Regionalized Safety Performance Functions

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Girish Modi (gmodi@pa.gov), Chief, Highway Safety, Risk Management and Crash Data Analysis, Pennsylvania Department of Transportation, served as the technical advisor on the project until retiring in June 2015. Gavin Gray (gagray@pa.gov), Chief, Highway Safety Section, subsequently served as the project technical advisor. Heather Heslop (hheslop@pa.gov) was the research project manager.

16. Abstract

The objectives of this project were to develop Pennsylvania-specific, regionalized safety performance functions (SPFs) that are consistent in functional form with the American Association of State Highway and Transportation Officials' *Highway Safety Manual*. Regionalized SPFs for three roadway classes are included in this project: (1) rural two-lane highways segments and intersections; (2) rural multilane highway segments and intersections; and (3) Urban and suburban arterial (non-freeway) segments and intersections. For each of these roadway classes, the regionalized SPFs were developed to predict total crash frequency and the frequency of fatal + injury crashes on roadway segments and common intersection types of state-owned roadways. The regionalized SPFs were designed to capture any differences in safety performance across different geographic regions in Pennsylvania. The regionalization effort considered SPFs at the county, planning organization (metropolitan and rural), and engineering district levels. The results showed that, when an adequate sample of roadway segments or intersections were available for statistical modeling, district-level SPFs, with county adjustment factors, outperformed other regional or statewide models based on the predictive power of the models. When an adequate sample size was not available to estimate regionalized SPFs, statewide models, with district-level adjustment factors, were recommended to account for geographic differences in the Commonwealth of Pennsylvania. The results underscore the importance of estimating local SPFs if crash and roadway inventory data are available.

17. Key Words

Safety performance functions, negative binomial regression, two-lane rural highways, rural multilane highways, urban and suburban arterials, intersections

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

The American Association of State Highway and Transportation Officials' (AASHTO) *Highway Safety Manual* (HSM) provides transportation professionals with quantitative tools that can be used to assess the safety performance of planned or existing highways. One set of tools currently available in the HSM are safety performance functions (SPFs), which relate the expected crash frequency of a roadway segment or intersection to anticipated traffic volumes, geometric characteristics, and other features. The HSM contains SPFs for rural two-lane, rural multilane, and urban and suburban arterial roadway segments and intersections. The HSM also provides a detailed calibration method to adapt the SPF for each roadway or intersection type to local conditions, since the data used to develop the crash frequency models do not reflect Pennsylvania driving conditions. Alternatively, SPFs can be developed using local data to provide crash frequency estimates that are more reliable for Pennsylvania roadways than simply applying the calibration procedure.

The objectives of this project were to develop Pennsylvania-specific, regionalized SPFs that are consistent with the HSM. SPFs for three roadway classes were included in this project:

1. Rural two-lane highways segments and intersections,
2. Rural multilane highway segments and intersections, and
3. Urban and suburban arterial (non-freeway) segments and intersections.

For each of these roadway classes, regionalized SPFs were developed to predict the total crash frequency and the frequency of fatal + injury crashes on roadway segments and common intersection types of state-owned roadways. The regionalized SPFs were designed to capture any differences in safety performance across different geographic regions of Pennsylvania. Three different regional levels were considered: county, metropolitan and rural planning organization (MPO and RPO), and PennDOT engineering district.

A previous research project (Work Order #1: *Safety Performance Functions*) developed statewide SPFs for rural two-lane highway segments and intersections. The present study used the data previously collected for the Work Order #1 project, which included all state-owned, two-lane rural roadways with three-digit or lower state route numbers, to develop regionalized SPFs that are likely to improve safety prediction estimates on this roadway type. For rural multilane highways and urban and suburban arterials, new data were collected to develop both statewide and regionalized SPFs.

The remainder of this report documents the development of these regionalized SPFs and is organized into five subsequent sections. The first describes the roadway segment and intersection types that were included in the statistical modeling effort. The second section explains the data collection method, including the data sources, elements, and structures. This is followed by a discussion of the methods used to estimate the statistical models and subsequently assess which level of regionalization was recommended for different geographic areas in the Commonwealth. The following section is a detailed discussion of the results, which is organized by roadway type. Finally, the report concludes with a summary of the findings, and recommendations to implement the results in the project development process.

ROADWAY SEGMENT AND INTERSECTION TYPES

Statewide and regionalized SPFs were developed to predict total crash frequency and the frequency of fatal + injury crashes for three roadway classes. Within each class, SPFs were developed for both roadway segments and common intersection forms. The roadway classes and intersection forms considered include:

1. Rural two-lane rural highway segments, with the following intersection forms:
    - 3-leg intersections with minor-street stop control
    - 4-leg intersections with minor-street stop control
    - 4-leg intersections with all-way stop control
    - 3-leg intersections with signal control
    - 4-leg intersections with signal control
2. Rural four-lane divided and undivided segments, with the following intersection forms:
    - 3-leg intersections with minor-street stop control
    - 4-leg intersections with minor-street stop control
    - 4-leg intersections with signal control
3. Urban and suburban arterials with the following segment and intersection types:
    - Two-lane undivided arterials
    - Four-lane undivided arterials
    - Four-lane divided arterials
    - 3-leg intersections with minor-street stop control
    - 4-leg intersections with minor-street stop control
    - 3-leg signalized intersections
    - 4-leg signalized intersections

Additional guidance on estimating crash frequencies on 4-leg all-way stop-controlled and 5-leg signalized intersections on urban and suburban arterials is provided in Appendix I of this report. Also included in Appendix I is guidance on estimating crash frequencies for 3-leg minor stop-controlled intersections with "STOP Except Right Turn" signs.

A previous research project (Work Order #1: *Safety Performance Functions*) identified all two-lane rural highway segments and intersections on three-digit or lower state routes in the Commonwealth of Pennsylvania and created analysis files used for the development of statewide SPFs. These files consisted of 10,106 centerline miles of roadway segments and 683 intersections for the years 2005 through 2012 (inclusive). The data files from this earlier effort were used to estimate the regionalized SPFs for rural two-lane highway segments and intersections in the present study. Additionally, this study developed analysis files for the rural multilane highway segments and intersections, as well as the urban and suburban highway segments and intersections. These data are described in more detail below.

DATA COLLECTION

This section of the report describes the roadway management system (RMS) data files, supplemental data collection, and electronic crash data files that were compiled to estimate the SPFs for the roadway segment and intersection types noted above.

