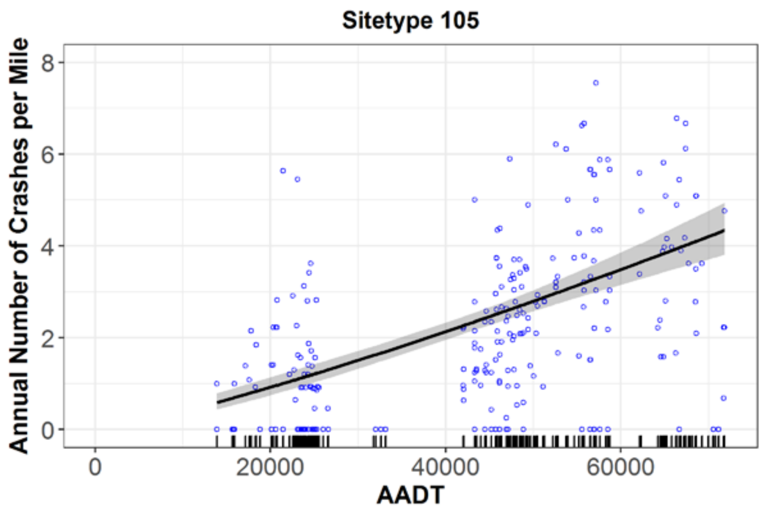
The graphs that follow, "SPFs With Only AADT in Logarithmic Functional Form for All RD Crashes," visualize the models in Table C1 with the segment length set at 1 mile for all RD crashes. In the graphs, a circle represents a segment; a solid line represents an SPF with the segment length of 1 mile and a corresponding AADT; and the gray band surrounding the solid line represents the 95th percentile mean prediction limit. It should also be noted that for visual clarity the graphs do not show all data points.

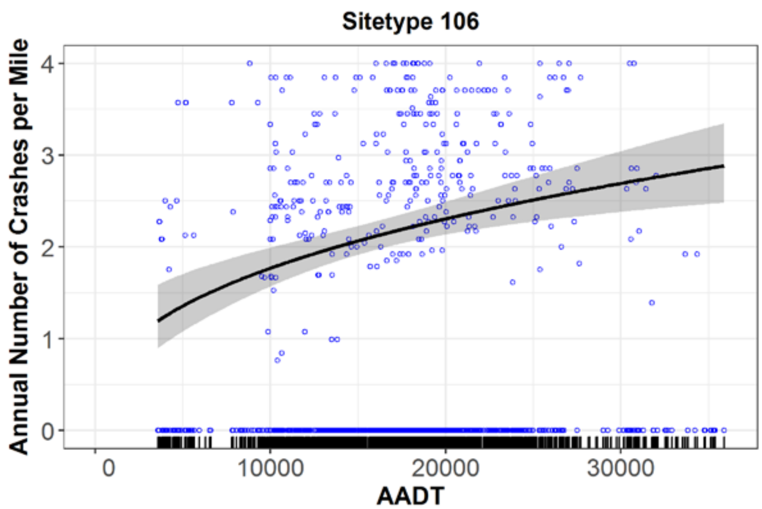


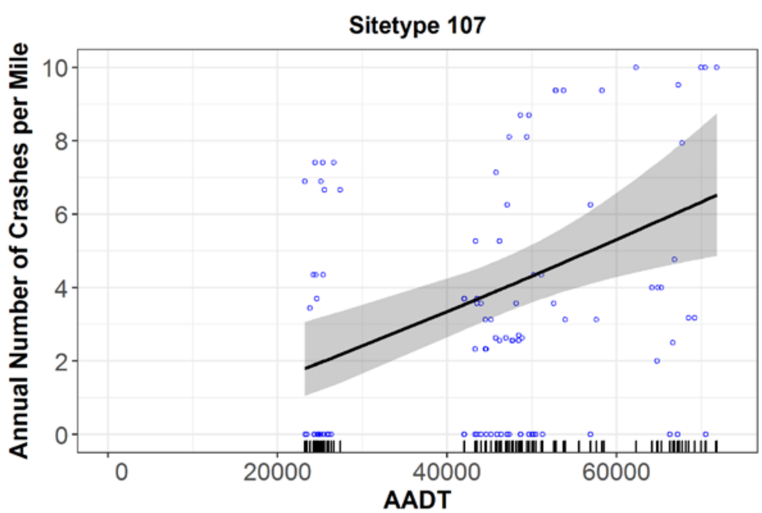

Sitetype 102
Annual Number of Crashes per Mile
0
1
2
3
4
0
10000
20000
30000
AADT

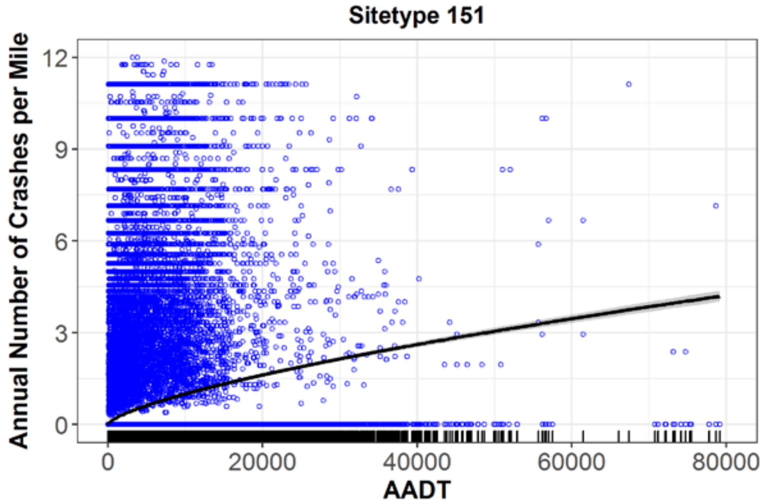

Sitetype 103
Annual Number of Crashes per Mile
0
2
4
6
8
10
0
20000
40000
60000
80000
AADT

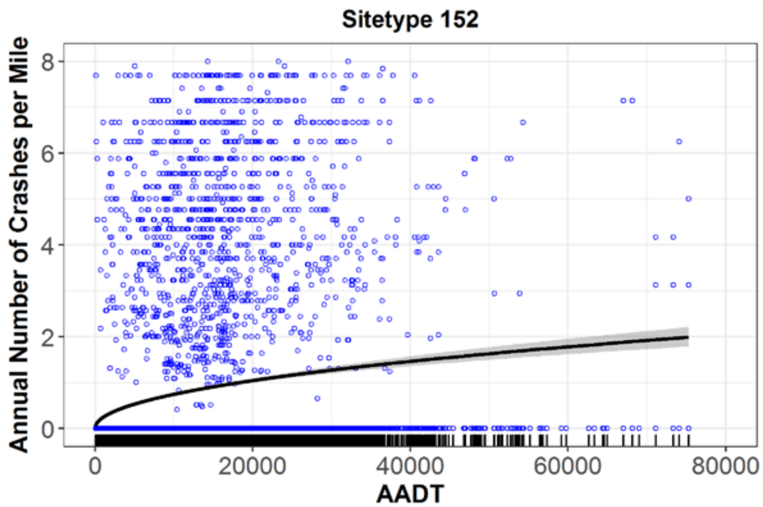

Sitetype 104
Annual Number of Crashes per Mile
0
1
2
3
4
0
10000
20000
30000
AADT

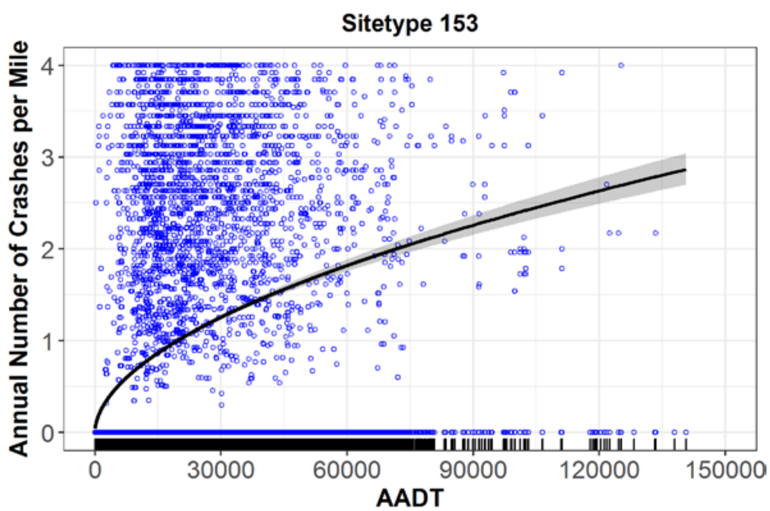

Sitetype 105
Annual Number of Crashes per Mile
8
6
4
2
0
0
20000
40000
60000
AADT

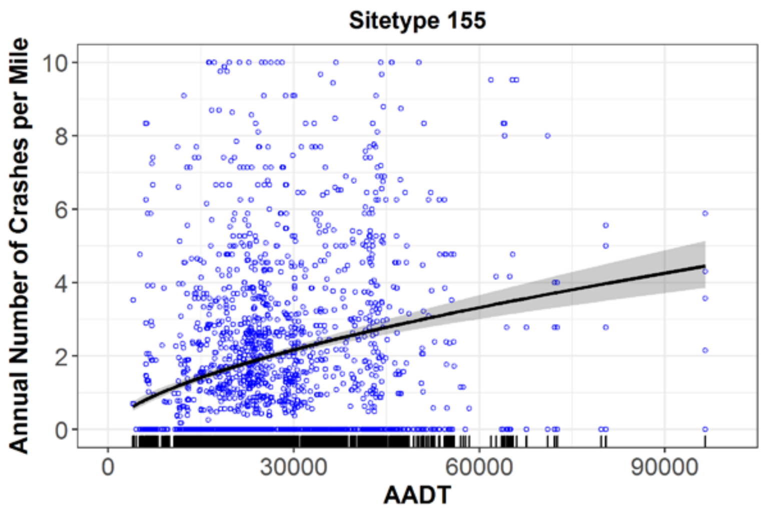

Sitetype 106
Annual Number of Crashes per Mile
4
3
2
1
0
0
10000
20000
30000
AADT

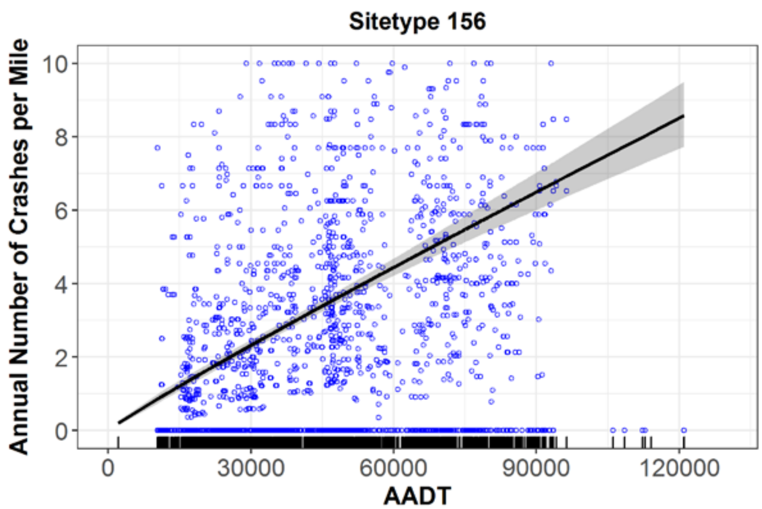

Sitetype 107
Annual Number of Crashes per Mile
10
8
6
4
2
0
0
20000
40000
60000
AADT

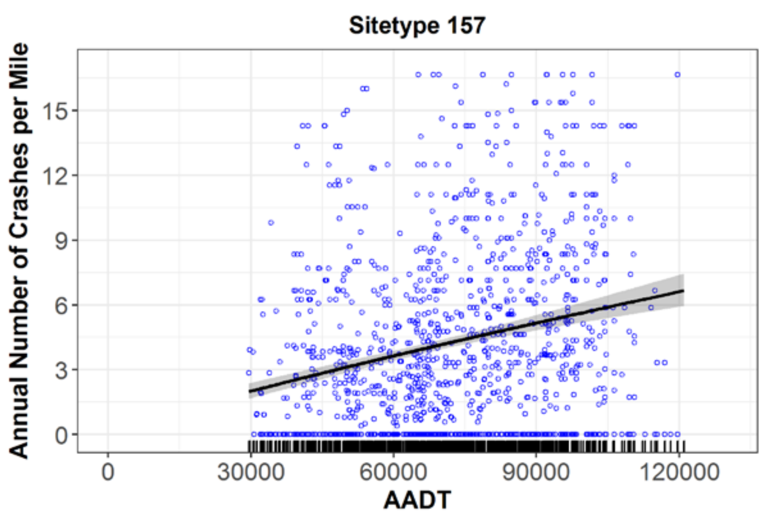

Sitetype 151
Annual Number of Crashes per Mile
0
3
6
9
12
0
20000
40000
60000
80000
AADT

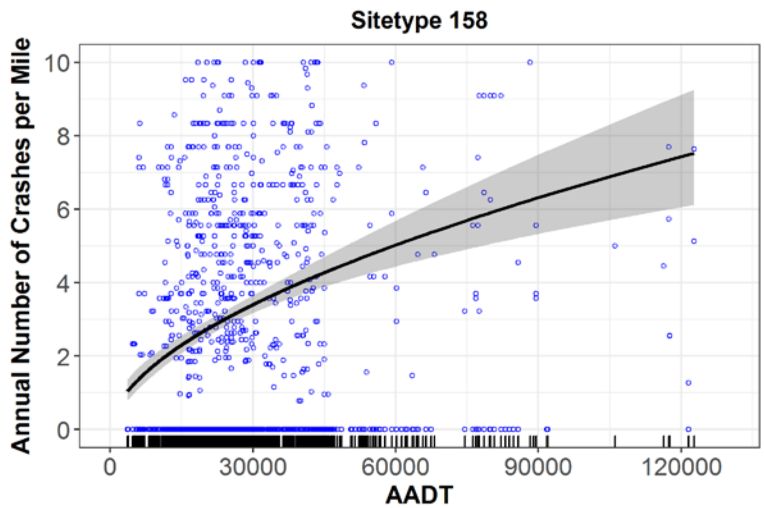

Sitetype 152
Annual Number of Crashes per Mile
0
2
4
6
8
0
20000
40000
60000
80000
AADT

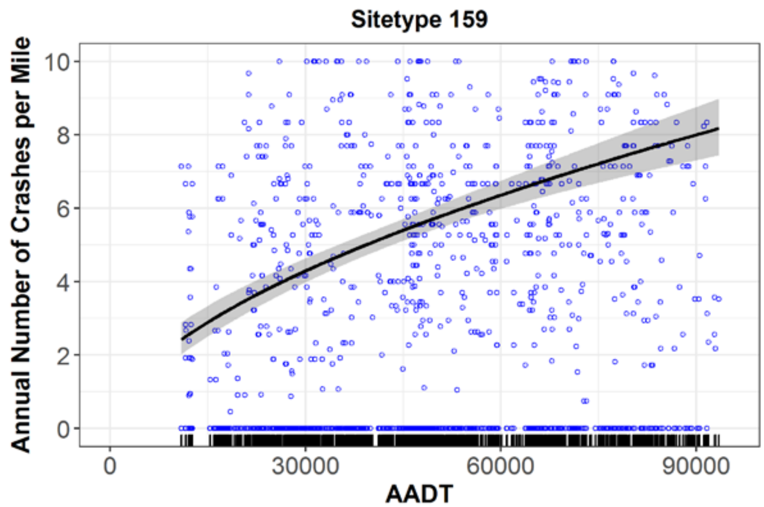

Sitetype 153
Annual Number of Crashes per Mile
0
1
2
3
4
0
30000
60000
90000
120000
150000
AADT

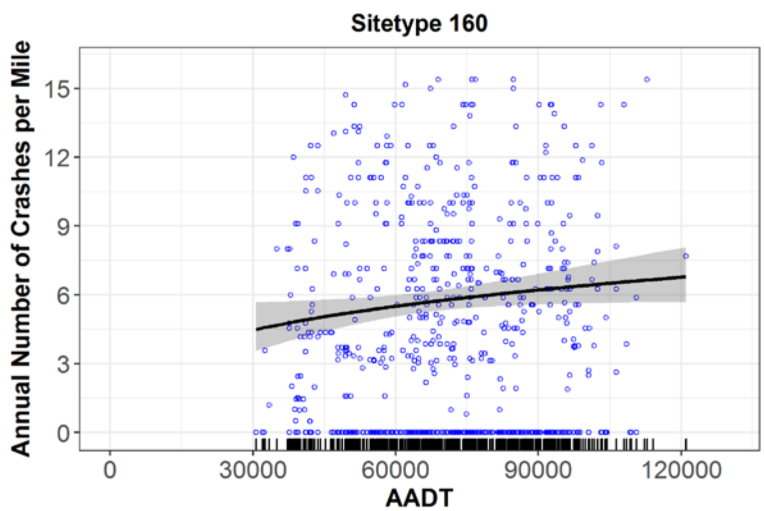

Sitetype 155
Annual Number of Crashes per Mile
0
2
4
6
8
10
0
30000
60000
90000
AADT


Sitetype 156
Annual Number of Crashes per Mile
0
2
4
6
8
10
0
30000
60000
90000
120000
AADT


Sitetype 157
Annual Number of Crashes per Mile
0
3
6
9
12
15
0
30000
60000
90000
120000
AADT







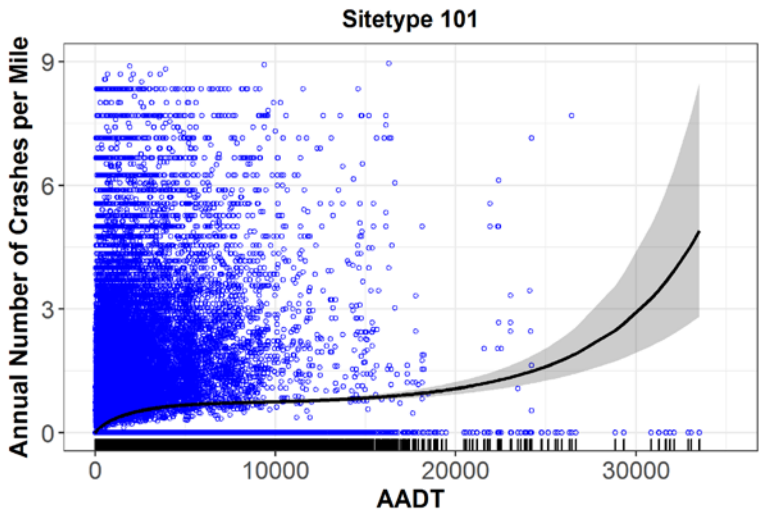
Developed NB models with only AADT in a customized functional form for all RD crashes are presented in Table C2; they are presented in a functional form in Table 4 in the body of the report.

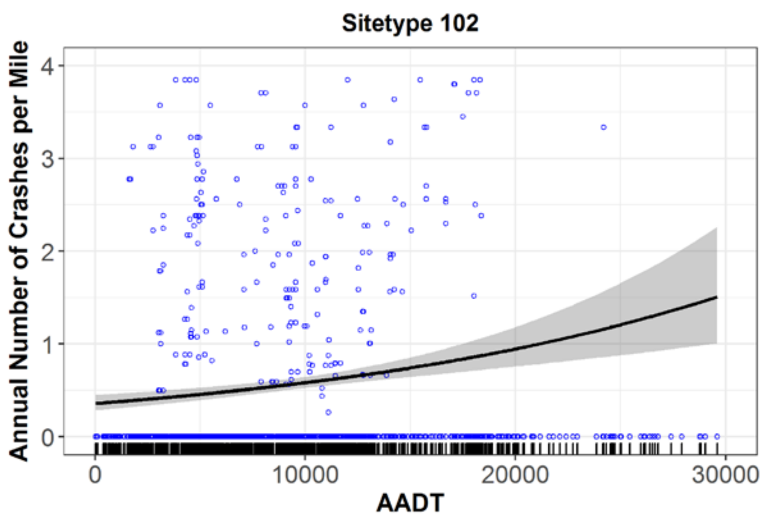
Table C2. Estimated NB Models With Only AADT in Customized Functional Form for All RD Crashes (2011-2015)

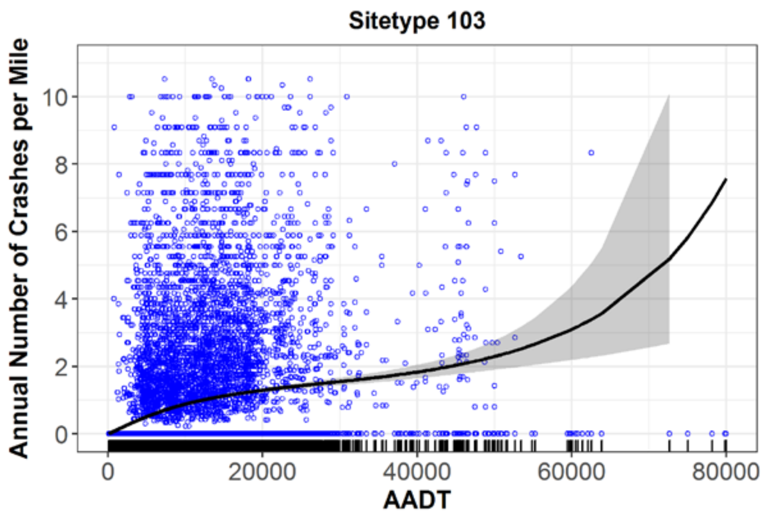
Site Type	Variable	Coefficient	Std. Err.	p-value	NB Dispersion	No. Obs.
101	Intercept	-7.58E+00	3.01E-01	2.00E-16	1.489	383,213
	AADT	-1.32E-04	1.98E-05	3.25E-11		
	$AADT^2$	4.14E-09	5.94E-10	3.40E-12		
	ln(AADT)	1.13E+00	1.06E-01	2.00E-16		
	$(\ln(AADT))^2$	-2.64E-02	9.46E-03	5.23E-03		
102	Intercept	-1.03E+00	1.17E-01	2.00E-16	1.767	3,774
	AADT	4.87E-05	1.03E-05	2.39E-06		
103	Intercept	-1.02E+01	1.01E+00	2.00E-16	2.184	21,527
	AADT	-6.00E-05	1.63E-05	2.41E-04		
	$AADT^2$	6.29E-10	2.06E-10	2.20E-03		
	ln(AADT)	1.15E+00	1.26E-01	2.00E-16		
104	Intercept	-1.17E+02	2.16E+01	6.76E-08	6.120	3,002
	AADT	2.41E-04	4.50E-05	8.95E-08		
	ln(AADT)	2.70E+01	5.08E+00	1.07E-07		
	$(\ln(AADT))^2$	-1.58E+00	3.02E-01	1.58E-07		
105	Intercept	-1.21E+01	1.28E+00	2.00E-16	7.441	275
	ln(AADT)	1.21E+00	1.19E-01	2.00E-16		
106	Intercept	-2.96E+00	8.79E-01	7.69E-04	1.813	1,614
	ln(AADT)	3.83E-01	9.01E-02	2.14E-05		
107	Intercept	9.75E-03	3.82E-01	9.80E-01	9.863	115
	AADT	2.79E-05	7.05E-06	7.53E-05		
151	Intercept	-8.94E+00	1.04E-01	2.00E-16	0.634	448,618
	AADT	-1.38E-04	4.83E-06	2.00E-16		
	$AADT^2$	1.54E-09	8.92E-11	2.00E-16		
	ln(AADT)	1.10E+00	1.51E-02	2.00E-16		
152	Intercept	8.38E+00	3.04E+00	5.76E-03	1.489	25,144
	AADT	-1.53E-04	2.74E-05	2.64E-08		
	$AADT^2$	1.08E-09	2.31E-10	3.29E-06		
	ln(AADT)	-3.52E+00	8.33E-01	2.33E-05		
	$(\ln(AADT))^2$	2.98E-01	5.79E-02	2.72E-07		
153	Intercept	-5.27E+00	1.65E-01	2.00E-16	1.189	67,309
	ln(AADT)	5.34E-01	1.63E-02	2.00E-16		
155	Intercept	-2.69E+00	1.26E+00	3.23E-02	2.164	2,513
	AADT	1.17E-05	4.58E-06	1.06E-02		
	ln(AADT)	2.99E-01	1.35E-01	2.74E-02		
156	Intercept	1.20E+02	1.79E+01	1.54E-11	2.456	2,291
	AADT	-9.77E-05	1.25E-05	5.00E-15		
	ln(AADT)	-2.70E+01	3.79E+00	1.07E-12		
	$(\ln(AADT))^2$	1.52E+00	2.03E-01	7.37E-14		
157	Intercept	-4.51E+03	1.30E+03	5.27E-04	2.913	1,528
	AADT	3.10E-03	8.87E-04	4.86E-04		
	$AADT^2$	-5.78E-09	1.67E-09	5.34E-04		
	ln(AADT)	9.34E+02	2.69E+02	5.23E-04		
	$(\ln(AADT))^2$	-4.90E+01	1.41E+01	5.20E-04		
158	Intercept	6.86E+00	6.80E-01	2.00E-16	1.392	1,883
	1/ln(AADT)	-5.80E+01	6.92E+00	2.00E-16		
159	Intercept	2.80E-01	1.67E-01	9.43E-02	1.993	1,952
	AADT	4.96E-05	6.90E-06	6.29E-13		
	$AADT^2$	-3.68E-10	6.52E-11	1.68E-08		
160	Intercept	-2.24E+02	4.31E+01	2.08E-07	2.225	956
	AADT	-6.74E-04	1.35E-04	6.52E-07		
	$AADT^2$	2.32E-09	4.88E-10	1.94E-06		
	ln(AADT)	2.34E+01	4.50E+00	1.90E-07		

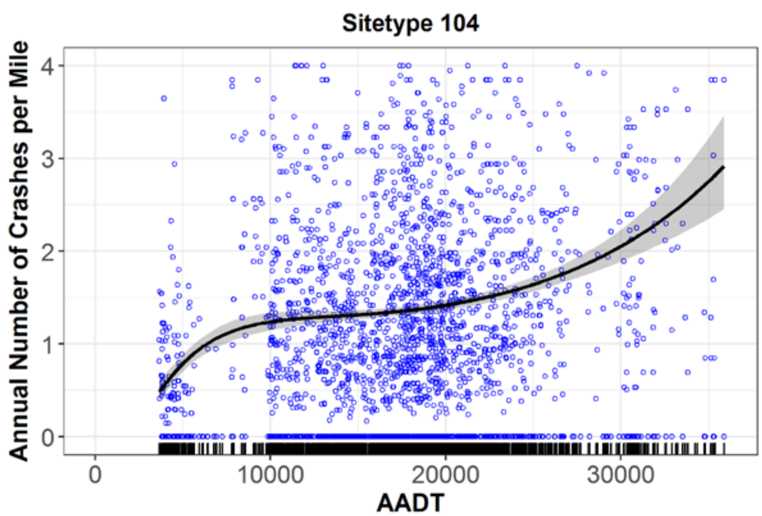
Note: Crashes occurring within 250 feet from an intersection are excluded.

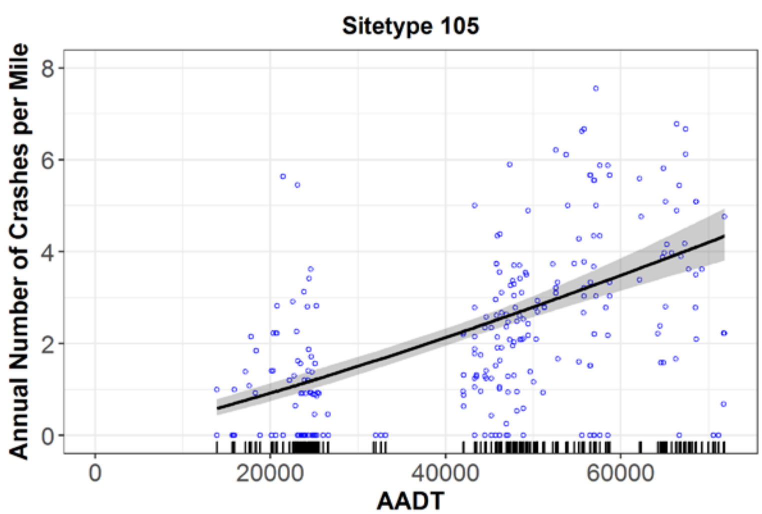
The graphs that follow, "SPFs With Only AADT in a Customized Functional Form for All RD Crashes," visualize the models in Table C2 with the segment length set at 1 mile for all RD crashes. In the graphs, a circle represents a segment; a solid line represents an SPF with the segment length of 1 mile and a corresponding AADT; and the gray band surrounding the solid line represents the 95th percentile mean prediction limit. It should also be noted that for visual clarity the graphs do not show all data points.

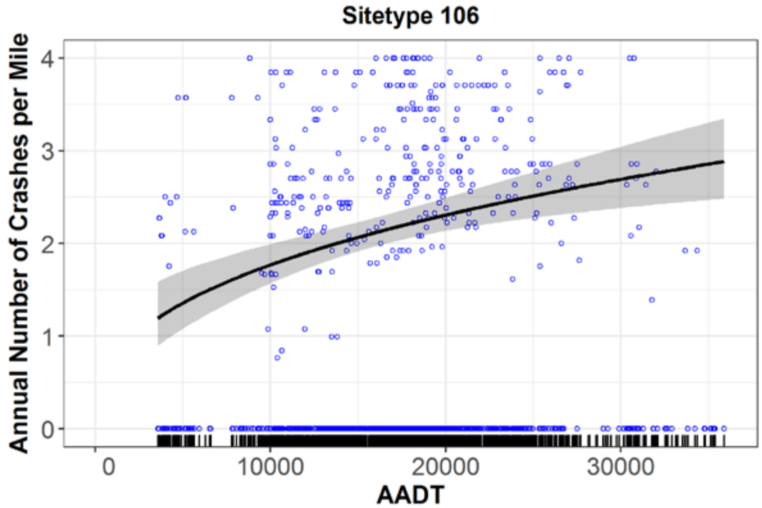


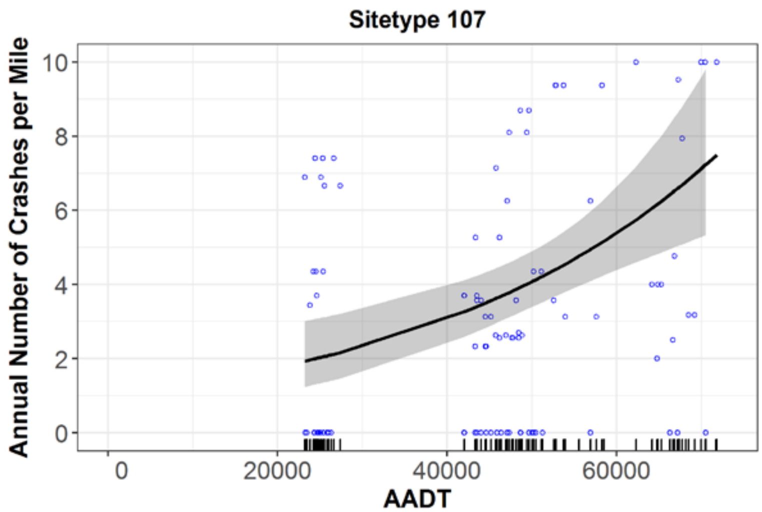


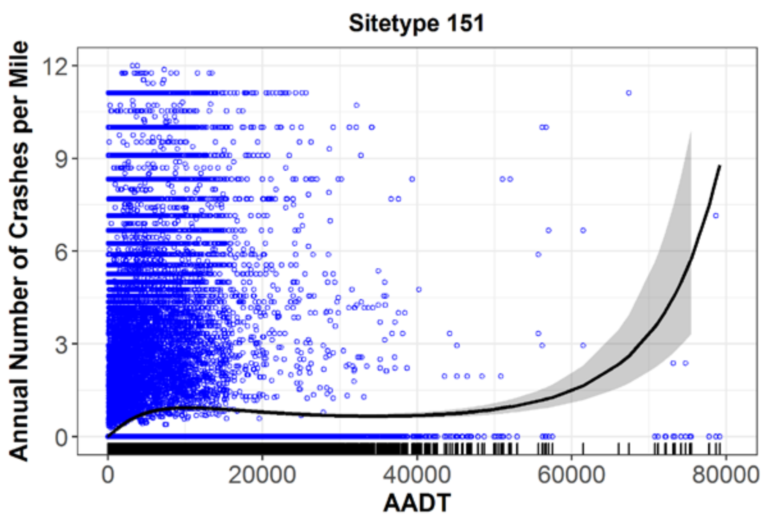

Sitetype 103
Annual Number of Crashes per Mile
0
2
4
6
8
10
0
20000
40000
60000
80000
AADT

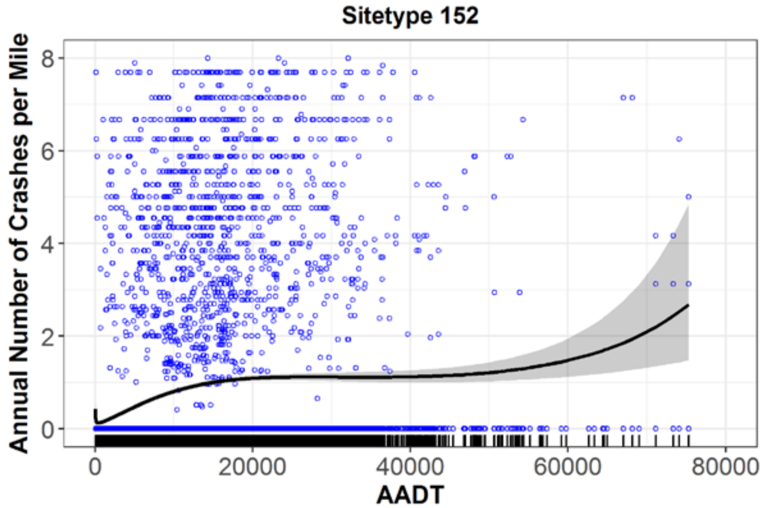

Sitetype 104
Annual Number of Crashes per Mile
0
1
2
3
4
0
10000
20000
30000
AADT

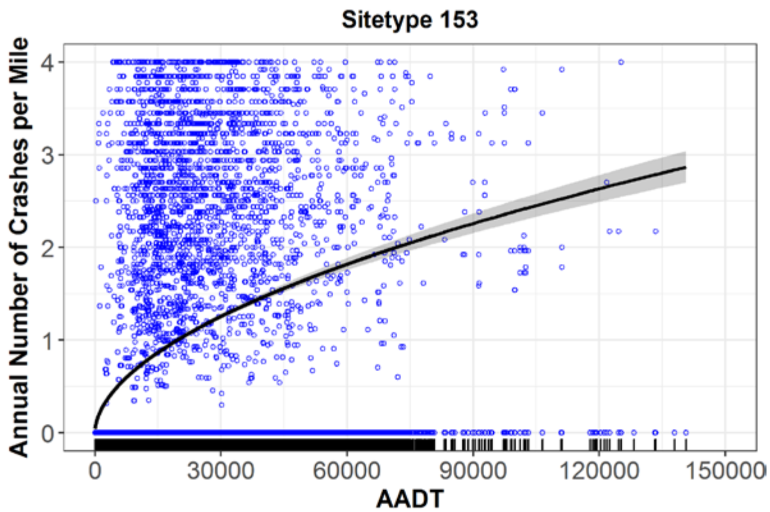

Sitetype 105
Annual Number of Crashes per Mile
0
2
4
6
8
0
20000
40000
60000
AADT

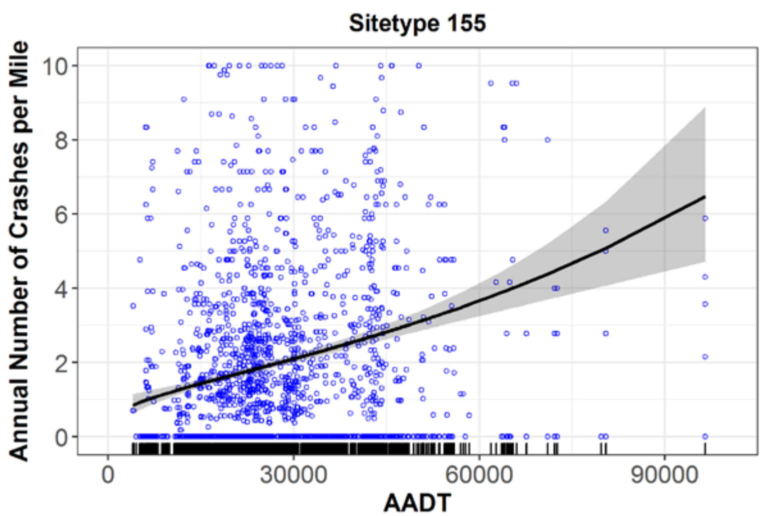

Sitetype 106
Annual Number of Crashes per Mile
0
1
2
3
4
0
10000
20000
30000
AADT

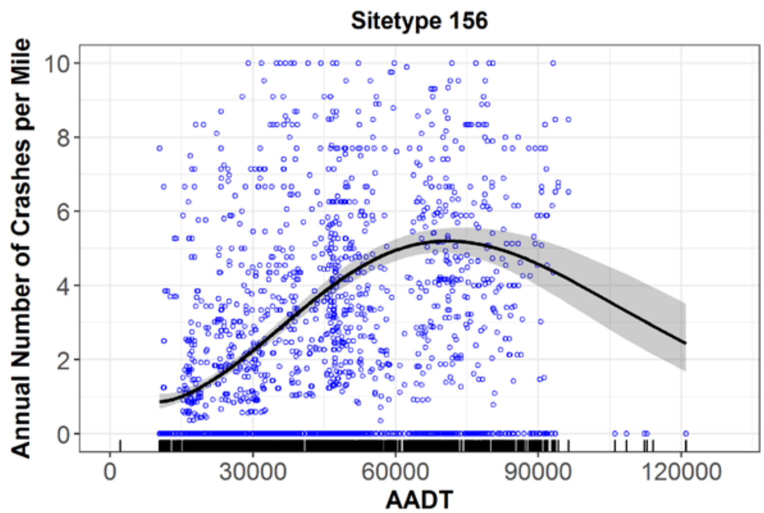

Sitetype 107
Annual Number of Crashes per Mile
0
2
4
6
8
10
0
20000
40000
60000
AADT