Roadway Management System Data

PennDOT's RMS data files include information about the roadway cross-section, traffic volume, access control, functional classification, posted speed limit, and intersection locations and traffic control. These data are codified based on PennDOT's linear referencing system, which is defined by the county, state route, and segment number. Two data files (for the years 2009 and 2013) were acquired from PennDOT for modeling purposes. These two data files were initially compared to determine if segments or intersections were added or deleted during this time period, perhaps due to new roadway construction, major reconstruction or changes in the functional classification of a segment. For the most part, roadway infrastructure elements in the data files (e.g., number of lanes, lane width, shoulder type, shoulder width, divisor type, and divisor width) remained unchanged between the years 2009 and 2013; however, differences between the files were identified. Since comparison of the segment and intersection data between the 2009 and 2013 files revealed that few differences existed, the 2013 file was used as the base file because it was the most recently updated.

Traffic volumes were the only variable expected to change significantly between the 2009 and 2013 RMS data files. These traffic volumes were provided as the average annual daily traffic (AADT) in units of vehicles per day. To account for changing traffic volumes for the interim years between 2009 and 2013, the research team used linear interpolation of these known volumes. As historical crash data included the year 2014, the linear trend between 2009 and 2013 was also used to estimate traffic volumes for the year 2014. As noted in the crash data file section below, only data for the period 2010 through 2014 (inclusive) were used to estimate the rural multilane and urban and suburban arterial segment and intersection SPFs.

The roadway segment analysis file for each roadway class contained the following data elements:

- Linear reference information (county, route, and segment)
- Segment length
- Average annual daily traffic (vehicles/day)
- Paved roadway width (including all travel lanes)
- Number of travel lanes in both directions
- Posted speed limit
- Divisor type
- Left- and right-shoulder type

- Left- and right-shoulder paved width (feet)
- Left- and right-shoulder total width

Intersection location information was acquired from the PennDOT RMS Intersection data files. The RMS Intersection data files include the county, state route number, segment, and offset where two roadways on the state-owned roadway network intersect. This intersection location information was appended to the segment data. After merging the RMS segment data with the RMS intersection data, a separate data file was developed for each of the roadway classes to estimate intersection SPFs. The intersection data file for each roadway class contained only the relevant data from intersection locations, including the segment-level data listed above for each intersecting roadway in the intersection data analysis files.

The RMS data file was used to identify each roadway class included in the present study. As noted previously, all two-lane rural highway segments and at-grade intersections were previously identified in the Work Order #1 project. To identify rural multilane highways, the codes shown in Table 1 were used. Freeways and expressways, with full-access control, were not included in the rural multilane highway class to maintain consistency with the first edition of the AASHTO *Highway Safety Manual*.

Table 1. Codes to Identify Rural Multilane Highways.

Variable	Code Definition
Divisor	1 = Paint divided 2 = Fixed barrier (man-made) 3 = Earth divided 4 = 4-foot greater painted center 7 = Natural barrier (trees, fill, etc.)
Maintenance Functional Class (MFC)	B = Other expressways and principal arterial C = Minor arterial highways D = Collector highways
Area	1 = Rural
Number of Lanes*	2 or more (per direction)
Access Control	2 = Partial 3 = None
Direction	B = Both
*Because the number of road segments with more than 2 lanes per direction was very small, only rural multilane highways with 2 lanes per direction were used to develop the SPFs.	

Urban and suburban arterials were identified using the codes shown in Table 2. Again, freeways and expressways were not included, as these are not part of the urban and suburban arterial class in the AASHTO *Highway Safety Manual*.

Table 2. Codes to Identify Urban and Suburban Arterials.

Variable	Code Definition
Maintenance Functional Class (MFC)	B = Other expressways and principal arterial C = Minor arterial highway
Area	2 = Small urban 3 = Urbanized (population 50,000 – 199,000) 4 = Urbanized (population 200,000 or more)
Number of Lanes	2 or more
Access Control	2 = Partial 3 = None
Parking Lanes	Both (B) Left (L) Right (R)
Center Left-turn Lane	Center (C)

Several supplemental data elements were collected as part of this project to enable inclusion of additional roadway and roadside features in the SPFs. At the segment-level, these included the roadside hazard rating, presence and radius/length of horizontal curve, and the presence of low-cost safety improvements (i.e.., shoulder or centerline rumble strips). At the intersection level, additional elements include the intersection control type, intersection skew angle, and presence of auxiliary lanes on intersection approaches (i.e., left- or right-turn lanes). Data collection strategies for each of these supplemental pieces of data are described below.

Supplemental Roadway and Intersection Data Elements

This section of the report is organized into two parts. The first describes the data elements that were collected and codified using PennDOT's online video photolog system. The second describes the data elements that were collected using the Google Earth web-based tool. Appendix A and Appendix B include the instructional guides for the online video photolog and Google Earth data collection methods, respectively.

Online Video Photolog Data Collection

PennDOT's video photolog system can be found online at the following link:

http://www.dot7.state.pa.us/VideoLog/Open.aspx

The web-based application contains a forward-looking view of the roadway and roadside from a driver's perspective. The distance between consecutive images varies from 21 to 210 feet. In addition to the forward-looking display, a map of the segment within the roadway network is displayed within the video photolog application.

For all of the multilane rural highway segments, the following data elements were collected using the video photolog system:

- Roadside hazard rating (RHR) on both sides of the roadway: measured using the 1 to 7 scale based on research by Zegeer et al. (1986)

- Presence of low-cost safety improvements, including: centerline and shoulder rumble strips and horizontal curve warning pavement markings
- Driveway density: the number of driveways and intersections along a segment that are not included in the state-owned intersection analysis database

Because urban and suburban arterials have limited variability with regard to RHR and contain few low-cost safety improvements, relevant data elements noted above were collected for only a 500-mile sample on this roadway type to determine if these features are associated with safety performance. The additional data collection also included the presence of medians and the presence of left-turn and no-U-turn signs at median openings.

For all rural multilane and urban-suburban arterial intersections, the following data elements were collected using the PennDOT video photolog system:

- Presence of intersection auxiliary lanes: left- or right-turn lanes
- Type of intersection traffic control: signalized or stop-controlled intersections
- Presence of pedestrian crosswalk on intersection approach.

Appendix A of this report includes an instructional guide that describes the data collection procedure and was used to ensure inter-rater consistency among the data collection team for the RHR.