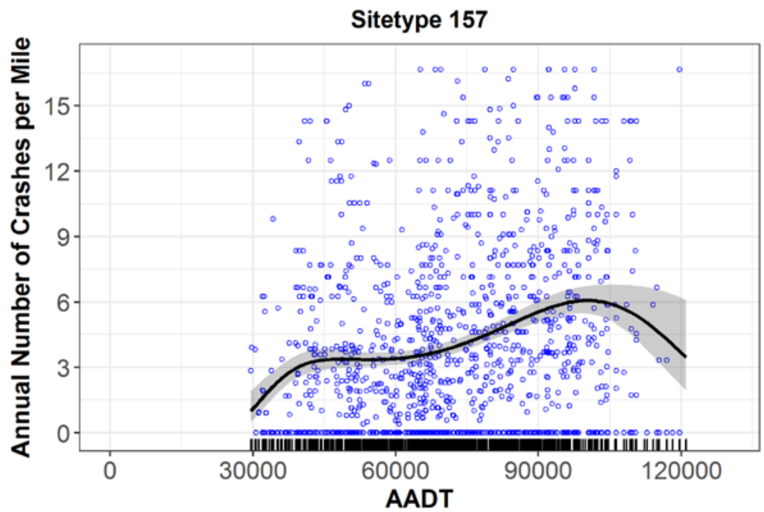

Sitetype 151
Annual Number of Crashes per Mile
0
3
6
9
12
0
20000
40000
60000
80000
AADT

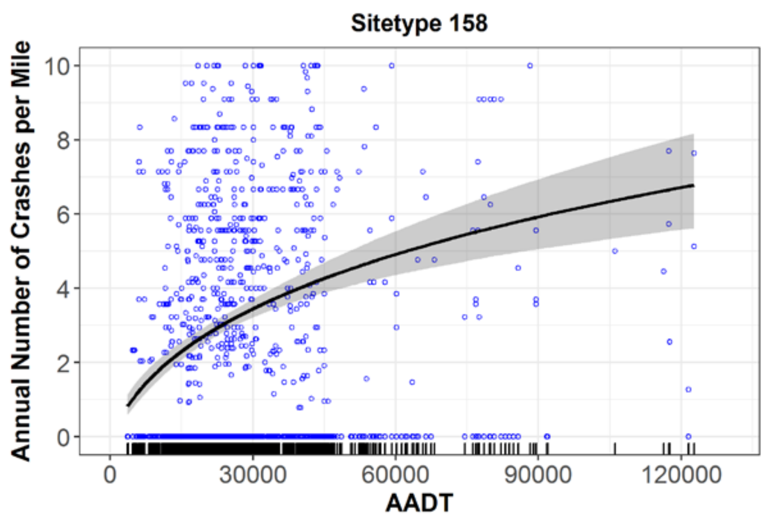

Sitetype 152
Annual Number of Crashes per Mile
0
2
4
6
8
0
20000
40000
60000
80000
AADT

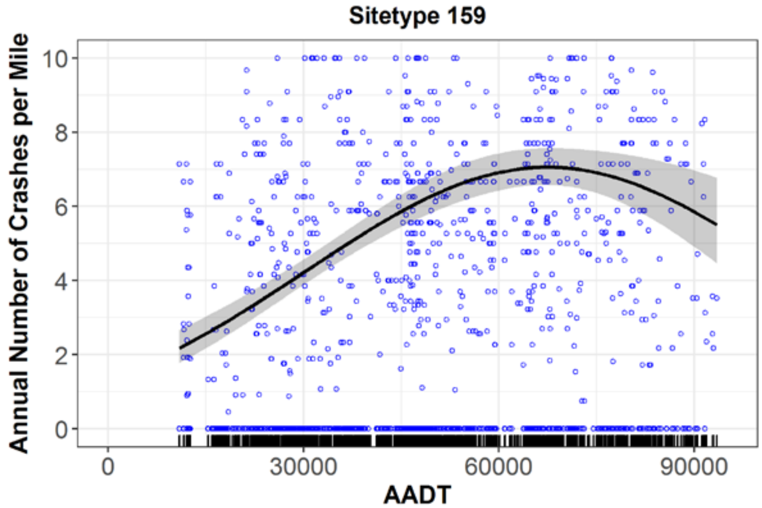

Sitetype 153
Annual Number of Crashes per Mile
0
1
2
3
4
0
30000
60000
90000
120000
150000
AADT

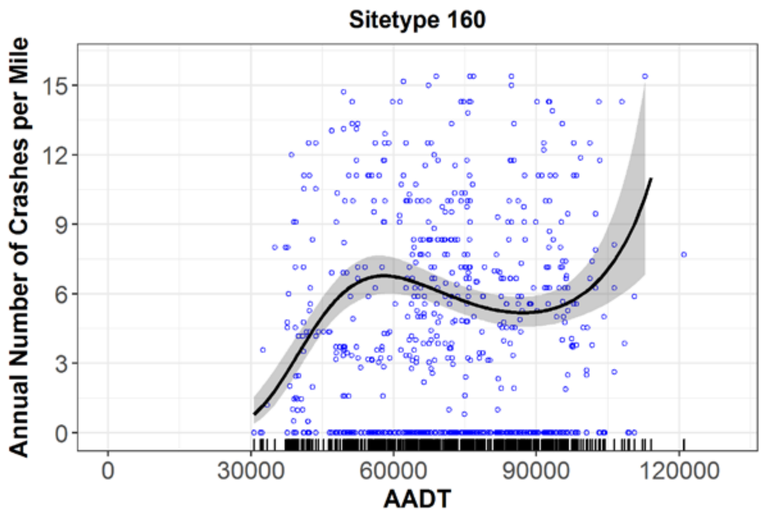

Sitetype 155
Annual Number of Crashes per Mile
0
2
4
6
8
10
0
30000
60000
90000
AADT


Sitetype 156
Annual Number of Crashes per Mile
0
2
4
6
8
10
0
30000
60000
90000
120000
AADT


Sitetype 157
Annual Number of Crashes per Mile
0
3
6
9
12
15
0
30000
60000
90000
120000
AADT


Sitetype 158
Annual Number of Crashes per Mile
0
2
4
6
8
10
0
30000
60000
90000
120000
AADT





Developed NB models with AADT and other predictors in customized functional forms for all RD crashes are presented in Table C3; they are presented in a functional form in Table 5 in the body of the report.

Table C3. Estimated NB Models With AADT and Other Predictors in Customized Functional Form for All RD Crashes (2011-2015)

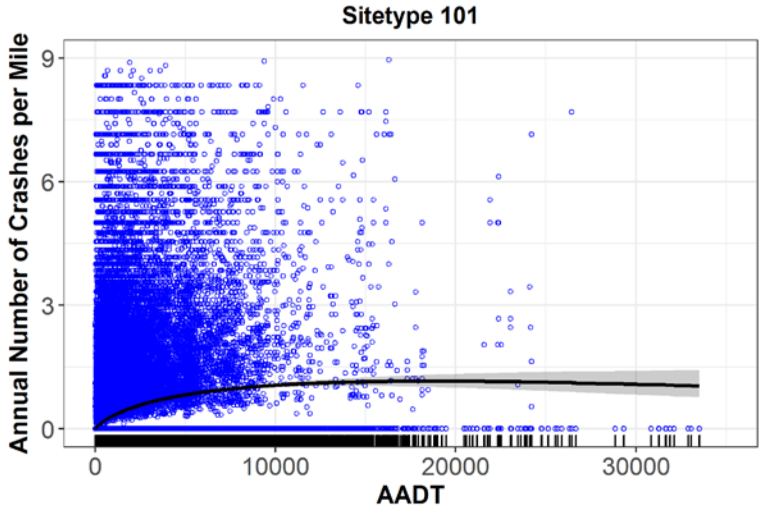
Site Type	Variable	Coefficient	Std. Err.	p-value	NB Dispersion	No. Obs.
101	Intercept	-8.16E+00	3.22E-01	2.00E-16	1.669	383,213
	AADT	-2.17E-05	8.51E-06	1.09E-02		
	ln(AADT)	1.51E+00	7.95E-02	2.00E-16		
	$(\ln(AADT))^2$	-5.59E-02	6.71E-03	2.00E-16		
	LaneWidth	-1.06E-01	9.84E-03	2.00E-16		
	$LaneWidth^2$	1.71E-03	3.56E-04	1.58E-06		
	ShouldWidth	-8.99E-02	3.81E-03	2.00E-16		
	ln(MedShldWidth+0.1)	1.79E-01	7.38E-02	1.51E-02		
	PaveRoughness	3.77E-04	1.47E-04	1.06E-02		
	PaveConditionV	8.68E-02	9.27E-03	2.00E-16		
	SurfaceType3456C	8.41E-01	1.31E-01	1.54E-10		
	CurbGutter25	-9.30E-01	6.22E-02	2.00E-16		
102	Intercept	-1.12E+00	1.22E-01	2.00E-16	1.825	3,774
	AADT	5.44E-05	1.05E-05	2.32E-07		
	ln(ShouldWidth+0.1)	1.11E-01	2.83E-02	9.08E-05		
103	Intercept	-1.74E+01	2.23E+00	6.52E-15	2.345	21,527
	AADT	-5.33E-05	1.62E-05	9.90E-04		
	$AADT^2$	5.94E-10	2.03E-10	3.40E-03		
	ln(AADT)	1.08E+00	1.25E-01	2.00E-16		
	LaneWidth	1.95E+00	4.52E-01	1.54E-05		
	$LaneWidth^2$	-1.58E-01	3.28E-02	1.62E-06		
	$LaneWidth^3$	3.86E-03	7.46E-04	2.27E-07		
	ShoulderWidth	1.47E-02	6.31E-03	1.94E-02		
	MedianWidth	2.40E-03	3.65E-04	4.86E-11		
	CurbGutter2	6.02E-01	2.26E-01	7.88E-03		
104	Intercept	-9.00E+01	2.25E+01	6.11E-05	6.263	3,002
	AADT	1.85E-04	4.68E-05	7.90E-05		
	ln(AADT)	2.09E+01	5.28E+00	7.54E-05		
	$(\ln(AADT))^2$	-1.22E+00	3.14E-01	1.04E-04		
	ShouldWidth	-1.77E-01	4.51E-02	8.73E-05		
	PaveRoughness	1.45E-03	3.95E-04	2.42E-04		
	SurfaceType8	1.96E-01	6.42E-02	2.24E-03		
	CurbGutter3	-7.23E-01	3.07E-01	1.86E-02		
	CurbGutter5	-2.47E+00	5.57E-01	9.43E-06		
105	Intercept	8.13E+01	2.46E+01	9.38E-04	15.250	275
	AADT	5.26E-04	1.41E-04	1.82E-04		
	$AADT^2$	-2.96E-09	8.38E-10	4.05E-04		
	ln(AADT)	-8.91E+00	2.72E+00	1.04E-03		
	MedianWidth	1.43E-02	5.63E-03	1.09E-02		
	$MedianWidth^2$	-1.07E-04	3.49E-05	2.08E-03		
	$MedianWidth^3$	2.03E-07	5.95E-08	6.28E-04		
	MedShldWidth	-2.63E+00	7.12E-01	2.18E-04		
	$MedShldWidth^2$	6.73E-01	2.10E-01	1.32E-03		
	$MedShldWidth^3$	-5.47E-02	1.94E-02	4.90E-03		
	PaveRoughness	1.87E-03	9.18E-04	4.12E-02		
106	Intercept	-2.58E+00	9.34E-01	5.77E-03	1.892	1,614
	ln(AADT)	3.82E-01	9.55E-02	6.27E-05		
	MedMedShldWidth	-1.09E-02	4.09E-03	7.57E-03		
	$MedMedShldWidth^2$	8.26E-05	2.95E-05	5.05E-03		
	$MedMedShldWidth^3$	-1.68E-07	5.76E-08	3.51E-03		

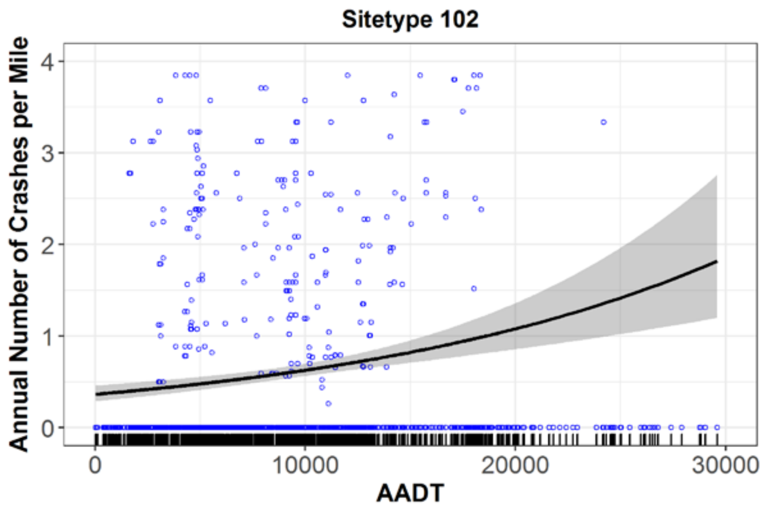
107	Intercept	-3.11E+00	1.27E+00	1.41E-02	58.866	115
	AADT	2.08E-05	7.21E-06	3.96E-03		
	ShoulderWidth	6.81E-01	2.71E-01	1.18E-02		
151	Intercept	-6.94E+00	1.38E-01	2.00E-16	1.000	448,618
	AADT	-1.27E-04	4.09E-06	2.00E-16		
	$AADT^2$	1.32E-09	6.89E-11	2.00E-16		
	ln(AADT)	1.10E+00	1.38E-02	2.00E-16		
	LaneWidth	-2.32E-01	2.03E-02	2.00E-16		
	$LaneWidth^2$	7.10E-03	1.22E-03	5.68E-09		
	$LaneWidth^3$	-7.27E-05	2.27E-05	1.37E-03		
	ShoulderWidth	-4.01E-02	1.02E-02	8.95E-05		
	$ShoulderWidth^2$	-6.36E-03	1.42E-03	6.90E-06		
	MedMedShldWidth	2.97E-02	3.44E-03	2.00E-16		
	$MedMedShldWidth^2$	-3.48E-04	5.97E-05	5.52E-09		
	$MedMedShldWidth^3$	9.66E-07	1.69E-07	1.13E-08		
152	Intercept	9.91E+00	3.03E+00	1.06E-03	1.701	25,144
	AADT	-1.71E-04	2.73E-05	3.83E-10		
	$AADT^2$	1.27E-09	2.29E-10	3.05E-08		
	ln(AADT)	-3.75E+00	8.29E-01	6.26E-06		
	(ln(AADT))2	3.17E-01	5.77E-02	3.86E-08		
	LaneWidth	-8.12E-02	1.51E-02	8.25E-08		
	PaveRoughness	-2.82E-03	8.41E-04	7.98E-04		
	$PaveRoughness^2$	2.09E-05	5.30E-06	8.26E-05		
	$PaveRoughness^3$	-2.29E-08	8.16E-09	5.01E-03		
	SurfaceType8	-4.08E-01	1.48E-01	5.79E-03		
153	Intercept	3.88E+00	3.71E-01	2.00E-16	1.287	67,309
	1/ln(AADT)	-3.87E+01	1.82E+00	2.00E-16		
	SurfaceWidth	-3.12E-02	1.47E-02	3.43E-02		
	$SurfaceWidth^2$	5.44E-04	2.45E-04	2.66E-02		
	$SurfaceWidth^3$	-2.72E-06	1.33E-06	4.04E-02		
	MedShldWidth	7.00E-02	4.77E-03	2.00E-16		
	$MedShldWidth^2$	1.91E-05	1.95E-06	2.00E-16		
	PaveRoughness	8.22E-04	1.86E-04	9.66E-06		
	PaveConditionV	3.85E-01	8.30E-02	3.46E-06		
	$PaveConditionV^2$	-8.84E-02	2.06E-02	1.77E-05		
	CurbGutter4	4.61E-01	1.80E-01	1.06E-02		
	CurbGutter1235	3.75E-01	1.05E-01	3.52E-04		
155	Intercept	-2.08E+00	7.16E-01	3.61E-03	2.656	2,513
	ln(AADT)	4.27E-01	5.44E-02	4.17E-15		
	LaneWidth	-7.74E-02	2.88E-02	7.25E-03		
	ShoulderWidth	-1.57E-01	1.78E-02	2.00E-16		
	MedShldWidth	2.54E-01	4.77E-02	1.00E-07		
	$MedShldWidth^2$	-3.20E-02	7.05E-03	5.62E-06		
	MedianWidthMin	-5.27E-03	9.44E-04	2.32E-08		
	PaveRoughness	-5.61E-03	1.98E-03	4.64E-03		
	$PaveRoughness^2$	9.75E-05	2.33E-05	2.85E-05		
	$PaveRoughness^3$	-2.87E-07	6.54E-08	1.15E-05		
156	Intercept	1.18E+02	1.78E+01	3.40E-11	2.607	2,291
	AADT	-9.49E-05	1.26E-05	4.56E-14		
	ln(AADT)	-2.65E+01	3.77E+00	2.31E-12		
	$(ln(AADT))^2$	1.49E+00	2.02E-01	1.86E-13		
	RtShldWidth	2.01E-02	4.56E-03	1.09E-05		
	MedShldWidth	4.29E-01	1.31E-01	1.04E-03		

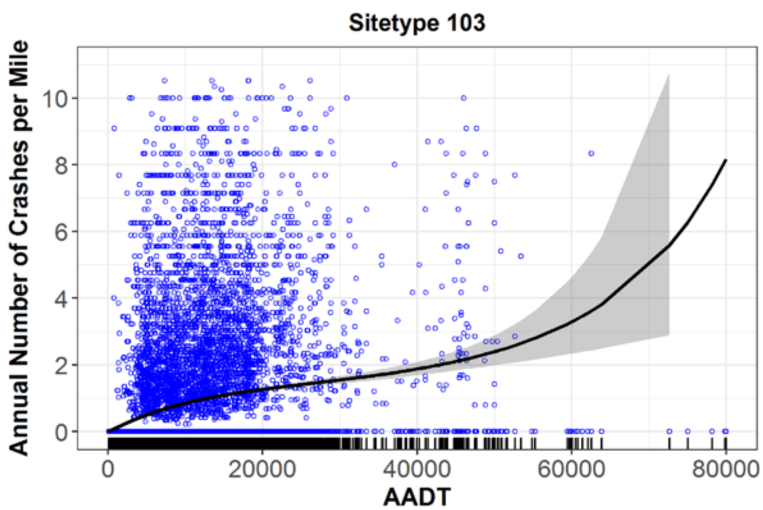
	$MedShldWidth^2$	-1.60E-01	4.98E-02	1.30E-03		
	$MedShldWidth^3$	1.76E-02	5.61E-03	1.65E-03		
	MedianWidth	-1.51E-03	3.48E-04	1.48E-05		
157	Intercept	-4.13E+03	1.30E+03	1.42E-03	3.415	1,528
	AADT	2.80E-03	8.91E-04	1.67E-03		
	$AADT^2$	-5.25E-09	1.69E-09	1.87E-03		
	ln(AADT)	8.54E+02	2.68E+02	1.45E-03		
	$(\ln(AADT))^2$	-4.47E+01	1.41E+01	1.48E-03		
	SurfaceWidth	2.26E-02	5.80E-03	9.98E-05		
	RtShldWidth	5.39E-01	1.47E-01	2.40E-04		
	$RtShldWidth^2$	-1.00E-01	2.89E-02	5.38E-04		
	$RtShldWidth^3$	4.58E-03	1.48E-03	1.89E-03		
	MedRtShldWidth	-5.54E-02	1.11E-02	5.42E-07		
	ln(MedWidthMin+0.1)	-4.66E-02	1.33E-02	4.71E-04		
	PaveRoughenss	4.73E-03	8.30E-04	1.17E-08		
158	Intercept	-3.27E+00	7.33E-01	8.28E-06	1.512	1,883
	ln(AADT)	4.87E-01	7.18E-02	1.19E-11		
	ShouldWidth	-8.21E-02	3.06E-02	7.37E-03		
	MedianWidth	-1.26E-03	6.72E-04	6.10E-02		
	PaveRoughness	-1.70E-02	4.43E-03	1.22E-04		
	$PaveRoughness^2$	2.36E-04	6.41E-05	2.35E-04		
	$PaveRoughness^3$	-7.40E-07	2.20E-07	7.81E-04		
159	Intercept	3.72E-01	1.70E-01	2.88E-02	2.061	1,952
	AADT	5.20E-05	6.94E-06	6.69E-14		
	$AADT^2$	-3.96E-10	6.55E-11	1.54E-09		
	ln(RtShldWidth+0.1)	4.46E-02	1.34E-02	8.64E-04		
	ln(MedWidthMin+0.1)	-5.03E-02	1.45E-02	5.21E-04		
160	Intercept	-2.06E+02	4.17E+01	7.47E-07	2.921	956
	AADT	-6.68E-04	1.30E-04	2.74E-07		
	$AADT^2$	2.39E-09	4.67E-10	2.98E-07		
	ln(AADT)	2.18E+01	4.35E+00	5.21E-07		
	MedRtShldWidth	-3.89E-02	1.07E-02	2.88E-04		
	MedianWidthMin	-4.82E-03	9.42E-04	3.06E-07		

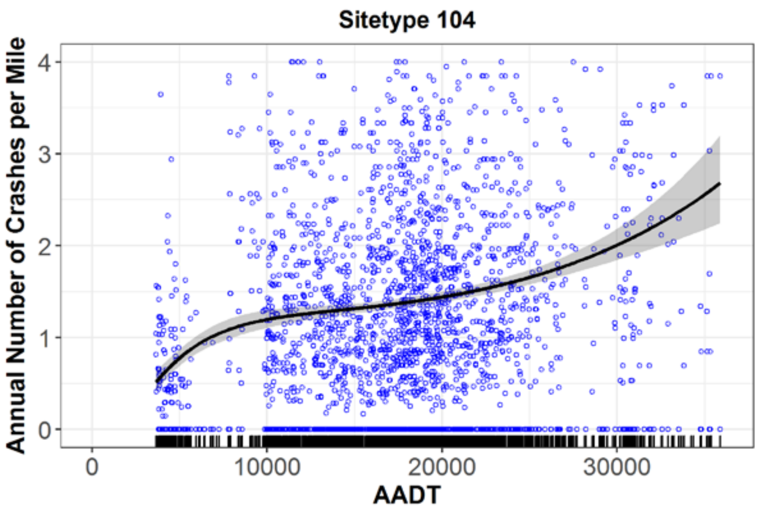
Note: Crashes occurring within 250 feet from an intersection are excluded.