<u>Google Earth Data Collection</u>

The Google Earth tool provides high-quality satellite imagery of Pennsylvania and built-in functions to measure features to scale. This satellite imagery was used to collect horizontal curve data. The radius (or degree of curvature) and length of horizontal curve were collected at the segment-level for all rural multilane highways in the analysis data files. However, since much of the urban-suburban arterial network is based on a grid pattern, horizontal curve data were not collected for all segments in the analysis file. Rather, a sample of the same 500-miles noted above (see Video Photolog section) was collected to determine if horizontal curvature was associated with crashes on urban-suburban arterials. The horizontal alignment indexes that were considered by the research team included (Fitzpatrick et al., 1999):

$$\frac{\sum DC_i}{L} \quad (1)$$

$$\frac{\sum CL_i}{L} \quad (2)$$

$$\frac{\sum R_i}{n} \quad (3)$$

where:

DC_i = degree of curve for curve i (i = 1, 2, …, n) [degrees];
L = length of segment (miles);
CL_i = length of curve for curve i (i = 1, 2, …, n) [miles];
R_i = Radius of curve i (i = 1, 2, …, n) [ft]; and,
n = number of horizontal curves per segment

Appendix B of this report includes an instructional guide that describes the data collection procedure and was used to ensure inter-rater consistency among the data collection team for the horizontal curve and intersection skew angle data elements.

Electronic Crash Data

The research team used the most recent five years of crash data (2010 through 2014, inclusive) to estimate the safety performance functions for rural multilane highway and urban-suburban arterial segments and intersections. These data files contain information about the event, driver, and vehicle occupants for each reported crash on the state-owned highway system in Pennsylvania. Only event information was used for the current study. The following data elements were used when developing the segment-level analysis database:

- Crash location: county, state route, segment, and offset
- Crash date: month, day, year
- Collision type: rear-end, head-on, angle, sideswipe, hit fixed object, hit pedestrian, other
- Intersection type: mid-block, four-way intersection, “t” intersection, “y” intersection, traffic circle/roundabout, multi-leg intersection, railroad crossing, other
- Location type: underpass, ramp, bridge, tunnel, toll booth, driveway or parking lot, ramp and bridge
- Work zone type: construction, maintenance, utility company
- Injury severity: fatality, major injury, moderate injury, minor injury, no injury

Several of the crash data elements were used to identify crashes occurring on roadway segments and intersections of interest for the present study. For example, crashes occurring on ramps were used as a check to ensure that the RMS files have correctly eliminated ramps from the analysis database. Similarly, crashes in construction work zones were not included in the analysis files as these conditions are temporary.

PennDOT’s linear referencing system was used to derive the “influence” area of each at-grade intersection for crash frequency modeling purposes. Many recent safety evaluation studies defined intersection-related crashes as those reported within 250-feet of the point where the two intersecting roadway alignments cross (e.g., Bauer and Harwood, 1996; Harwood et al., 2003; Mitra and Washington, 2012; Wang and Abdel-

Aty, 2006). The same influence area was used in this study for each of the state-owned at-grade intersections identified using the RMS data.

Crash data were merged with the RMS and supplemental data files based on the location of the crash (county, route, and segment). Crash counts (total, total for each severity level, and total for each crash type) for each roadway segment and intersection were generated for each analysis year. Locations that did not experience a crash during any one or more years were retained in the analysis database.

As noted earlier in this report, the Work Order #1 project used data for the period 2005 through 2012 (inclusive) to estimate the statewide two-lane rural highway SPFs, so these same data files were used for the regionalized SPFs for two-lane rural highway segments and intersections.

METHODOLOGY

The following sections of the report describe the statistical methodology and regionalization process used to estimate the regionalized SFPs for each roadway type.

Statistical Methodology

Because PennDOT is modifying various *Highway Safety Manual* tools for application in the Commonwealth, the statistical modeling approach used in the present study is consistent with the methods used to develop the first edition of the manual. As such, negative binomial regression was used to estimate all segment and intersection SPFs. Such an approach models the expected number of crashes per year on each roadway segment or intersection as a function of one or more explanatory variables. This is a common approach to model roadway segment crash frequency (e.g., Miaou, 1994; Shankar et al., 1995; Chang et al., 2005; El-Basyouny and Sayed, 2006) and intersection crash frequency (e.g., Poch and Mannering, 1996; Bauer and Harwood, 1996; Washington et al., 2005) because it accounts for the overdispersion that is often found in crash data. Overdispersion results from the variance exceeding the mean in the crash frequency distribution. The general functional form of the negative binomial regression model is:

$$\ln \lambda_i = \beta X_i + \varepsilon_i \qquad (4)$$

where:

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

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

$$Var(y_i) = E(y_i)[1 + \alpha E(y_i)] \qquad (5)$$

where:

- $Var(y_i)$ = variance of reported crashes y occurring on roadway segment *i*;
- $E(y_i)$ = expected crash frequency on roadway segment *i*; and,
- α = overdispersion parameter.

The appropriateness of the negative binomial (NB) regression model is based on the significance of the overdispersion parameter. When α is not significantly different from zero, the negative binomial model reduces to the Poisson model. For all the models that were estimated, the estimate of α is reported to verify the appropriateness of the negative binomial approach.

The method of maximum likelihood is used to estimate the model parameters. This method estimates model parameters by selecting those that maximize a likelihood function that describes the underlying statistical distribution assumed for the regression model. The likelihood function for the NB model that was used in this study is shown in equation (6):

$$L(\lambda_i) = \prod_{i=1}^{N} \frac{\Gamma(\theta + y_i)}{\Gamma(\theta) y_i!} \left[\frac{\theta}{\theta + \lambda_i}\right]^{\theta} \left[\frac{\lambda_i}{\theta + \lambda_i}\right]^{y_i} \qquad (6)$$

where:

N = total number of roadway segments in the sample;
Γ = gamma function; and,
θ = $1/\alpha$.

To apply the negative binomial regression models estimated in this study, the following functional form was used for roadway segments:

$$\lambda_i = e^{\beta_0} \times L \times AADT^{\beta_1} \times e^{(\beta_2 X_2 + \ldots + \beta_n X_n)} \qquad (7)$$

where:

λ_i = expected number of crashes per year on roadway segment *i*;
e = exponential function;
β_0 = regression coefficient for constant;
L = roadway segment length (miles);
$AADT$ = average annual daily traffic (veh/day);
β_1 = regression coefficient for AADT;
$\beta_2, \ldots, \beta_n$ = regression coefficients for explanatory variables, $i = 2, \ldots, n$; and,
$X_2, \ldots, X_n$ = vector of geometric design, traffic volume, and other site-specific data.