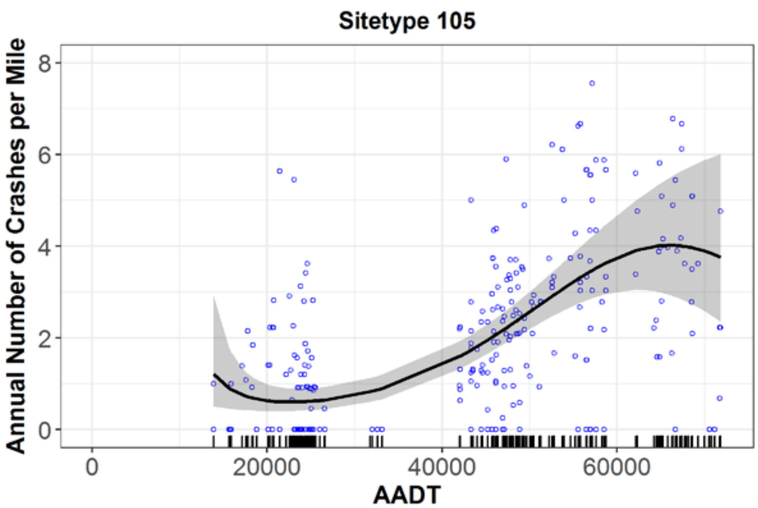
The graphs that follow, “SPFs With AADT and Other Predictors in Customized Functional Forms for All RD Crashes,” visualize the models in Table C3 with the segment length set at 1 mile for all RD crashes. All the predictors except AADT and indicator variables (e.g., CurbGutter4 and SurfaceType8) are set at the average values. In the graphs, a circle represents a segment; a solid line represents an SPF with the segment length of 1 mile and a corresponding AADT; and the gray band surrounding the solid line represents the 95th percentile mean prediction limit. It should also be noted that for visual clarity the graphs do not show all data points.

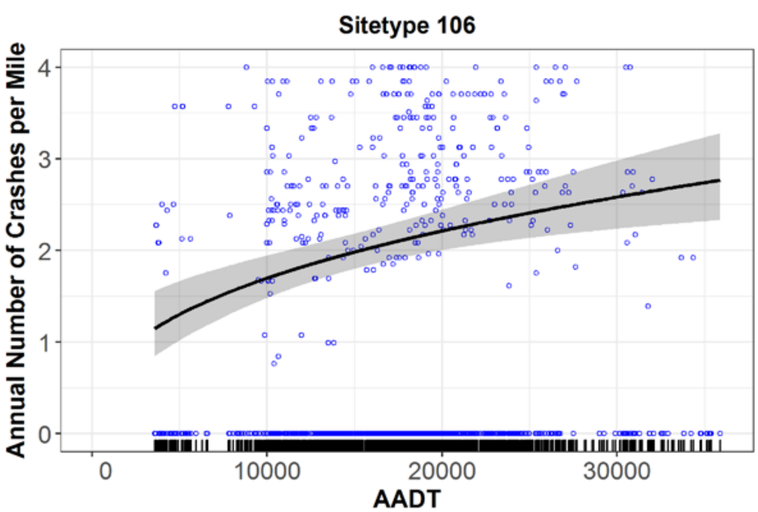

Sitetype 101
Annual Number of Crashes per Mile
0
3
6
9
0
10000
20000
30000
AADT

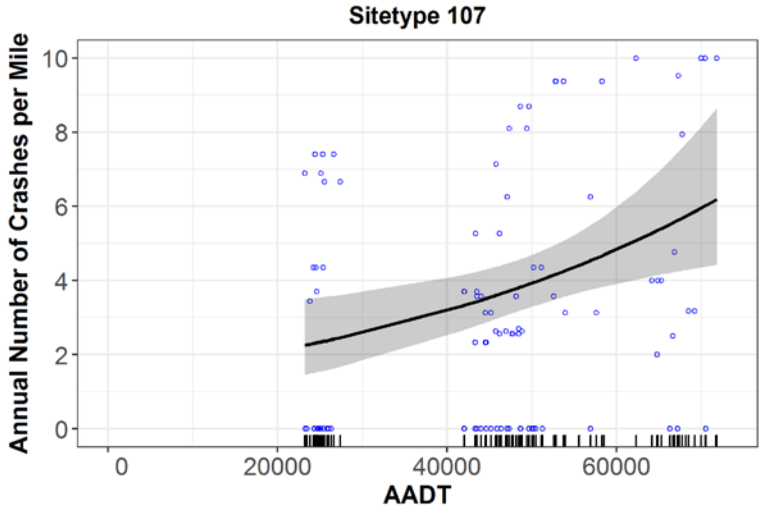

Sitetype 102
Annual Number of Crashes per Mile
0
1
2
3
4
0
10000
20000
30000
AADT


Sitetype 103
Annual Number of Crashes per Mile
0
2
4
6
8
10
0
20000
40000
60000
80000
AADT

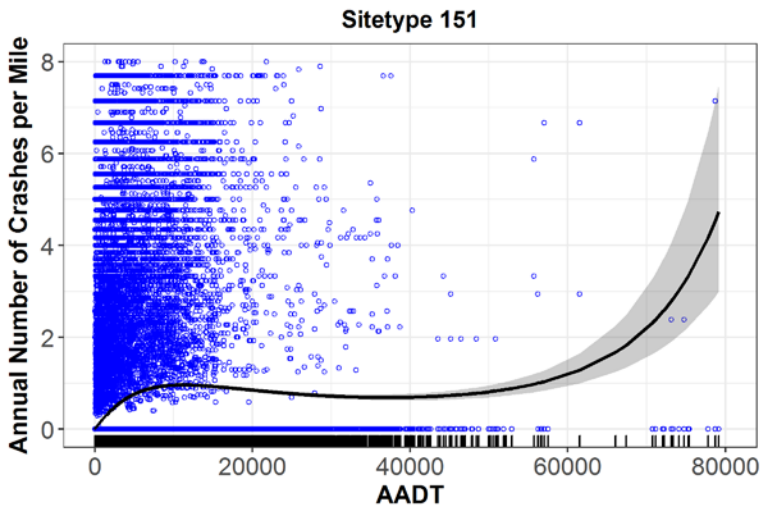

Sitetype 104
Annual Number of Crashes per Mile
0
1
2
3
4
0
10000
20000
30000
AADT


Sitetype 105
Annual Number of Crashes per Mile
0
2
4
6
8
0
20000
40000
60000
AADT

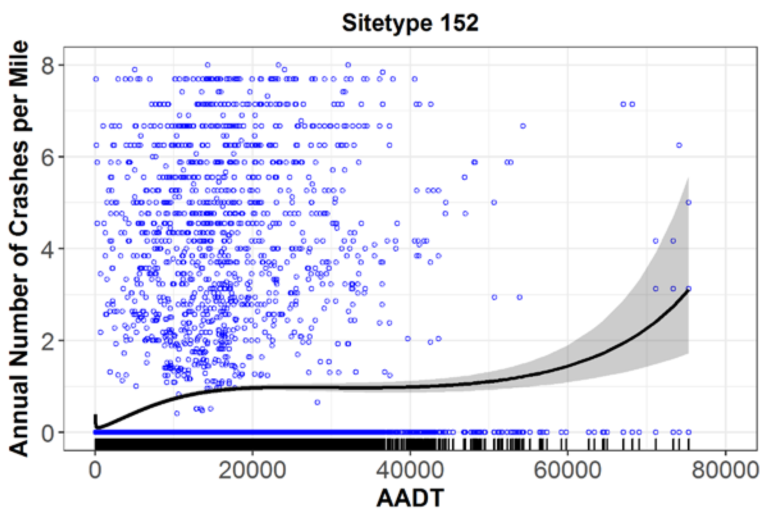

Sitetype 106
Annual Number of Crashes per Mile
0
1
2
3
4
0
10000
20000
30000
AADT



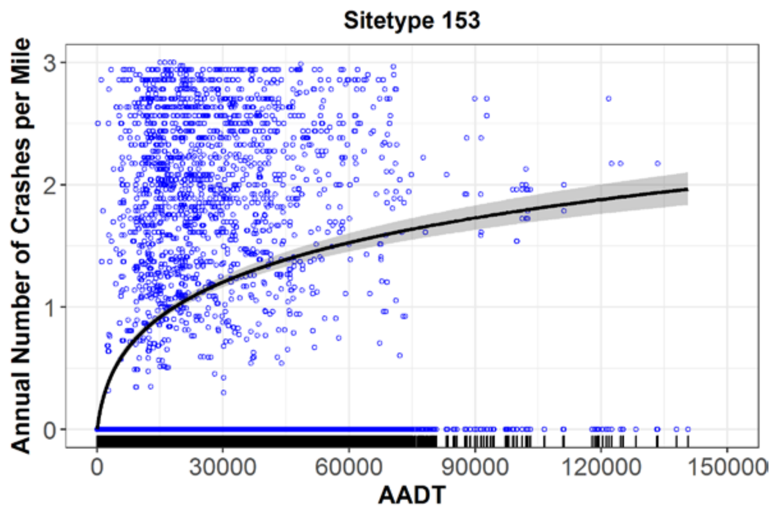
Sitetype 107
Annual Number of Crashes per Mile
0
2
4
6
8
10
0
20000
40000
60000
AADT

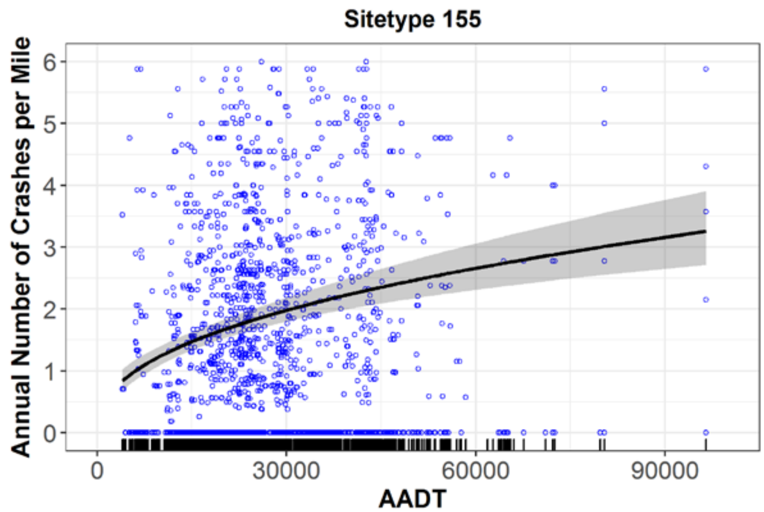


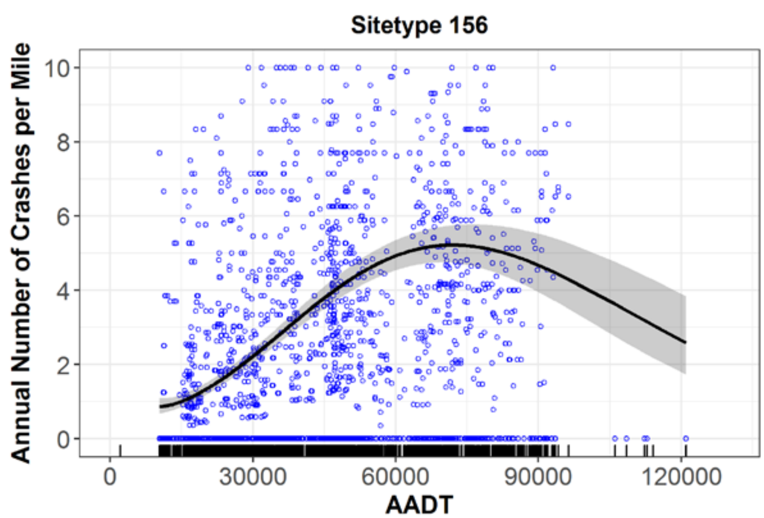
Sitetype 151
Annual Number of Crashes per Mile
0
2
4
6
8
0
20000
40000
60000
80000
AADT

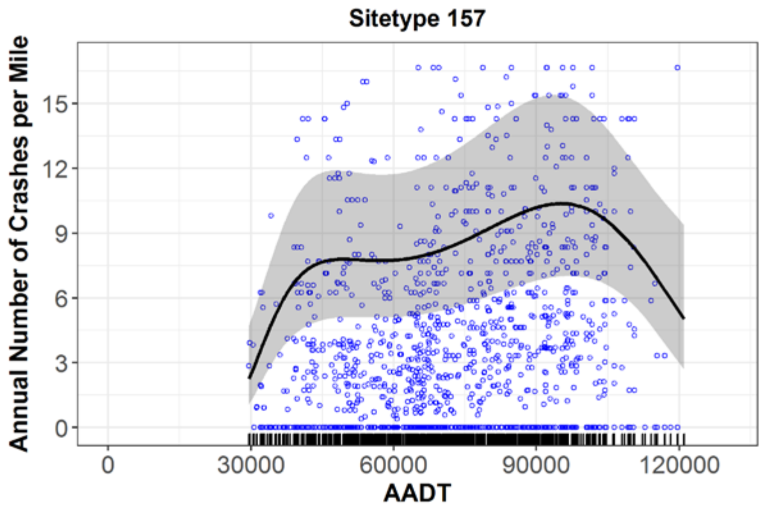


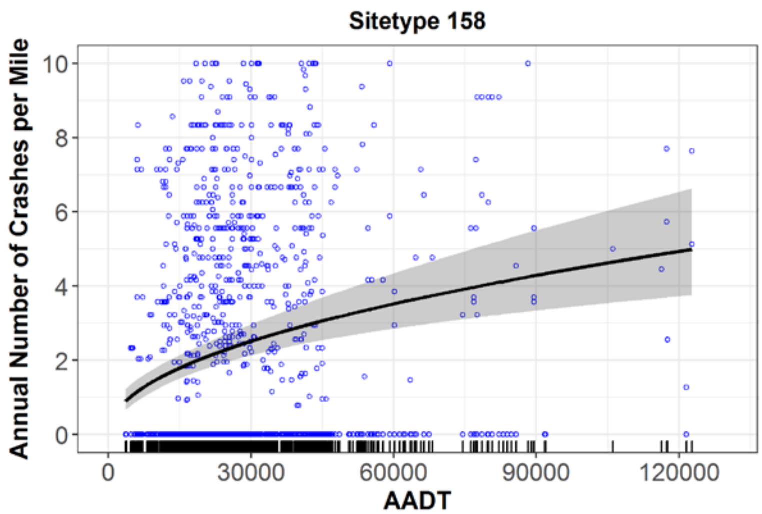
Sitetype 152
Annual Number of Crashes per Mile
0
2
4
6
8
0
20000
40000
60000
80000
AADT

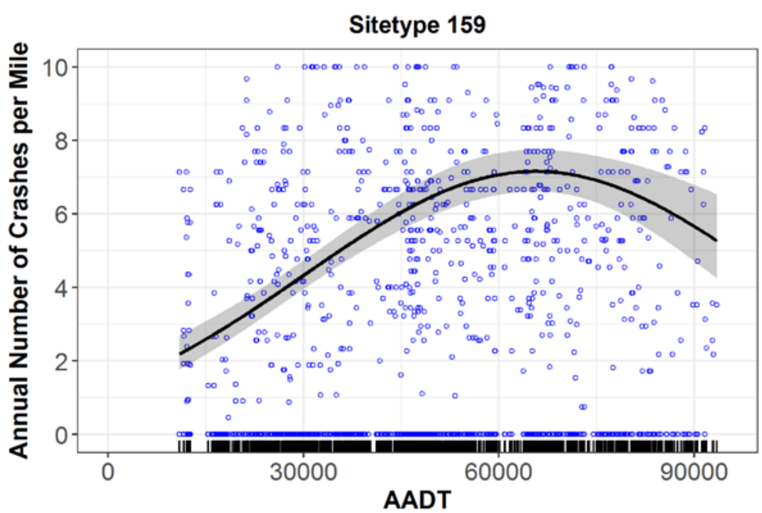

Sitetype 153
Annual Number of Crashes per Mile
0
1
2
3
0
30000
60000
90000
120000
150000
AADT

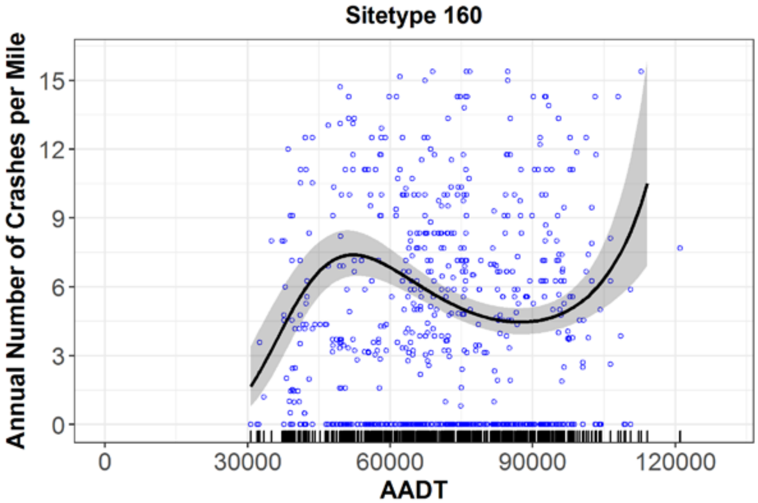

Sitetype 155
Annual Number of Crashes per Mile
0
1
2
3
4
5
6
0
30000
60000
90000
AADT


Sitetype 156
Annual Number of Crashes per Mile
0
2
4
6
8
10
0
30000
60000
90000
120000
AADT


Sitetype 157
Annual Number of Crashes per Mile
0
3
6
9
12
15
0
30000
60000
90000
120000
AADT


Sitetype 158
Annual Number of Crashes per Mile
0
2
4
6
8
10
0
30000
60000
90000
120000
AADT


Sitetype 159
Annual Number of Crashes per Mile
0
2
4
6
8
10
0
30000
60000
90000
AADT



Fatal and Injury Roadway Departure (RD) Crashes

Developed NB models with only AADT in a logarithmic functional form for fatal and injury RD crashes are presented in Table C4; they are presented in a functional form in Table 6 in the body of the report. Estimation of the model for Site Type 107 did not succeed; thus, no model was developed for the type.