The following functional form was used for all intersection SPFs:

$$\lambda_i = e^{\beta_0} \times AADT_{major}^{\beta_1} \times AADT_{minor}^{\beta_2} \times e^{(\beta_3 X_3 + \ldots + \beta_n X_n)} \qquad (8)$$

where:

λ_i = expected number of crashes at intersection *i*;
e = exponential function;
β_0 = regression coefficient for constant;
$AADT_{major}$ = average annual daily traffic (veh/day) for major roadway;
$AADT_{minor}$ = average annual daily traffic (veh/day) for minor roadway;
β_1, β_2 = regression coefficients for major and minor road AADT, respectively,
$\beta_3, \ldots, \beta_n$ = regression coefficients for explanatory variables, $i = 3, \ldots, n$; and,

$X_3, \ldots, X_n$ = vector of geometric design and other site-specific data.

The elasticity of each independent variable included in the model can be used to help interpret the results of the SPFs. The elasticities provide a measure of responsiveness of one variable to a change in another. For the continuous explanatory variables considered in this study (e.g., AADT), the elasticity is interpreted as the percent change in the expected roadway segment crash frequency given a one percent change in that continuous variable. In general, the elasticity of the expected crash frequency for continuous explanatory variable '*k*' on roadway segment '*i*' during time period '*j*' is defined as:

$$E_{x_{ijk}}^{\lambda_{ij}} = \frac{\partial \lambda_{ij}}{\partial x_{ijk}} \times \frac{x_{ijk}}{\lambda_{ij}} \quad (9)$$

Equation (9) reduces to the following expressions for the log-log (10) and log-linear (11) functional forms, respectively. These represent the two types of functional forms considered here. The first represents the relationship between expected crash frequency and the AADT variable and the second represents the relationship between expected crash frequency and all other continuous variables in the roadway segment SPFs.

$$E_{x_{ijk}}^{\lambda_{ij}} = \beta_k \quad (10)$$

$$E_{x_{ijk}}^{\lambda_{ij}} = \beta_k x_{ijk} \quad (11)$$

The elasticity for indicator variables (e.g., presence of passing zones), termed *pseudo-elasticity* by Lee and Mannering (2002), is the percent change in expected crash frequency given a change in the value of the indicator variable from zero to unity. In general, the elasticity of the expected crash frequency for indicator variable '*k*' on roadway segment '*i*' during time period '*j*' is defined as:

$$E_{x_{ijk}}^{\lambda_{ij}} = \exp(\beta_k) - 1 \quad (12)$$

Regionalization Process

In addition to statewide models, regionalized SPFs were developed at several spatial levels to account for differences in safety performance within the Commonwealth. This section presents the 10-step process that was used to develop these regionalized SPFs. Three different levels were originally considered for the regional models: county, engineering district, and planning organization levels (MPO and RPO). However, as depicted in Figure 1 to Figure 4, there is considerable overlap between the individual counties/engineering districts and the MPOs and RPOs. For this reason, the regionalization process only focused on engineering district and county-level SPFs, in addition to statewide SPFs.

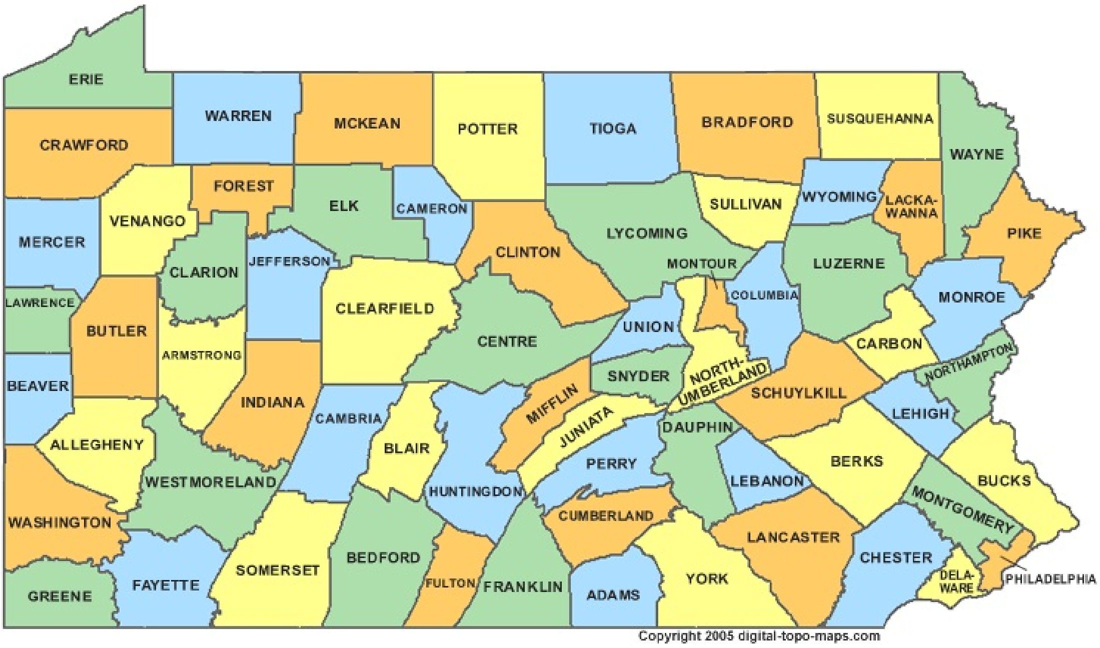

Figure 1. Map of Counties Within Pennsylvania.

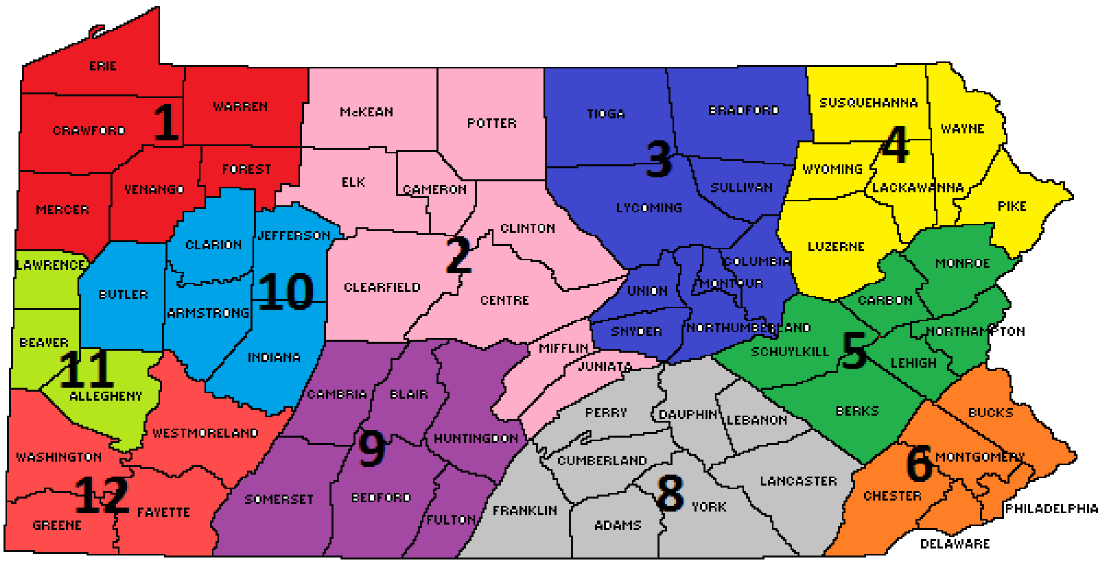

Figure 2. Map of Counties Grouped by Engineering Districts.

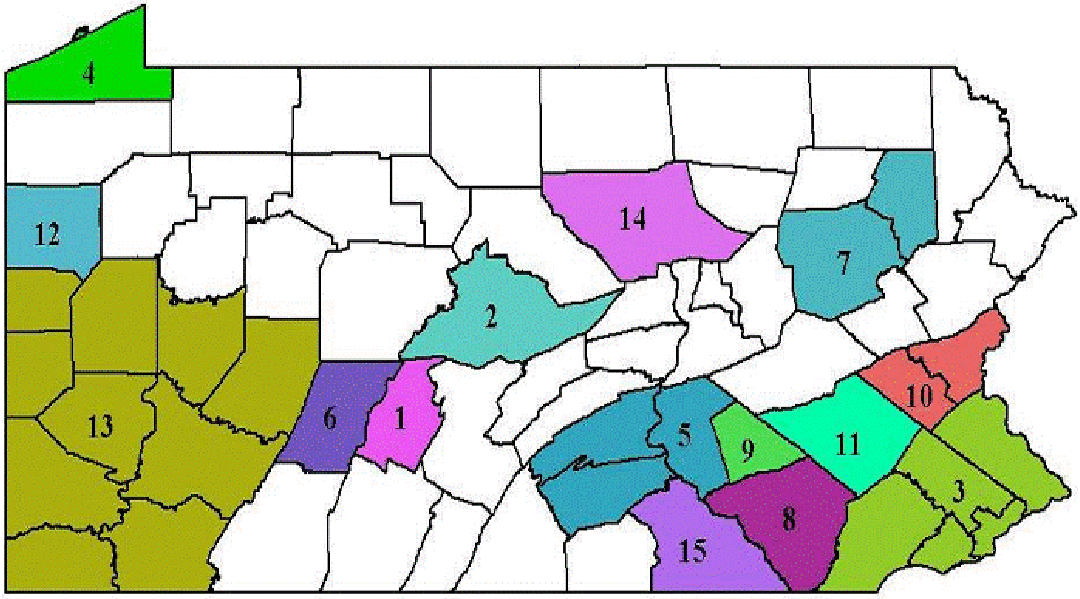

Figure 3. Map of Counties Grouped by Metropolitan Planning Organizations (MPOs).

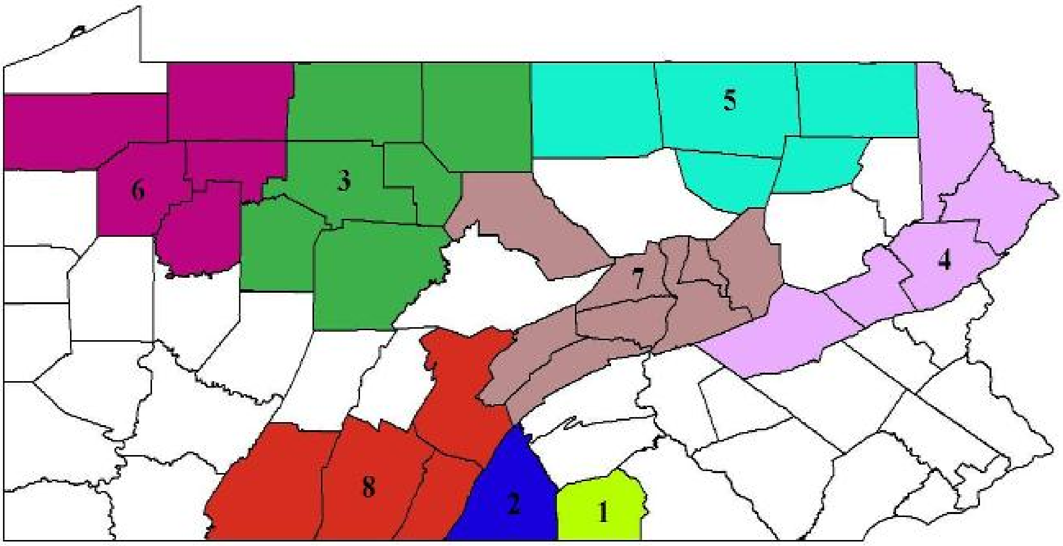

Figure 4. Map of Counties Grouped by Regional Planning Organization (RPOs).

The following SPF regionalization process was applied to all of the segment and intersection SPFs outlined previously:

Step 1 – Develop statewide SPF: these were estimated for all roadway segment and intersection types.

Because counties are the smallest area, and likely have the most consistency with regards to design features and crash reporting, the regionalization process begins at this level.

Step 2 – Determine if there are a sufficient number of observations within each county to consider developing county-specific SPFs

- Intersections: at least **50** observations per county per year
- Segments: at least **30** miles per county per year
- Crashes: at least **100** crashes per year for roadway segments or intersections
- For counties that do not meet these criteria, the statewide or a district-level SPF should be considered as a county-specific SPF cannot be estimated. For remaining counties, move to Step 3.