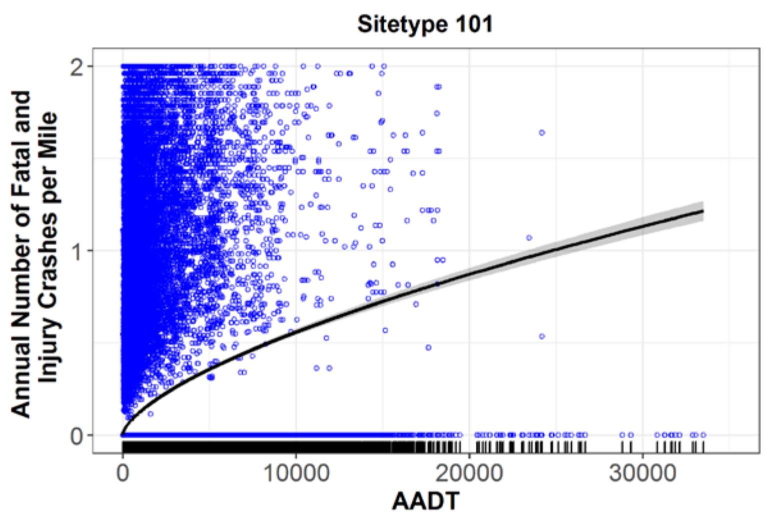
Table C4. Estimated NB Models With Only AADT in Logarithmic Functional Form for Fatal and Injury RD Crashes (2011-2015)

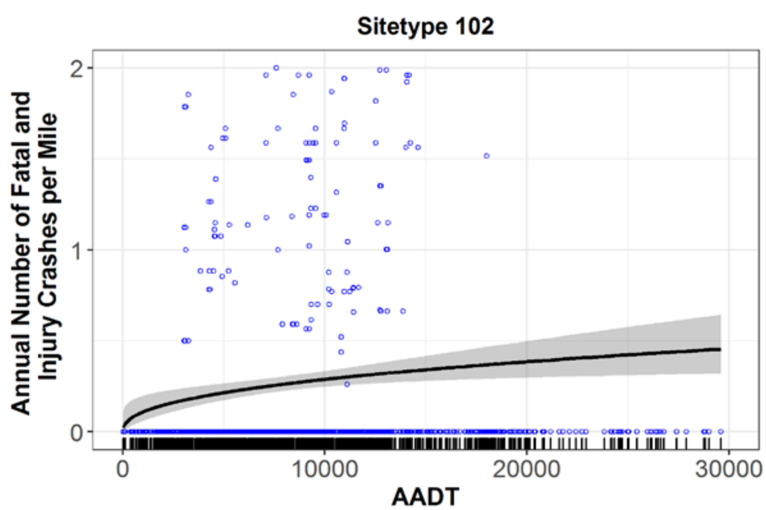
Site Type	Variable	Coefficient	Std. Err.	p-value	NB Dispersion	No. Obs.
101	Intercept	-6.50E+00	4.14E-02	2.00E-16	1.404	383,213
	ln(AADT)	6.43E-01	5.93E-03	2.00E-16		
102	Intercept	-5.12E+00	1.23E+00	3.06E-05	1.188	3,774
	ln(AADT)	4.21E-01	1.35E-01	1.80E-03		
103	Intercept	-6.93E+00	3.20E-01	2.00E-16	2.012	21,527
	ln(AADT)	6.47E-01	3.40E-02	2.00E-16		
104	Intercept	-5.89E+00	5.52E-01	2.00E-16	6.119	3,002
	ln(AADT)	5.32E-01	5.65E-02	2.00E-16		
105	Intercept	-1.27E+01	2.02E+00	3.52E-10	7.639	275
	ln(AADT)	1.16E+00	1.88E-01	7.83E-10		
106	Intercept	-5.79E+00	1.39E+00	3.09E-05	2.848	1,614
	ln(AADT)	5.62E-01	1.42E-01	7.65E-05		
107	NA					115
151	Intercept	-7.50E+00	8.00E-02	2.00E-16	0.667	448,618
	ln(AADT)	7.16E-01	9.60E-03	2.00E-16		
152	Intercept	-6.70E+00	4.57E-01	2.00E-16	1.005	25,144
	ln(AADT)	5.99E-01	4.74E-02	2.00E-16		
153	Intercept	-5.91E+00	2.40E-01	2.00E-16	1.106	67,309
	ln(AADT)	5.10E-01	2.36E-02	2.00E-16		
155	Intercept	-7.26E+00	7.78E-01	2.00E-16	2.522	2,513
	ln(AADT)	6.72E-01	7.62E-02	2.00E-16		
156	Intercept	-9.28E+00	6.89E-01	2.00E-16	4.121	2,291
	ln(AADT)	8.78E-01	6.39E-02	2.00E-16		
157	Intercept	-8.26E+00	1.57E+00	1.52E-07	2.474	1,528
	ln(AADT)	7.75E-01	1.41E-01	3.66E-08		

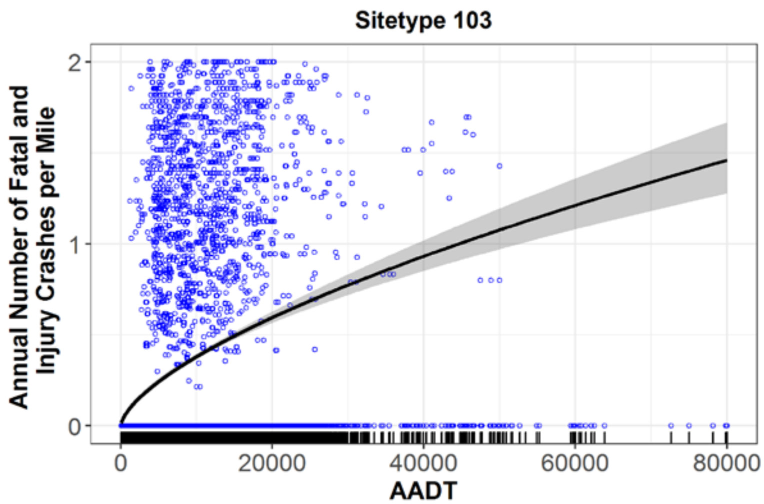
158	Intercept	-3.91E+00	9.77E-01	6.28E-05	1.986	1,883
	ln(AADT)	3.79E-01	9.55E-02	7.28E-05		
159	Intercept	-5.48E+00	9.45E-01	6.72E-09	1.685	1,952
	ln(AADT)	5.61E-01	8.75E-02	1.48E-10		
160	Intercept	-5.51E+00	2.18E+00	1.14E-02	2.026	956
	ln(AADT)	5.53E-01	1.95E-01	4.65E-03		

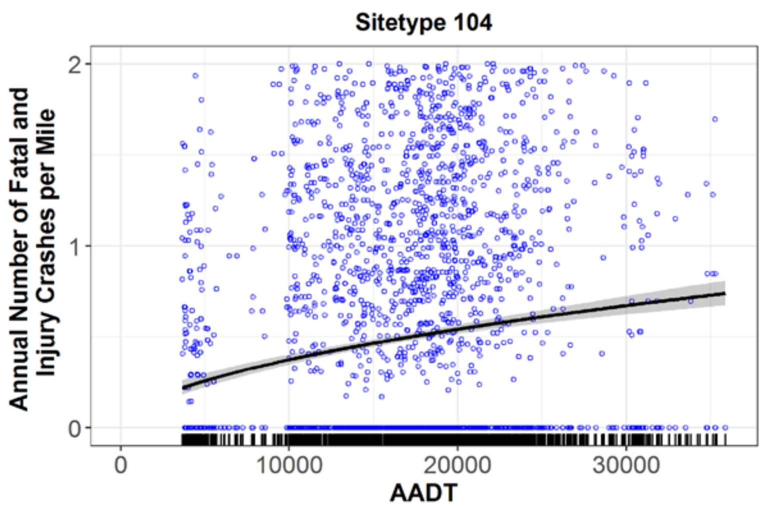
NA = not available (a statistically significant SPF was not developed).
Note: Crashes occurring within 250 feet from an intersection are excluded.

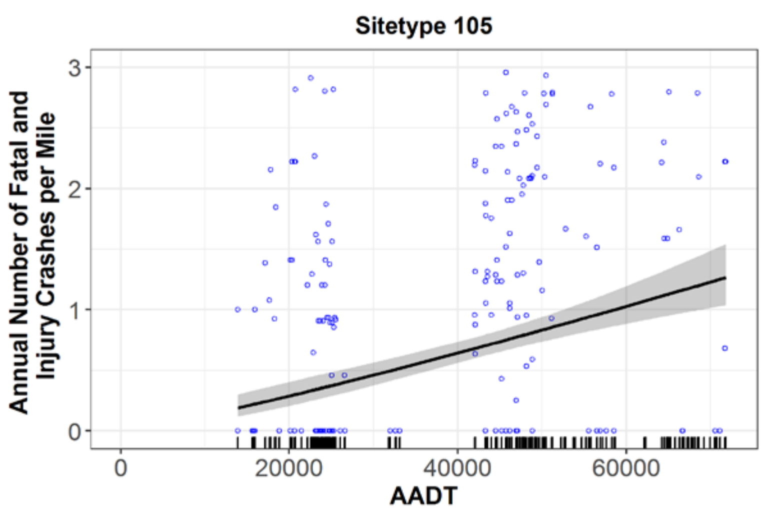
The graphs that follow, "SPFs With Only AADT in a Logarithmic Functional Form for Fatal and Injury RD Crashes," visualize the models in Table C4 with the segment length set at 1 mile for fatal and injury RD crashes. In the graphs, a circle represents a segment; a solid line represents an SPF with the segment length of 1 mile and a corresponding AADT; and the gray band surrounding the solid line represents the 95th percentile mean prediction limit. It should be noted that the graphs were created for illustration purposes and may not show the entire range of data points.

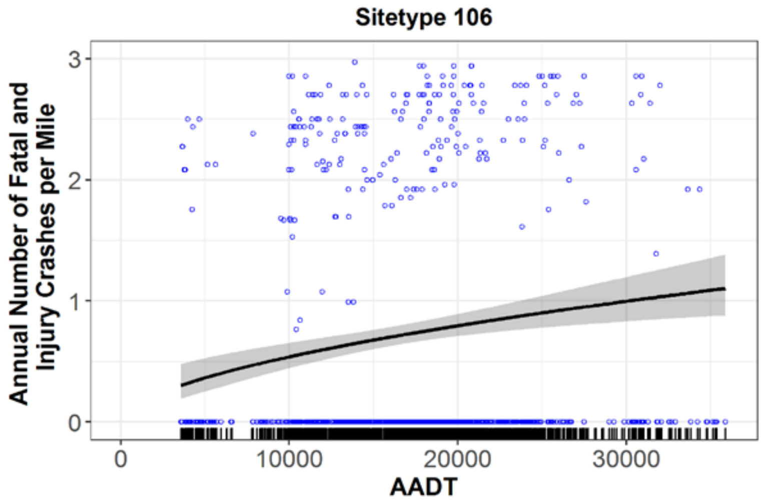


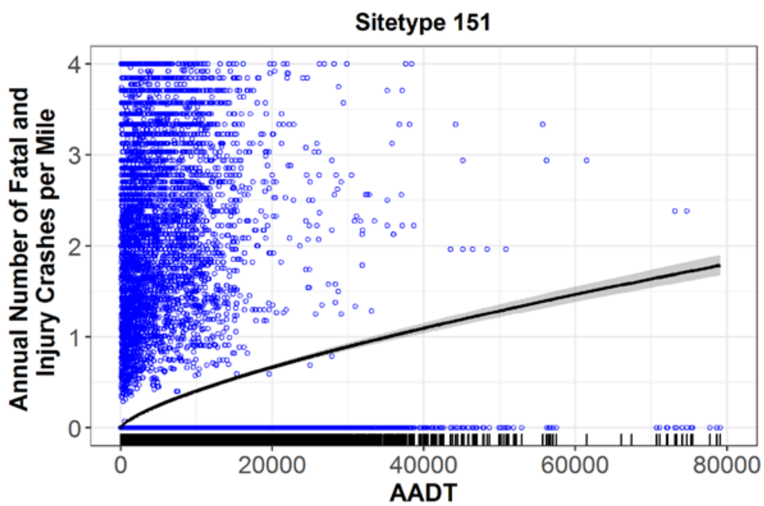


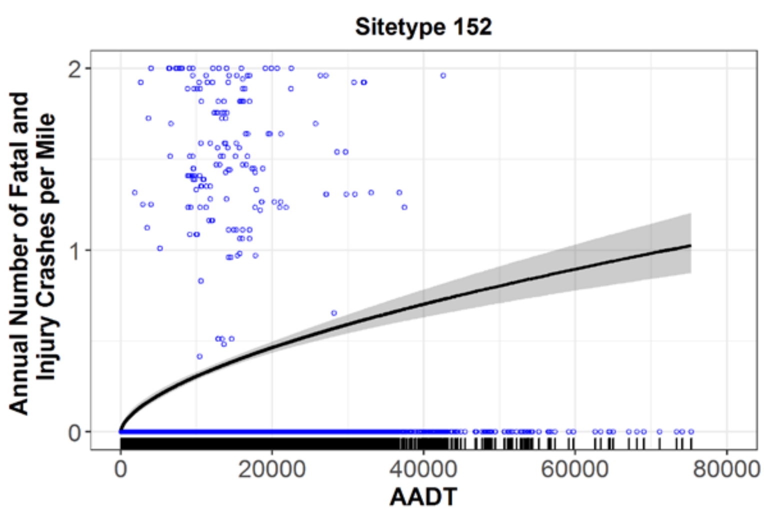

Sitetype 103
Annual Number of Fatal and Injury Crashes per Mile
AADT
0
1
2
0
20000
40000
60000
80000

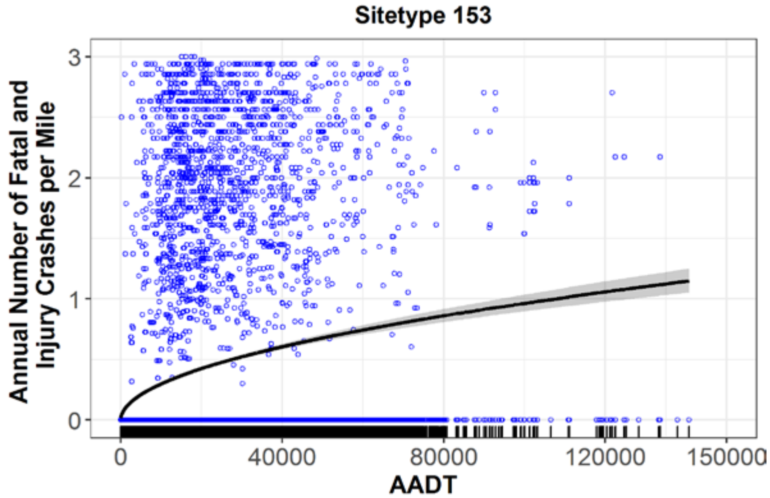

Sitetype 104
Annual Number of Fatal and Injury Crashes per Mile
AADT
0
1
2
0
10000
20000
30000


Sitetype 105
Annual Number of Fatal and Injury Crashes per Mile
AADT
0
1
2
3
0
20000
40000
60000

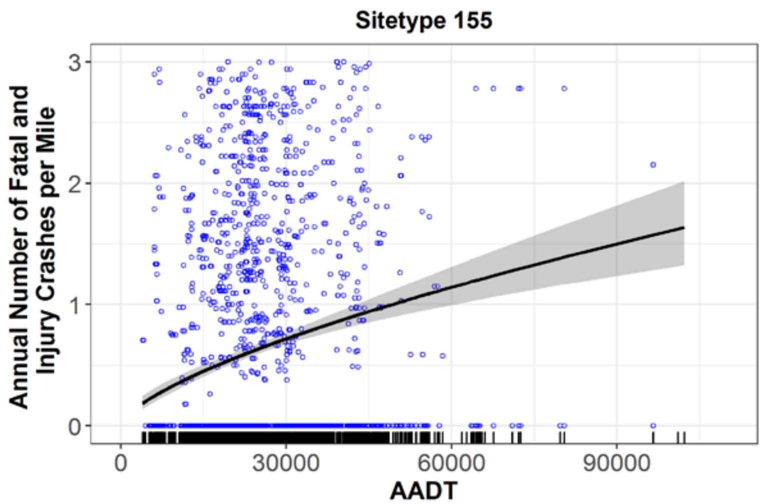

Sitetype 106
Annual Number of Fatal and Injury Crashes per Mile
AADT
0
10000
20000
30000
0
1
2
3


Sitetype 151
Annual Number of Fatal and Injury Crashes per Mile
AADT
0
20000
40000
60000
80000
0
1
2
3
4

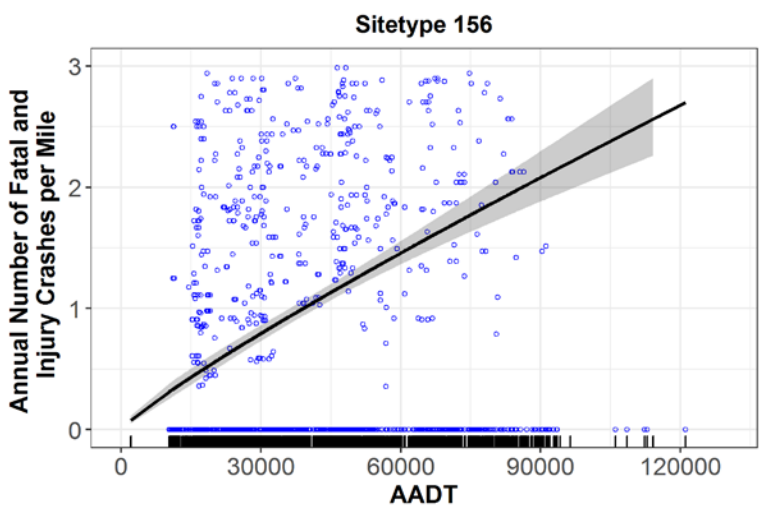

Sitetype 152
Annual Number of Fatal and Injury Crashes per Mile
AADT
0
20000
40000
60000
80000
0
1
2