Step 3 – Determine if there is sufficient variation in observations within each county to continue with the development of county-specific SPFs

- For categorical variables (e.g., RHR, presence of shoulder rumble strips, etc.), there should generally be at least 10% of the sample in each category. If not, categorical variables should be grouped such that each category included in the SPF has approximately 10% or more of the observations in the analysis data file.
- For counties that do not meet these criteria, a statewide or district-level SPF should considered as a county-specific SPF cannot be estimated. For remaining counties, move to Step 4.

Step 4 – Develop county-specific SPF for each county

- In general, county-specific SPFs cannot include as many explanatory variables as the statewide SPFs due to fewer observations being available for model estimation. Therefore, county-specific SPFs will generally include only traffic volumes (AADT values) as the primary explanatory variables.

After assessing the opportunity to estimate county-level SPFs, the next step was to consider more aggregate levels of regionalization. The following series of steps describe the process used to estimate engineering district-level SPFs.

Step 5 – Determine if there are a sufficient number of observations within each district to develop a district-specific SPF

- Intersections: at least **50** observations per district
- Segments: at least **30** miles per district
- Crashes: at least **100** crashes per year for segments and intersections
- For districts that do not meet these criteria, the statewide SPF should be used because a reliable district-specific SPF cannot be estimated. For remaining districts, move to Step 6.

Step 6 – Determine if there is sufficient variation in observations within each district

- For categorical variables (e.g., RHR, presence of shoulder rumble strips, etc.), there should generally be at least 10% of the sample in each category. If not, categorical variables were grouped such that each category included in the SPF has approximately 10% or more of the observations in the data file.
- For districts that do not meet these criteria, the statewide SPF should be used because a district-specific SPF cannot be estimated. For remaining districts, move to Step 7.

Step 7 – Develop district-level SPFs and determine if county-specific adjustments are needed within each district SPF

- Include county-specific indicator variables within each district-level SPF
  - Regression coefficients that are not statistically significant suggests that county-specific adjustment is not necessary for that county
  - A statistically significant regression coefficient suggests county-specific adjustment is necessary for that county

Step 8 – Re-estimate statewide SPF with consideration for district-specific adjustments

- Include district-specific indicator variables within the statewide SPF
  - Regression coefficients that are not statistically significant suggests that district-specific adjustment is not necessary for that district
  - Statistically significant regression coefficients suggests that district-specific adjustment is necessary for that district

Step 9 – Compare statewide, county-specific (if estimated), district-specific (if estimated) and statewide with district-specific adjustment SPFs

- For each observation in the modeling dataset, estimate the crash frequency using each of the developed SPFs and the SPF provided in the HSM
- For each county, calculate the root mean-square error (RMSE) between the reported crash frequency and the estimated crash frequency for each of the SPF types developed and the SPF provided in the HSM
  - The RMSE provides the average error between the reported crash frequency and that predicted from the SPF; therefore, smaller values are indicative of more accurate SPFs. The RMSE is computed as shown in Equation (9):

$$RMSE_m = \sqrt{\frac{y_i - \hat{y}_{i,m}}{n}} \quad (13)$$

where y_i is the reported crash frequency for segment i in the analysis database for a given county; $\hat{y}_i$ is the predicted crash frequency for segment i in the analysis database for a given county using a specific model m, and n is the number of observations in the crash database within the given county.

Step 10 – Make a recommendation for the regionalized SPF that provides the best predictive power

- Select the SPF type that provides the RMSE nearest 0 for the majority of counties in the dataset

RESULTS

This section provides a summary of the data collection and describes the results of the model estimation process. This includes the results of the regionalization process, the recommended regionalized SPFs and a comparison of these SPFs with the SPFs provided in the HSM. A separate subsection is provided for each SPF type: two-lane rural roadway segments, two-lane rural roadway intersections, rural multilane highway segments, rural multilane highway intersections, urban-suburban arterial segments, and urban-suburban arterial intersections. The final subsection describes additional CMFs that were developed for the urban-suburban arterial segments.

Two-Lane Rural Roadway Segment SPFs

A statewide SPF was previously developed for two-lane rural roadway segments as a part of the Work Order #1 project. The data collected for this prior project was used to develop regionalized SPFs. The remainder of this section summarizes the data available for the development of regionalized SPFs, the selection of the most appropriate regionalization level, the final SPF recommendations, interpretation of the models, and a comparison with the SPF shown in the HSM.

<u>Data Summary</u>

A total of 21,340 unique roadway segments were available in the two-lane rural roadway segment analysis file. Because eight years of crash data were available for each segment (2005 to 2012), the analytical database consisted of 170,720 total observations. Table 3 provides summary statistics of the analysis database for total crashes, fatal, injury, and PDO crashes, traffic volume, and the roadway and roadside characteristics included in the analysis database. As shown in Table 3, there are more injury and property damage only (PDO) crashes per segment than fatal crashes per segment. The categorical variables are shown in the lower panel of Table 3. The majority of roadway segments have a roadside hazard rating (RHR) or 4, 5, or 6. Fewer than 2 percent of roadway segments have curve warning, intersection warning, or "aggressive driving dots" traffic control devices.

Table 3. Crash, Traffic Volume, and Site Characteristic Data Summary for Two-Lane Rural Roadway Segments.

Variables	Mean	Standard Deviation	Minimum	Maximum
Total crashes per year	0.667	1.144	0	23
Total fatal crashes per year	0.015	0.123	0	3
Total injury crashes per year	0.347	0.724	0	13
Total property-damage only (PDO) crashes per year	0.306	0.672	0	13
Average annual daily traffic (veh/day)	3282	2933	74	28,674
Segment length (miles)	0.474	0.129	0.003	1.476
Posted speed limit (mph)	47.421	7.650	15	55
Left paved shoulder width (feet)	3.002	2.305	0	22
Right paved shoulder width (feet)	3.048	2.304	0	19
Access density (access points and intersections per mile)	16.300	14.307	0	330
Horizontal curve density (curves per mile)	2.299	2.506	0	42.581
Degree of curve per mile	19.100	44.178	0	1263.478
Length of curve per mile	1004.945	1237.694	0	29,256.37
Categorical Variables	Category		Proportion	
Roadside hazard rating (1 to 7)	1		0.1	
	2		0.5	
	3		5.1	
	4		21.6	
	5		53.1	
	6		19.4	
	7		0.2	
Presence of a passing zone	Yes		28.4	
	No		71.6	
Presence of centerline rumble strips	Yes		21.0	
	No		79.0	
Presence of shoulder rumble strips	Yes		8.1	
	No		91.9	
Presence of curve warning pavement marking	Yes		1.3	
	No		98.7	
Presence of intersection warning pavement marking	Yes		0.5	
	No		99.5	
Presence of “aggressive driving dots”	Yes		0.1	
	No		99.9	