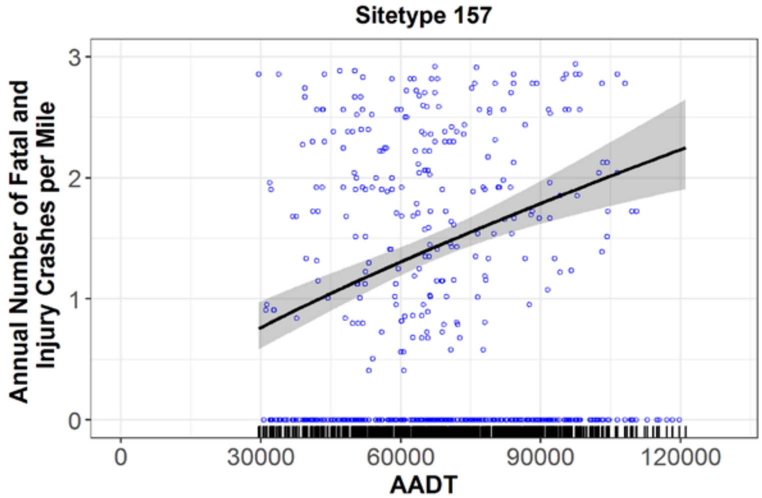
Sitetype 153
Annual Number of Fatal and Injury Crashes per Mile
AADT
0
1
2
3
0
40000
80000
120000
150000

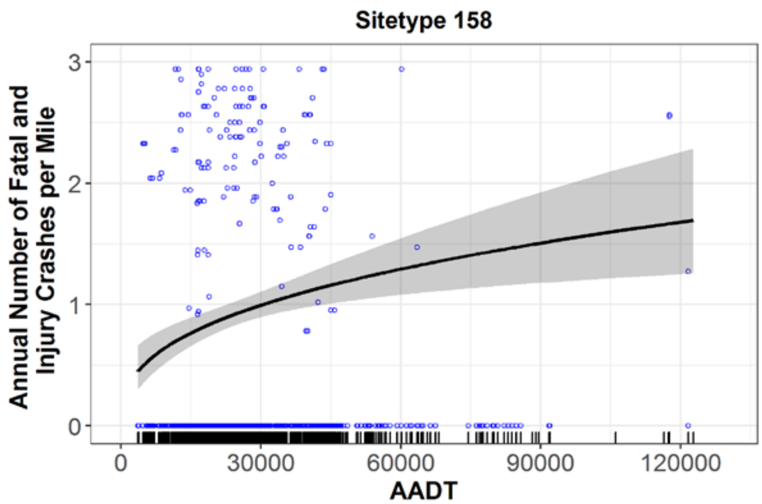


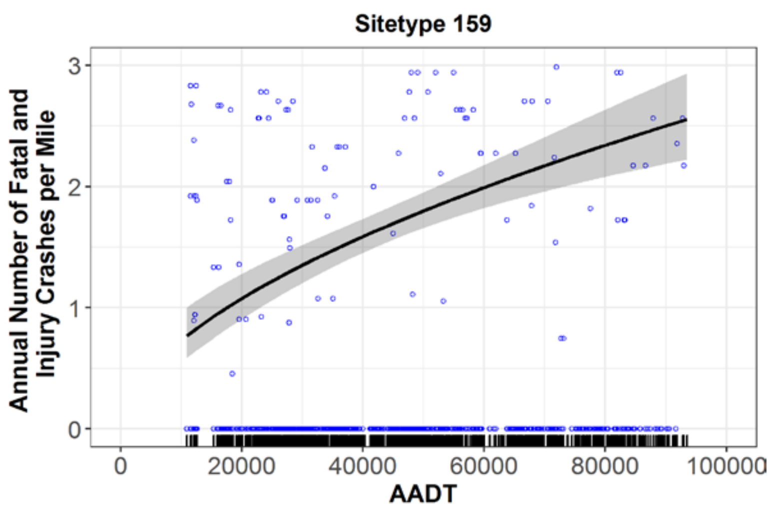
Sitetype 155
Annual Number of Fatal and Injury Crashes per Mile
AADT
0
1
2
3
0
30000
60000
90000

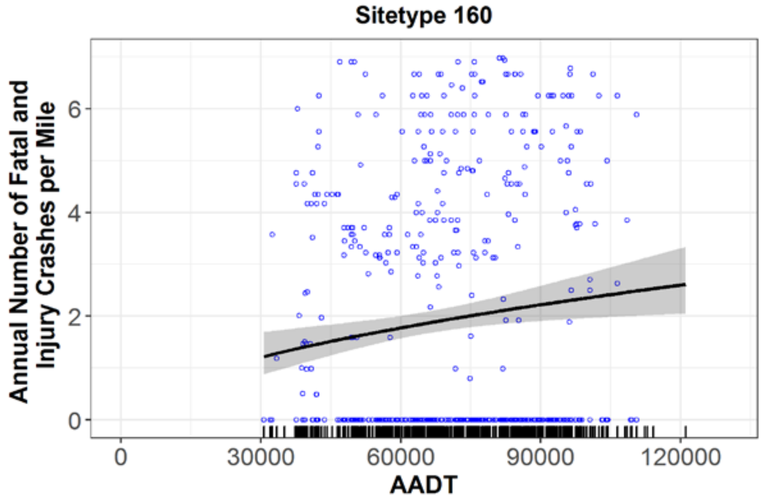


Sitetype 156
Annual Number of Fatal and Injury Crashes per Mile
AADT
0
1
2
3
0
30000
60000
90000
120000


Sitetype 157
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
0
30000
60000
90000
120000
AADT


Sitetype 158
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
0
30000
60000
90000
120000
AADT


Sitetype 159
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
0
20000
40000
60000
80000
100000
AADT



Developed NB models with only AADT in a customized functional form for fatal and injury RD crashes are presented in Table C5; they are presented in a functional form in Table 7 in the body of the report. Estimation of the model for Site Type 107 was not successful; thus, no model was developed for the type.

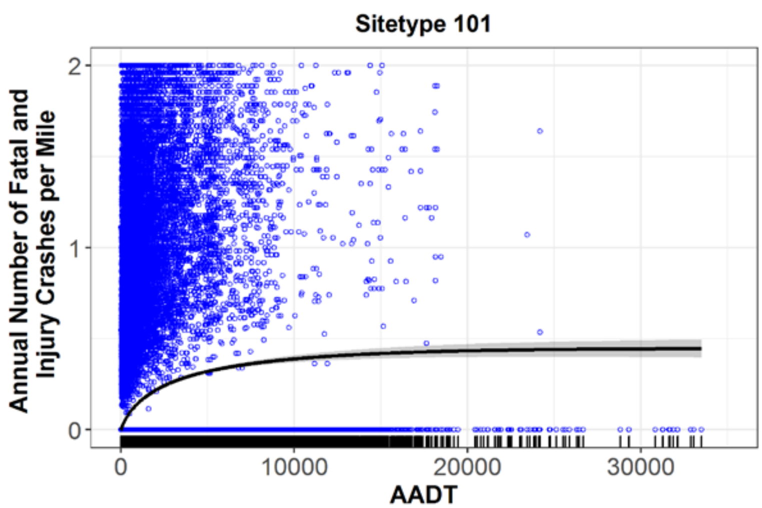
Table C5. Estimated NB Models With Only AADT in a Customized Functional Form for Fatal and Injury RD Crashes (2011-2015)

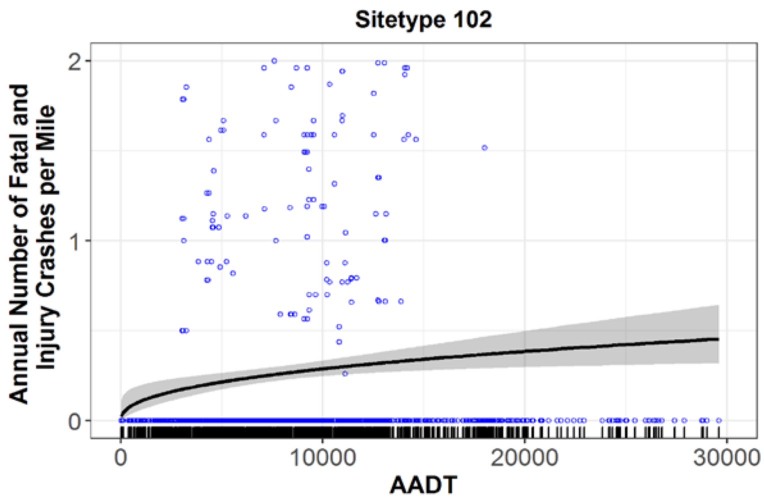
Site Type	Variable	Coefficient	Std. Err.	p-value	NB Dispersion	No. Obs.
101	Intercept	-1.05E+01	2.12E-01	2.00E-16	1.475	383,213
	ln(AADT)	1.86E+00	6.29E-02	2.00E-16		
	$(\ln(AADT))^2$	-8.91E-02	4.58E-03	2.00E-16		
102	Intercept	-5.12E+00	1.23E+00	3.06E-05	1.188	3,774
	ln(AADT)	4.21E-01	1.35E-01	1.80E-03		
103	Intercept	-1.77E+00	6.21E-02	2.00E-16	1.979	21,527
	AADT	8.58E-05	6.92E-06	2.00E-16		
	$AADT^2$	-1.07E-09	1.58E-10	1.14E-11		
104	Intercept	-9.77E+01	3.15E+01	1.91E-03	6.517	3,002
	AADT	2.19E-04	6.51E-05	7.77E-04		
	ln(AADT)	2.25E+01	7.40E+00	2.37E-03		
	$(\ln(AADT))^2$	-1.33E+00	4.40E-01	2.55E-03		
105	Intercept	-1.78E+00	2.28E-01	6.46E-15	9.973	275
	AADT	3.09E-05	4.46E-06	4.01E-12		
106	Intercept	-5.79E+00	1.39E+00	3.09E-05	2.848	1,614
	ln(AADT)	5.62E-01	1.42E-01	7.65E-05		
107	NA					115
151	Intercept	-1.05E+01	1.70E-01	2.00E-16	0.772	448,618
	AADT	-1.41E-04	7.17E-06	2.00E-16		
	$AADT^2$	1.48E-09	1.26E-10	2.00E-16		
	ln(AADT)	1.17E+00	2.42E-02	2.00E-16		
152	Intercept	-1.16E+01	1.16E+00	2.00E-16	1.029	25,144
	AADT	-3.93E-05	8.18E-06	1.57E-06		
	ln(AADT)	1.18E+00	1.34E-01	2.00E-16		
153	Intercept	-2.42E+01	4.99E+00	1.28E-06	1.106	67,309
	AADT	1.83E-05	5.12E-06	3.54E-04		
	ln(AADT)	4.59E+00	1.10E+00	3.18E-05		
	$(\ln(AADT))^2$	-2.30E-01	6.16E-02	1.95E-04		

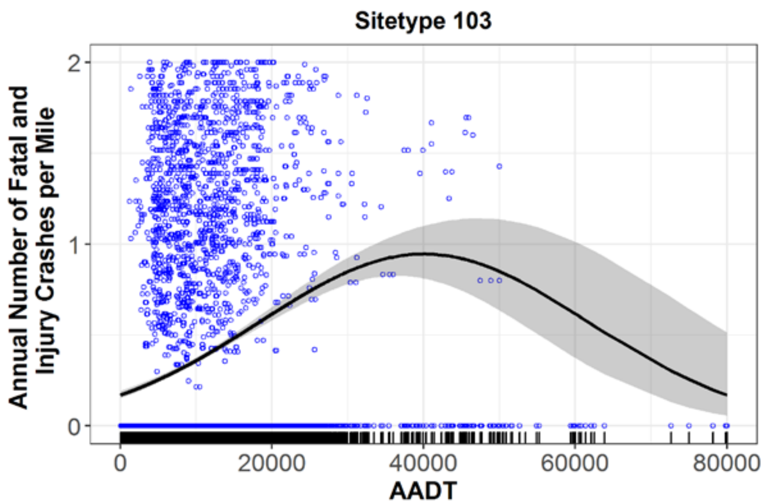
155	Intercept	-7.26E+00	7.78E-01	2.00E-16	2.522	2,513
	ln(AADT)	6.72E-01	7.62E-02	2.00E-16		
156	Intercept	1.16E+02	1.97E+01	3.95E-09	4.430	2,291
	AADT	-8.71E-05	1.50E-05	6.57E-09		
	ln(AADT)	-2.58E+01	4.21E+00	8.08E-10		
	$(\ln(AADT))^2$	1.44E+00	2.28E-01	2.45E-10		
157	Intercept	-5.22E+03	1.88E+03	5.54E-03	2.639	1,528
	AADT	3.71E-03	1.29E-03	4.12E-03		
	AADT2	-7.09E-09	2.45E-09	3.84E-03		
	ln(AADT)	1.09E+03	3.90E+02	5.38E-03		
	$(\ln(AADT))^2$	-5.71E+01	2.05E+01	5.23E-03		
158	Intercept	-3.91E+00	9.77E-01	6.28E-05	1.986	1,883
	ln(AADT)	3.79E-01	9.55E-02	7.28E-05		
159	Intercept	-9.67E-01	2.56E-01	1.61E-04	1.746	1,952
	AADT	5.40E-05	1.05E-05	2.55E-07		
	$AADT^2$	-4.12E-10	9.85E-11	2.91E-05		
160	Intercept	-9.15E+00	2.27E+00	5.57E-05	2.456	956
	AADT	4.13E-04	9.99E-05	3.63E-05		
	$AADT^2$	-5.56E-09	1.40E-09	7.38E-05		
	$AADT^3$	2.42E-14	6.32E-15	1.27E-04		

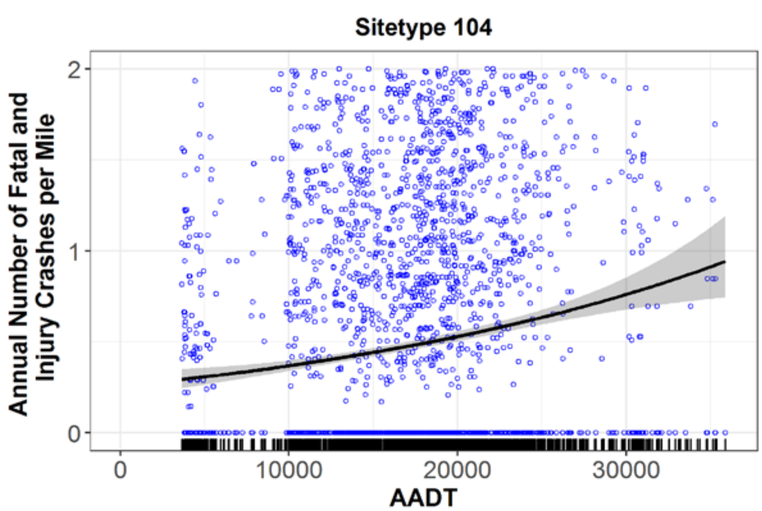
NA = not available (a statistically significant SPF was not developed).
Note: Crashes occurring within 250 feet from an intersection are excluded.

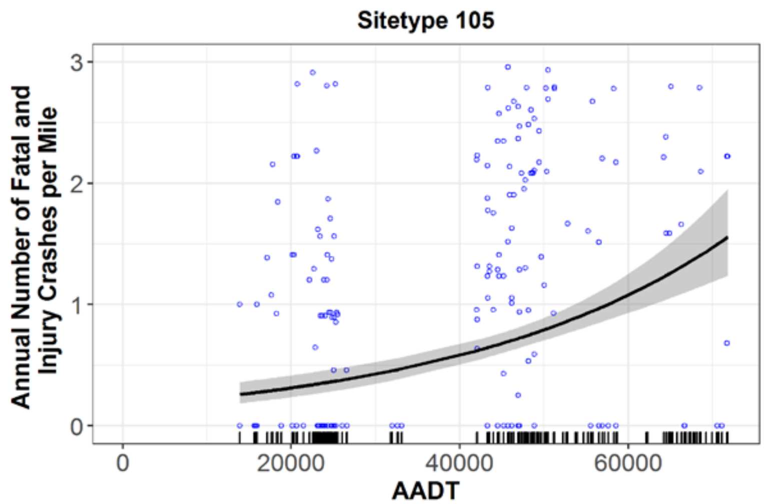
The graphs that follow, "SPFs With Only AADT in a Customized Functional Form for Fatal and Injury RD Crashes," visualize the models in Table C5 with the segment length set at 1 mile for fatal and injury RD crashes. In the graphs, a circle represents a segment; a solid line represents an SPF with the segment length of 1 mile and a corresponding AADT; and the gray band surrounding the solid line represents the 95th percentile mean prediction limit. It should be noted that the graphs were created for illustration purposes and may not show the entire range of data points.

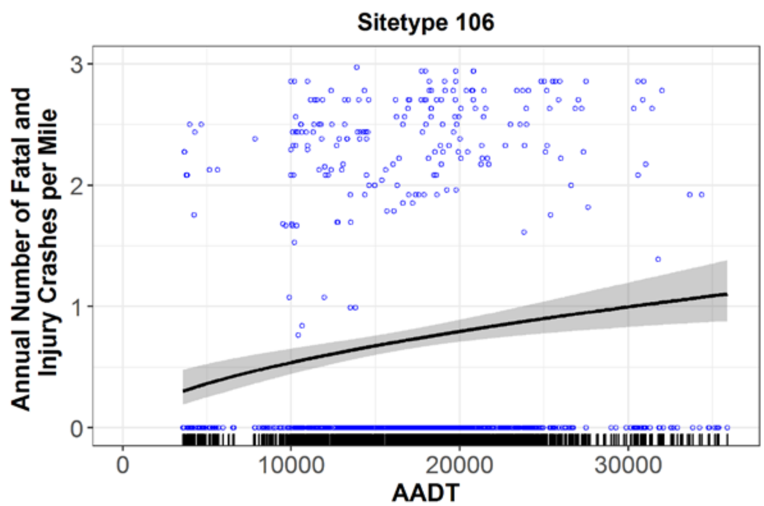


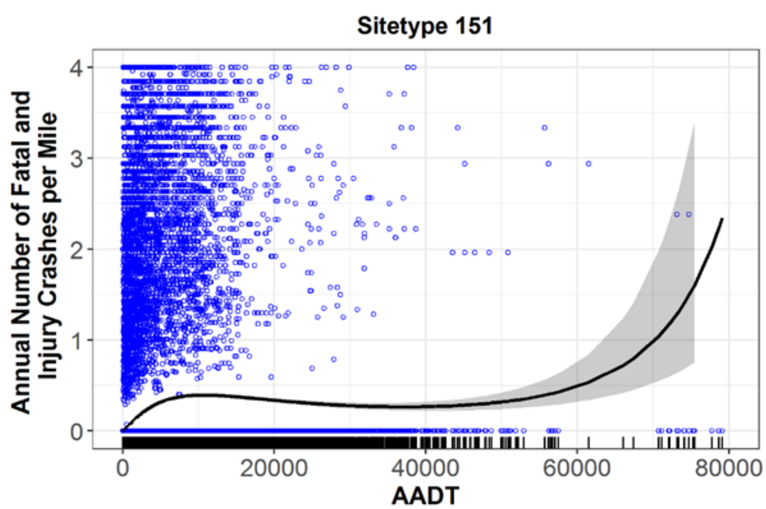

Sitetype 102
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
0
10000
20000
30000
AADT