Regionalization of SPFs

Table 4 shows the two-lane rural highway segment mileage and 8-year crash totals (from Work Order #1) for all 67 counties in the Commonwealth. There are more than 10,106 miles and more than 113,600 reported crashes among the sample. The majority of the counties meet the minimum crash frequency (100 per year) and roadway mileage (30 miles) for the development of county-level SPFs. The exceptions are Potter, Clinton, Sullivan, Forest, Cameron, Mifflin, Union, Montour and Lehigh counties, which do not meet the crash frequency requirement; Montgomery and Allegheny counties, which do not meet either requirement; and Delaware and Philadelphia counties, which do not contain any two-lane rural roads. Reliable county-level models cannot be developed for these counties.

Table 4. Rural Two-lane Highway County Segment Mileage and Crashes.

County No.	Name	Miles	8-year crashes	County No.	Name	Miles	8-year crashes
20	CRAWFORD	291.6	2713	26	FAYETTE	142.0	1743
42	MCKEAN	272.7	1620	11	CAMBRIA	139.7	1387
17	CLEARFIELD	269.8	2476	1	ADAMS	138.7	2907
57	SUSQUEHANNA	267.7	1793	51	PIKE	138.1	2054
31	HUNTINGDON	267.3	1878	45	MONROE	136.5	4204
41	LYCOMING	248.0	1526	24	ELK	133.6	1217
5	BEDFORD	243.3	2107	30	GREENE	129.6	1061
55	SOMERSET	239.6	2043	19	COLUMBIA	128.6	1227
64	WESTMORELAND	238.3	2964	34	JUNIATA	128.2	825
32	INDIANA	235.6	2258	49	NORTHUMBERLAND	126.7	1409
63	WAYNE	232.1	2098	6	BERKS	126.0	4124
58	TIOGA	229.5	1916	65	WYOMING	113.4	1411
8	BRADFORD	225.6	2417	56	SULLIVAN	112.4	498
14	CENTRE	225.1	2122	3	ARMSTRONG	108.7	1275
62	WASHINGTON	220.8	2397	40	LUZERNE	104.3	1583
28	FRANKLIN	219.8	2737	38	LEBANON	97.9	1777
43	MERCER	216.4	2514	4	BEAVER	97.8	1290
52	POTTER	205.6	704	13	CARBON	92.5	1308
66	YORK	203.7	3338	27	FOREST	91.3	441
25	ERIE	201.9	2457	9	BUCKS	86.8	1822
36	LANCASTER	200.0	5060	35	LACKAWANNA	79.9	861
10	BUTLER	192.3	2706	54	SNYDER	77.3	845
53	SCHUYLKILL	191.9	2389	12	CAMERON	73.1	328
50	PERRY	183.2	1782	44	MIFFLIN	72.6	526
33	JEFFERSON	179.7	1636	7	BLAIR	69.8	852
16	CLARION	178.7	1770	48	NORTHAMPTON	65.0	1680
60	VENANGO	173.0	1426	59	UNION	63.1	573
21	CUMBERLAND	168.7	2137	47	MONTOUR	38.6	397
61	WARREN	168.2	1210	39	LEHIGH	36.0	706
15	CHESTER	155.4	3208	46	MONTGOMERY	12.4	433
29	FULTON	151.7	1060	2	ALLEGHENY	6.4	138
37	LAWRENCE	151.6	1499	23	DELAWARE	0.0	0
22	DAUPHIN	146.9	2028	67	PHILADELPHIA	0.0	0
18	CLINTON	143.6	795	Total		10,106.1	113,686

Table 5 provides the segment mileage and 8-year crash totals at the engineering district level. Sufficient observations exist within each district for the development of district-level SPFs.

Table 5. Rural Two-lane Highway District Segment Mileage and Crashes.

District No.	Miles	8-year crashes
1	1142.3	10,718
2	1524.3	10,594
3	1249.7	10,740
4	935.5	9745
5	647.9	14,387
6	254.7	5461
8	1359.0	21,783
9	1111.4	9335
10	895.0	9633
11	255.7	2927
12	730.6	8165
Total	10106.1	113,488

The 10-sep regionalization process previously described was applied to develop regionalized SPFs for two-lane rural roadway segments. County-level SPFs were developed for each of the counties that had sufficient observations of two-lane rural roadway segments. District-level SPFs were also developed that included county-specific indicator variables to assess any differences in safety performance within the counties that make up any particular district. The statewide SPF developed in the Work Order #1 project was also re-estimated to include district-specific indicator variables to account for any differences in safety performance within the engineering districts.

Each of the independent variables included in Table 3 with sufficient variability in observations within the specific region were included in preliminary models and their statistical significance were assessed. All SPFs were estimated in a form consistent with Equation (7) above. Those variables with the expected sign that were either statistically significant ($p \leq 0.05$) or marginally significant ($p \leq 0.3$) were retained in the final models. Note that several variables that are included in the HSM SPFs for two-lane rural roads were not considered in the regionalized SPFs developed for Pennsylvania due to lack of data availability, limited confidence in data quality or lack of application in Pennsylvania. For example, automated speed enforcement and roadway segment lighting are not applied in Pennsylvania and thus these variables were not included in the model. Cross-sectional information like lane widths and paved shoulder widths were found to generally be unreliable and thus were not considered useful for modeling purposes.

County-level SPFs generally had few independent variables due to the relatively small number of observations within each county; in most cases, traffic volume (i.e., AADT) was the only significant independent variable retained in the models. District-level and statewide SPFs had considerably larger number of observations and more variability within the data; therefore, these models generally included many more independent variables. Furthermore, the preliminary models revealed that some variables were more appropriately treated in a form that differs from the HSM models. For example, the preliminary models revealed that adjacent roadside hazard ratings could be grouped since the safety performance of roadways segments were the same for some adjacent ratings (e.g., the regression coefficients for ratings ‘3’ and ‘4’ were the same, so these were grouped into a single category). These groupings were used whenever appropriate.