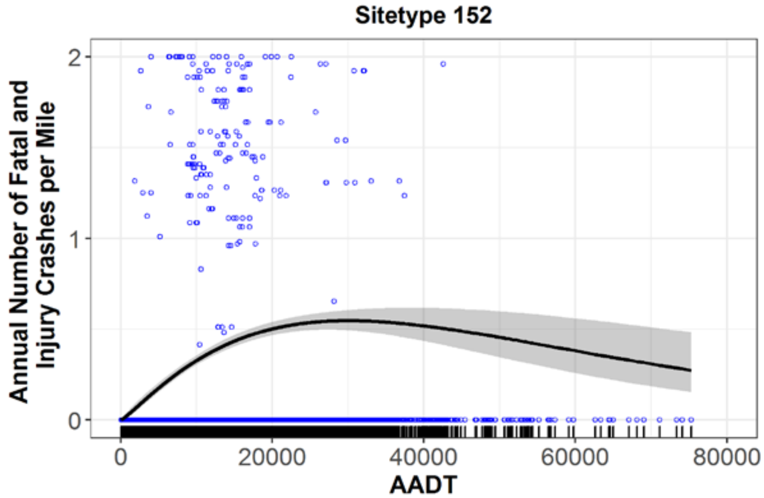

Sitetype 103
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
0
20000
40000
60000
80000
AADT

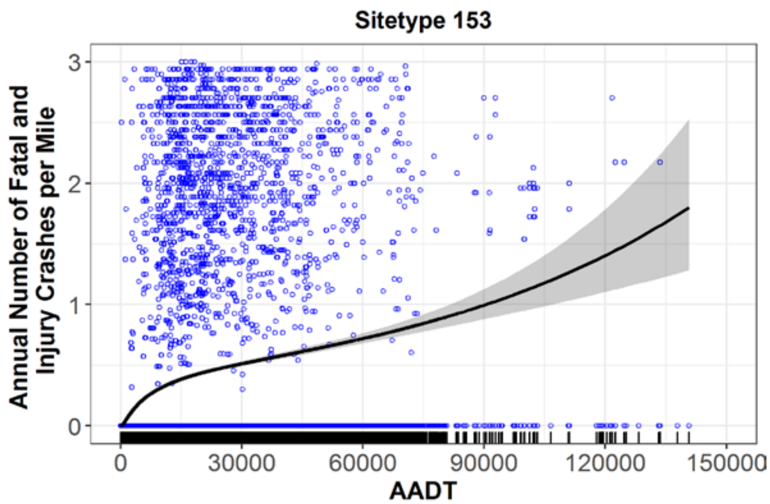

Sitetype 104
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
0
10000
20000
30000
AADT

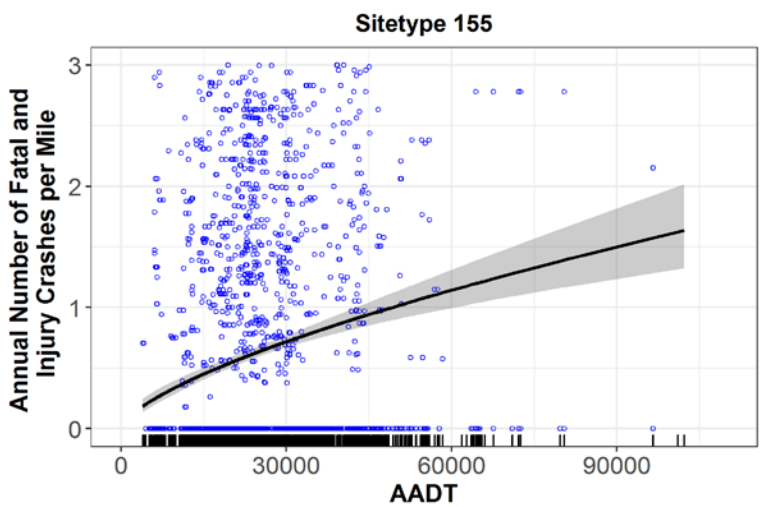

Sitetype 105
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
0
20000
40000
60000
AADT

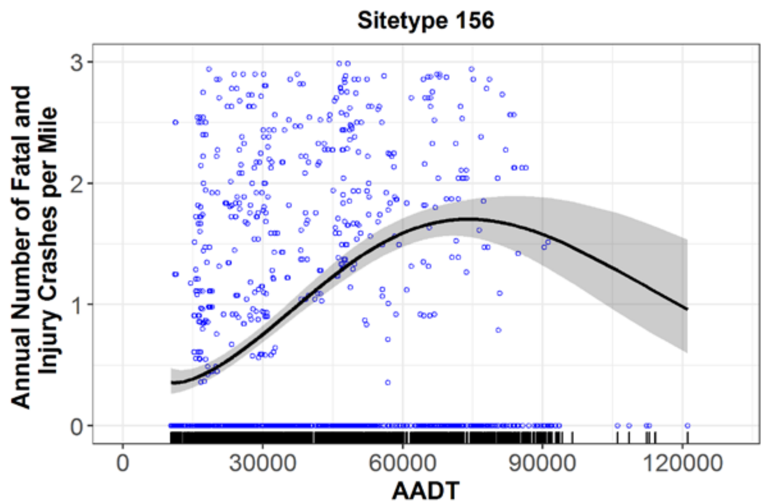

Sitetype 106
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
0
10000
20000
30000
AADT

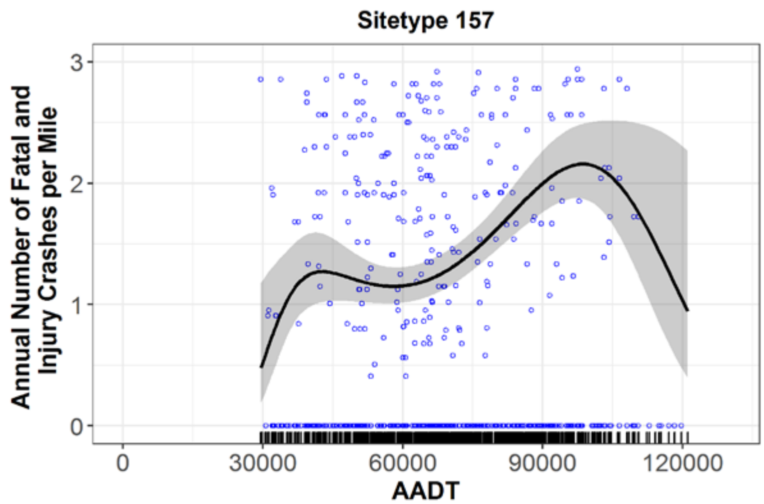

Sitetype 151
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
4
0
20000
40000
60000
80000
AADT

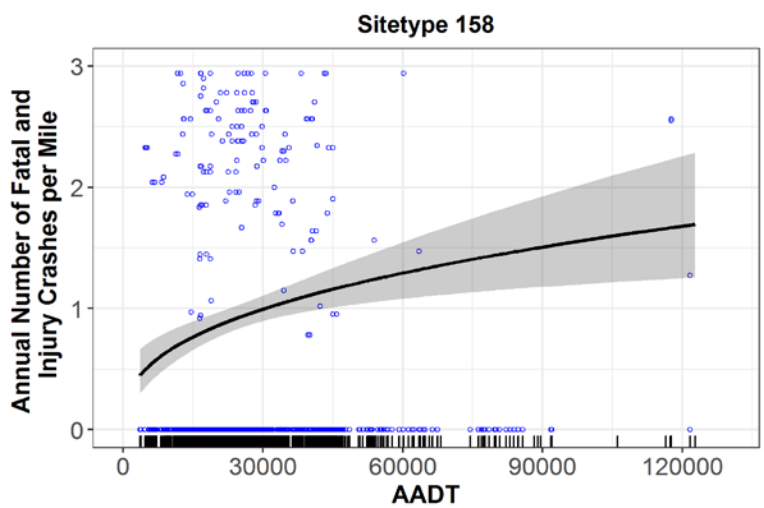

Sitetype 152
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
0
20000
40000
60000
80000
AADT

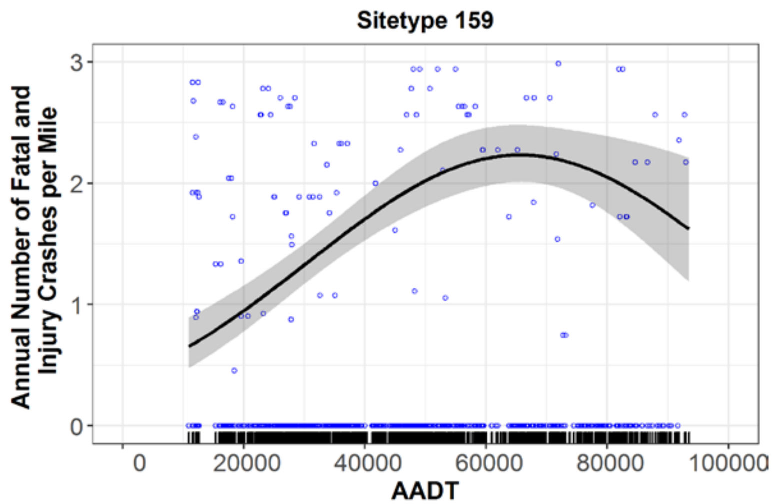

Sitetype 153
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
0
30000
60000
90000
120000
150000
AADT

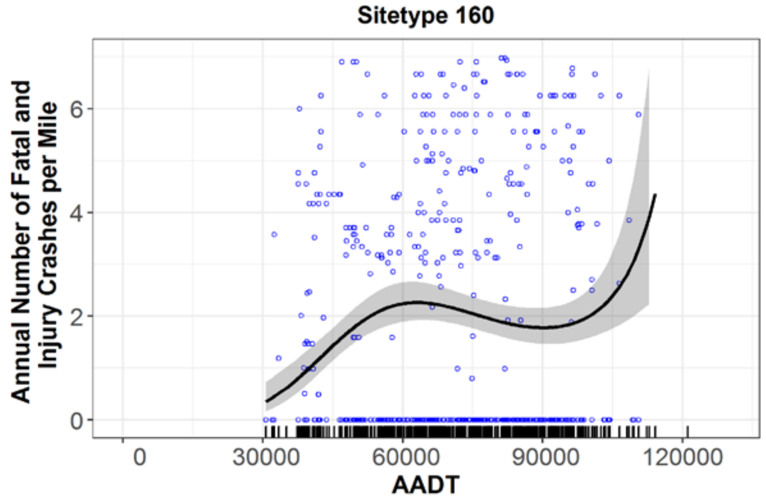

Sitetype 155
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
0
30000
60000
90000
AADT


Sitetype 156
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
0
30000
60000
90000
120000
AADT


Sitetype 157
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
0
30000
60000
90000
120000
AADT


Sitetype 158
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
0
30000
60000
90000
120000
AADT





Developed NB models with AADT and other predictors in customized functional forms for fatal and injury RD crashes are presented in Table C6; they are presented in a functional form in Table 8 in the body of the report. Estimation of the model for Site Type 107 was not successful; thus, no model was developed for the type.

Table C6. Estimated NB Models With AADT and Other Predictors in Customized Functional Forms for Fatal and Injury RD Crashes (2011-2015)

Site Type	Variable	Coefficient	Std. Err.	p-value	NB Dispersion	No. Obs.
101	Intercept	-1.08E+01	2.88E-01	2.00E-16	1.611	383,213
	ln(AADT)	1.81E+00	6.37E-02	2.00E-16		
	$(\ln(AADT))^2$	-8.11E-02	4.67E-03	2.00E-16		
	LaneWidth	-4.64E-02	6.67E-03	3.39E-12		
	ShoulderWidth	-7.23E-02	5.27E-03	2.00E-16		
	PaveRoughness	1.03E-03	2.02E-04	3.51E-07		
	PaveConditionV	9.52E-02	1.28E-02	8.22E-14		
	SurfaceType3456C	9.89E-01	1.99E-01	6.65E-07		
	CurbGutter25	-1.26E+00	1.03E-01	2.00E-16		
102	Intercept	-5.46E+00	1.27E+00	1.58E-05	1.196	3,774
	AADT	4.54E-01	1.39E-01	1.05E-03		
	ln(ShoulderWidth + 0.1)	1.00E-01	4.07E-02	1.38E-02		

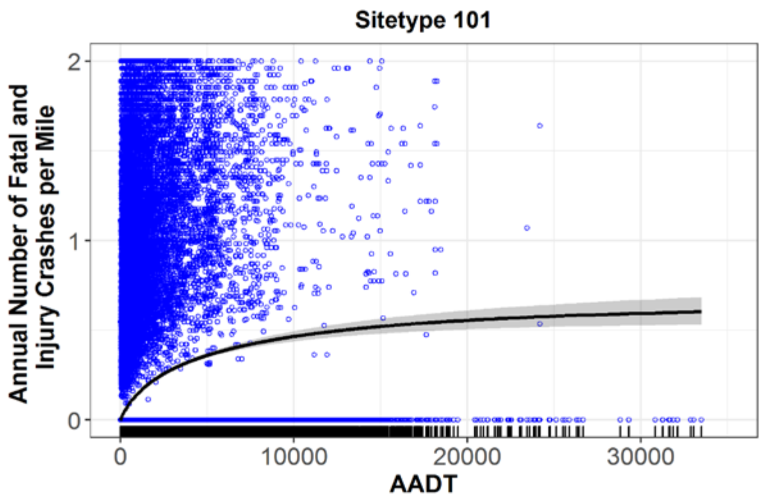
103	Intercept	-1.85E+01	3.62E+00	3.11E-07	2.279	21,527
	ln(AADT)	6.59E-01	3.43E-02	2.00E-16		
	MedianWidth	3.15E-03	4.79E-04	5.20E-11		
	LaneWidth	2.86E+00	8.07E-01	3.90E-04		
	$LaneWidth^2$	-2.22E-01	5.79E-02	1.24E-04		
	$LaneWidth^3$	5.20E-03	1.30E-03	6.53E-05		
104	Intercept	-1.34E-01	3.65E-01	7.14E-01	6.432	3,002
	AADT	3.61E-05	3.59E-06	2.00E-16		
	ShoulderWidth	-2.52E-01	7.11E-02	4.00E-04		
	PaveRoughness	1.27E-03	5.73E-04	2.68E-02		
	SurfaceType8	2.23E-01	8.98E-02	1.29E-02		
	CurbGutter3	-1.32E+00	4.90E-01	6.93E-03		
	CurbGutter5	-3.13E+00	1.07E+00	3.35E-03		
105	Intercept	-1.76E+00	2.28E-01	9.84E-15	12.307	275
	AADT	3.81E-05	5.66E-06	1.58E-11		
	MedianWidth	-2.26E-03	1.11E-03	4.13E-02		
106	Intercept	-5.79E+00	1.39E+00	3.09E-05	3.176	1,614
	ln(AADT)	5.69E-01	1.49E-01	1.37E-04		
	MedMedShldWidth	5.55E-03	2.62E-03	3.42E-02		
	$MedMedShldWidth^2$	-1.84E-05	7.45E-06	1.37E-02		
107	NA					115
151	Intercept	-9.22E+00	1.78E-01	2.00E-16	0.885	448,618
	AADT	-1.34E-04	7.27E-06	2.00E-16		
	$AADT^2$	1.35E-09	1.30E-10	2.00E-16		
	ln(AADT)	1.17E+00	2.43E-02	2.00E-16		
	LaneWidth	-9.39E-02	4.40E-03	2.00E-16		
	ShoulderWidth	-6.14E-02	5.66E-03	2.00E-16		
	MedMedShldWidth	9.29E-03	1.64E-03	1.33E-08		
	PaveRoughness	1.07E-03	2.31E-04	3.75E-06		
152	Intercept	-1.05E+01	1.19E+00	2.00E-16	1.161	25,144
	AADT	-4.05E-05	8.22E-06	8.67E-07		
	ln(AADT)	1.13E+00	1.35E-01	2.00E-16		
	LaneWidth	-6.32E-02	2.23E-02	4.56E-03		
	MedMedShldWidth	1.85E-02	9.08E-03	4.17E-02		
	PaveRoughness	1.46E-03	3.56E-04	4.09E-05		
	SurfaceType8	-5.08E-01	2.26E-01	2.47E-02		
153	Intercept	-1.46E+01	2.32E+00	2.86E-10	1.265	67,309
	ln(AADT)	2.34E+00	4.69E-01	6.26E-07		
	$(\ln(AADT))^2$	-1.02E-01	2.37E-02	1.81E-05		
	SurfaceWidth	9.65E-03	1.65E-03	5.07E-09		
	LaneWidth	-3.88E-02	1.73E-02	2.46E-02		
	MedShldWidth	6.46E-02	8.44E-03	1.93E-14		
	MedianWidth	2.97E-03	5.40E-04	3.65E-08		
	PaveRoughness	8.10E-04	2.68E-04	2.51E-03		
	CurbGutter1235	3.44E-01	1.36E-01	1.11E-02		
	ShoulderWidth	1.08E-02	4.80E-03	2.46E-02		
155	Intercept	-6.03E+00	7.99E-01	4.55E-14	3.161	2,513
	ln(AADT)	6.27E-01	7.60E-02	2.00E-16		
	ShoulderWidth	-1.75E-01	2.75E-02	1.87E-10		
	ln(MedShldWidth + 0.1)	1.20E-01	3.62E-02	8.79E-04		
	PaveRoughness	1.16E-03	5.88E-04	4.86E-02		
156	Intercept	1.49E+01	5.43E+00	6.24E-03	4.669	2,291
	AADT	1.53E-04	3.07E-05	6.05E-07		

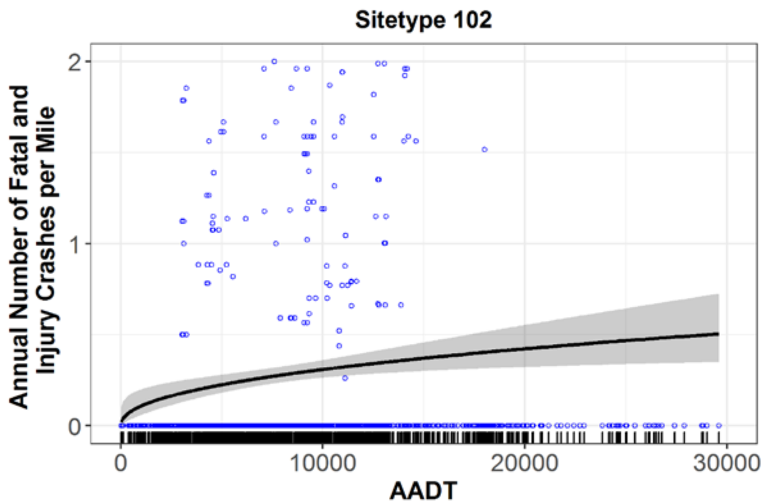
	$AADT^2$	-8.95E-10	1.73E-10	2.31E-07		
	ln(AADT)	-1.84E+00	6.03E-01	2.21E-03		
	RtShldWidth	1.65E-02	5.81E-03	4.41E-03		
	MedianWidth	-1.65E-03	3.73E-04	9.54E-06		
157	Intercept	-5.00E+03	1.87E+03	7.43E-03	3.067	1,528
	AADT	3.49E-03	1.29E-03	6.90E-03		
	$AADT^2$	-6.58E-09	2.46E-09	7.43E-03		
	ln(AADT)	1.04E+03	3.87E+02	7.25E-03		
	$(\ln(AADT))^2$	-5.46E+01	2.03E+01	7.20E-03		
	SurfaceWidth	2.96E-02	8.03E-03	2.25E-04		
	LaneWidth	-1.03E+00	3.52E-01	3.51E-03		
	RtShldWidth	-4.65E-02	1.65E-02	4.69E-03		
	MedRtShldWidth	-5.17E-02	1.57E-02	9.57E-04		
	PaveRoughness	7.28E-03	1.33E-03	4.37E-08		
	CurbGutter25	-7.53E-01	2.26E-01	8.79E-04		
158	Intercept	-2.61E+00	1.02E+00	1.02E-02	2.283	1,883
	ln(AADT)	2.57E-01	9.99E-02	1.02E-02		
	PaveRoughness	-2.83E-02	7.19E-03	8.48E-05		
	$PaveRoughness^2$	4.08E-04	1.06E-04	1.21E-04		
	$PaveRoughness^3$	-1.33E-06	3.71E-07	3.40E-04		
159	Intercept	-8.09E-01	2.64E-01	2.16E-03	1.807	1,952
	AADT	5.26E-05	1.05E-05	5.18E-07		
	$AADT^2$	-3.97E-10	9.78E-11	4.89E-05		
	MedianWidthMin	-3.86E-03	1.20E-03	1.30E-03		
160	Intercept	-9.45E+00	2.29E+00	3.60E-05	2.535	956
	AADT	4.28E-04	1.01E-04	2.08E-05		
	$AADT^2$	-5.80E-09	1.41E-09	3.85E-05		
	$AADT^3$	2.53E-14	6.34E-15	6.63E-05		
	ln(MedRtShldWidth + 0.1)	-6.96E-02	2.94E-02	1.77E-02		

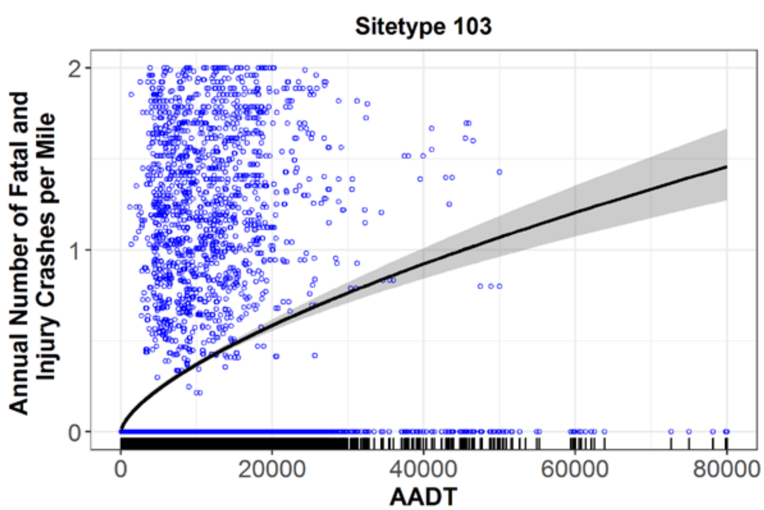
NA = not available (a statistically significant SPF was not developed).

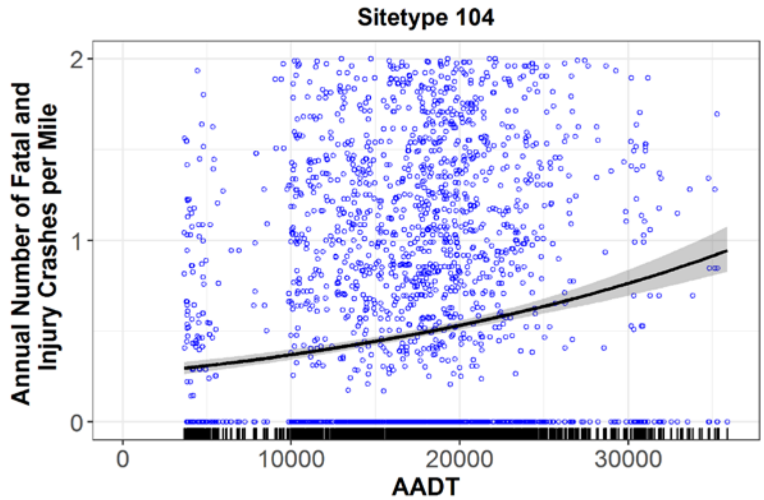
Note: Crashes occurring within 250 feet from an intersection are excluded.

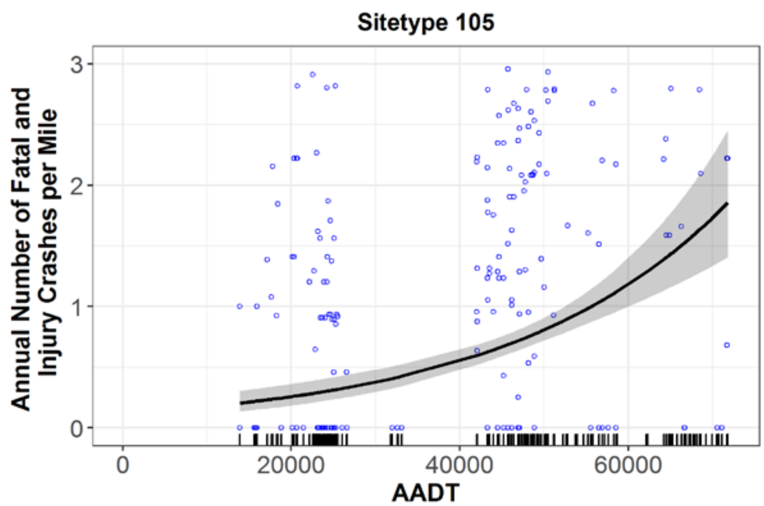
The graphs that follow, "SPFs With AADT and Other Predictors in Customized Functional Forms for Fatal and Injury RD Crashes," visualize the models in Table C6 with the segment length set at 1 mile for fatal and injury RD crashes. All the predictors except AADT and indicator variables (e.g., CurbGutter4 and SurfaceType8) are set at the average values for illustration purposes. In the graphs, a circle represents a segment; a solid line represents an SPF with the segment length of 1 mile and a corresponding AADT; and the gray band surrounding the solid line represents the 95th percentile mean prediction limit. It should be noted that the graphs were created for illustration purposes and may not show the entire range of data points.

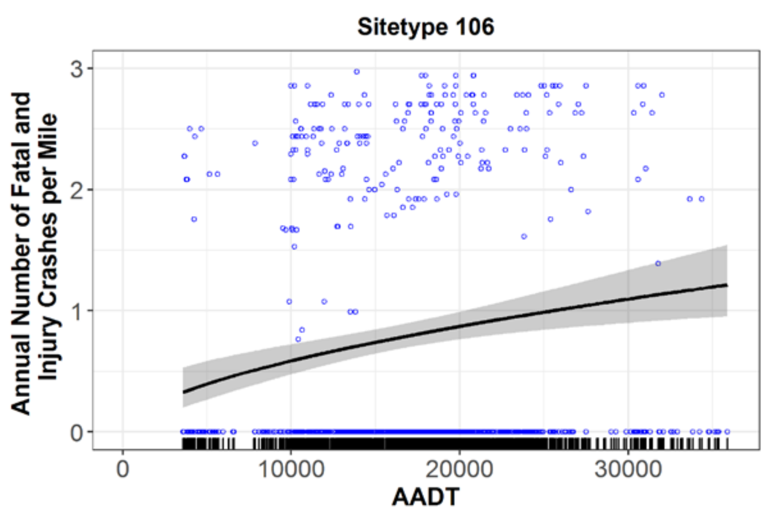

Sitetype 101
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
0
10000
20000
30000
AADT

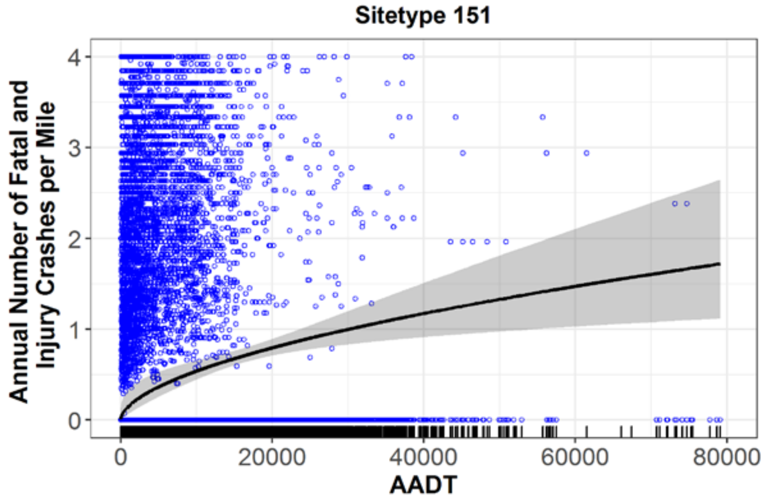

Sitetype 102
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
0
10000
20000
30000
AADT

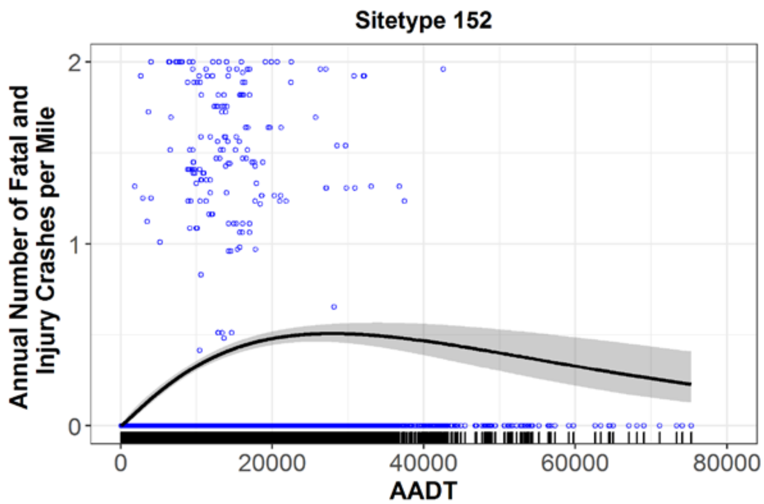

Sitetype 103
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
0
20000
40000
60000
80000
AADT

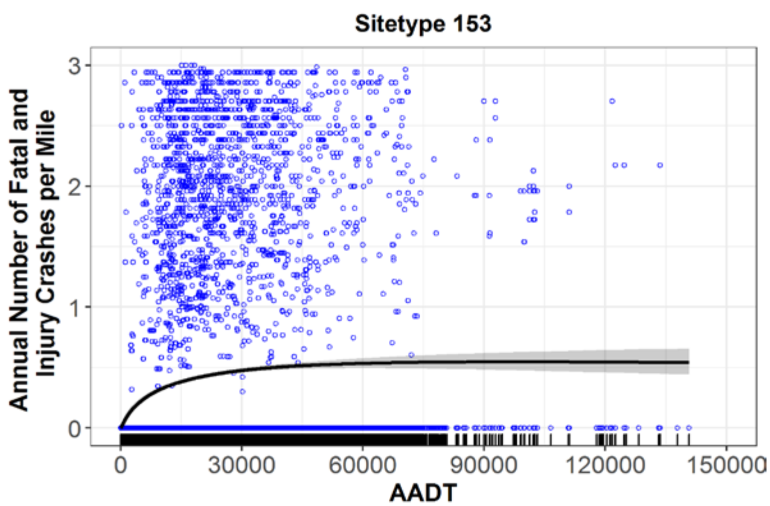

Sitetype 104
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
0
10000
20000
30000
AADT

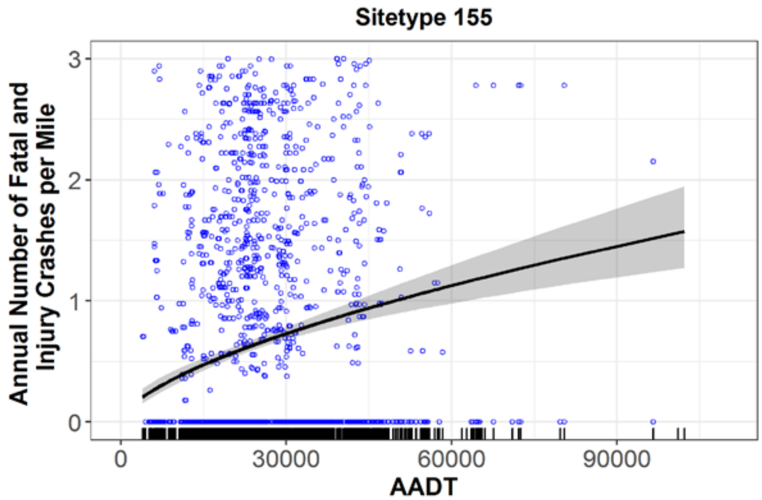

Sitetype 105
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
0
20000
40000
60000
AADT

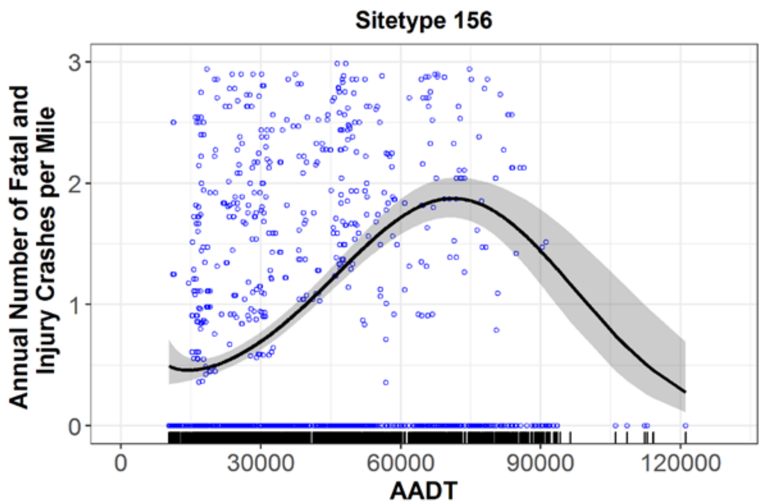

Sitetype 106
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
0
10000
20000
30000
AADT

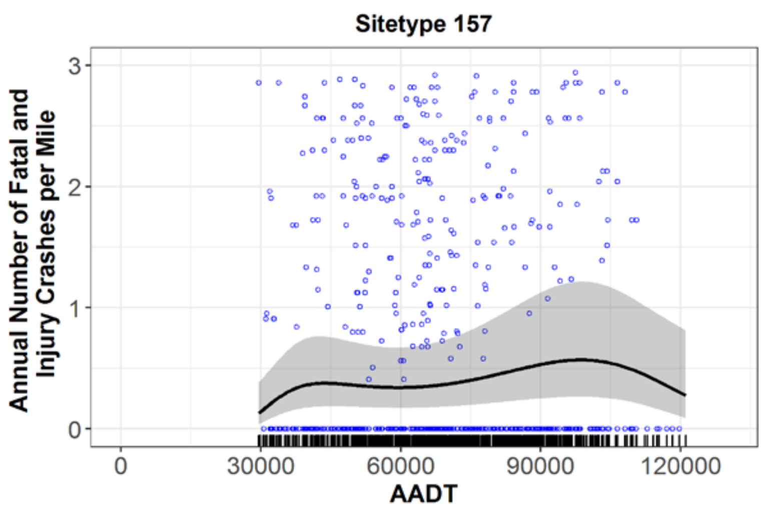

Sitetype 151
Annual Number of Fatal and Injury Crashes per Mile
AADT
0
1
2
3
4
0
20000
40000
60000
80000

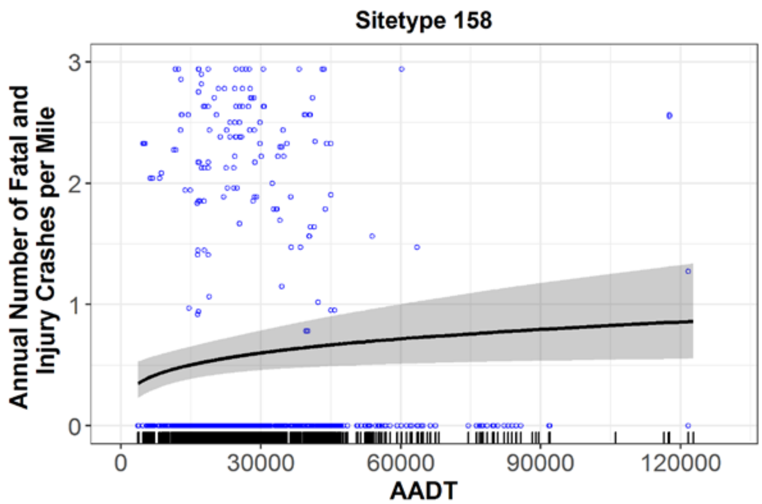

Sitetype 152
Annual Number of Fatal and Injury Crashes per Mile
AADT
0
1
2
0
20000
40000
60000
80000


Sitetype 153
Annual Number of Fatal and Injury Crashes per Mile
AADT
0
1
2
3
0
30000
60000
90000
120000
150000

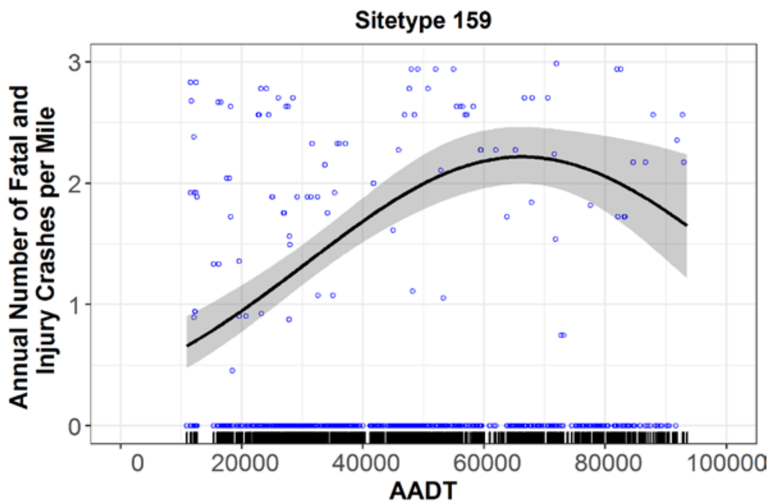

Sitetype 155
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
0
30000
60000
90000
AADT


Sitetype 156
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
0
30000
60000
90000
120000
AADT

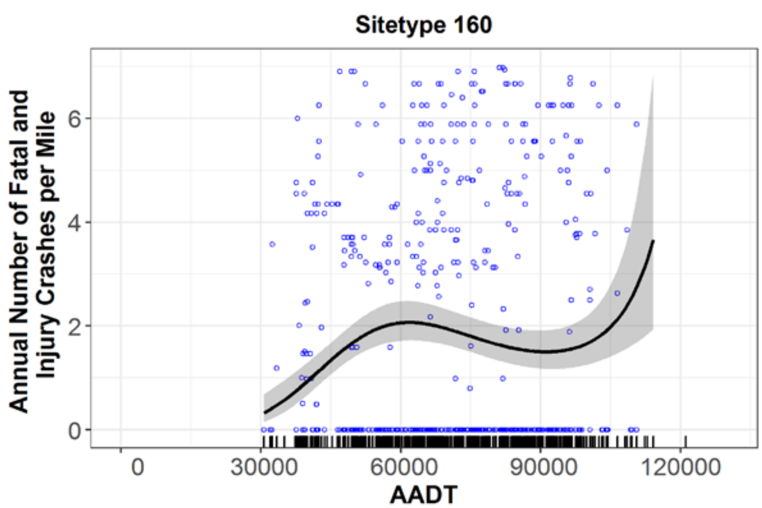

Sitetype 157
Annual Number of Fatal and Injury Crashes per Mile
0
1
2
3
0
30000
60000
90000
120000
AADT



Sitetype 158
Annual Number of Fatal and Injury Crashes per Mile
AADT
0
30000
60000
90000
120000
0
1
2
3



Sitetype 159
Annual Number of Fatal and Injury Crashes per Mile
AADT
0
20000
40000
60000
80000
100000
0
1
2
3



Sitetype 160
Annual Number of Fatal and Injury Crashes per Mile
AADT
0
30000
60000
90000
120000
0
2
4
6