The RMSE values for the county-level, district-level and statewide SPFs were calculated for each level of regionalization. Table 6 provides a summary of these RMSE values for total crash frequency. For each county, the bolded value in the table represents the smallest RMSE value across the three regionalized SPFs. The results in Table 6 reveals that the district-level SPF produced the lowest RMSE value for the majority of counties (54 of 65 counties that had two-lane rural roads). The last row of Table 6 also provides the average RMSE value measured across the entire Commonwealth. The district-level SPFs provide the lowest RMSE values of the three different regionalization types considered. This suggests that the district-level SPFs are generally more accurate than the statewide and county-level SPFs for two-lane rural roadway segments.

Table 6. County RMSE Summary for Two-Lane Rural Roadway Segment SPFs.

County	Seg #	Mileage	SPF Prediction RMSE		
			Statewide	District	County
1	2,200	138.7	1.522	1.499	1.498
2	112	6.4	1.501	1.477	---
3	2,056	108.7	0.917	0.907	0.911
4	1,464	97.8	1.169	1.159	1.177
5	3,832	243.3	0.874	0.869	0.881
6	2,264	126.0	2.119	2.102	2.110
7	1,152	69.8	1.060	1.031	1.033
8	4,088	225.6	0.903	0.911	0.922
9	1,416	86.8	1.411	1.413	1.432
10	3,280	192.3	1.064	1.049	1.068
11	2,168	139.7	0.898	0.873	0.880
12	1,272	73.1	0.545	0.542	---
13	1,520	92.5	1.131	1.131	1.157
14	3,816	225.1	0.845	0.833	0.839
15	2,616	155.4	1.590	1.568	1.622
16	3,328	178.7	0.803	0.799	0.801
17	4,584	269.8	0.893	0.869	0.880
18	2,464	143.6	0.650	0.648	---
19	2,264	128.6	0.858	0.857	0.856
20	5,038	291.6	0.847	0.845	0.852
21	2,840	168.7	1.086	1.084	1.096
22	2,504	146.9	1.184	1.174	1.183
24	2,336	133.6	0.879	0.862	0.869
25	3,524	201.9	0.993	0.994	1.021
26	2,312	142.0	0.978	0.970	0.980
27	1,560	91.3	0.572	0.567	---
28	3,736	219.8	1.083	1.080	1.082
29	2,416	151.7	0.830	0.812	0.869
30	2,028	129.6	0.836	0.898	0.826
31	4,480	267.3	0.747	0.733	0.743
32	3,815	235.6	0.840	0.822	0.831
33	3,193	179.7	0.837	0.779	0.783
34	2,352	128.2	0.621	0.621	0.627
35	1,344	79.9	0.923	0.921	0.931
36	3,376	200.0	1.860	1.832	1.844
37	2,504	151.6	0.947	0.899	0.905
38	1,656	97.9	1.403	1.402	1.422
39	560	36.0	1.664	1.670	---
40	1,688	104.4	1.194	1.198	1.199
41	4,432	248.0	0.682	0.679	0.681
42	4,352	272.7	0.674	0.664	0.666
43	3,600	216.4	0.980	0.974	0.989
44	1,248	72.6	0.784	0.707	---
45	2,176	136.5	2.219	1.985	2.142
46	240	12.4	2.446	2.375	---
47	656	38.6	0.887	0.907	---
48	1,040	65.0	1.688	1.667	1.689
49	2,312	126.7	0.971	0.949	0.955
50	3,168	183.2	0.911	0.920	0.916
51	2,238	138.1	1.168	1.163	1.193
52	3,528	205.6	0.511	0.478	---
53	3,208	191.9	1.121	1.115	1.119
54	1,368	77.3	0.912	0.881	0.884

County	Seg #	Mileage	SPF Prediction RMSE		
			Statewide	District	County
55	3,744	239.6	0.848	0.827	0.817
56	2,040	112.4	0.552	0.551	---
57	4,456	267.7	0.705	0.700	0.707
58	4,216	229.5	0.774	0.766	0.770
59	1,112	63.1	0.854	0.815	---
60	2,944	173.0	0.790	0.789	0.789
61	2,816	168.2	0.723	0.715	0.719
62	3,688	220.8	0.958	0.952	0.960
63	3,808	232.1	0.828	0.822	0.834
64	3,728	238.3	1.043	1.038	1.044
65	1,776	113.4	1.181	1.181	1.192
66	3,416	203.7	1.205	1.203	1.203
Average		10106.1	1.026	1.010	1.022

Based on the regionalization process, the research team recommends using **district-level SPFs with county-specific adjustments** for two-lane rural roadway segments.

Interpretation of Safety Performance Functions

For each of the 11 engineering districts, two SPFs were developed for two-lane rural roadway segments: one to estimate total crash frequency and one to estimate the frequency of fatal + injury crashes. As an illustrative example, Table 7 shows the District 1 SPF for total crash frequency on two-lane rural roadway segments.

Table 7. Statistical Modeling Output for Two-Lane Rural Roadway SPF for Total Crash Frequency (District 1).

Variable	Coefficient	Standard Error	t-statistic	p-value
Constant	-4.946	0.188	-26.29	<0.001
Natural logarithm of AADT	0.587	0.017	33.68	<0.001
Roadside hazard rating of 3 or 4 (1 if RHR is 3 or 4; 0 otherwise)	0.333	0.133	2.51	0.012
Roadside hazard rating of 5, 6 or 7 (1 if RHR is 5, 6 or 7; 0 otherwise)	0.435	0.133	3.28	0.001
Presence of a passing zone (1 if present; 0 otherwise)	-0.173	0.024	-7.31	<0.001
Presence of shoulder rumble strips (1 if present; 0 otherwise)	-0.086	0.036	-2.38	0.017
Access density	0.009	0.001	14.16	<0.001
Horizontal curve density (number of curves per mile)	0.056	0.008	6.67	<0.001
Degree of curvature per mile	0.002	0.001	2.7	0.007
Indicator for Forest (20), Venango (60), Warren (61) Counties (1 if yes, 0 otherwise)	-0.245	0.027	-9.04	<0.001
Overdispersion parameter = 0.450 Pseudo R^2 = 0.0566 Log-likelihood at convergence = -18569.866				

The statistical model output in Table 7 can be written in the form of Equation (7) as follows:

$$N_{cr,pr} = Length \times AADT^{0.587} \times e^{-4.946} \times e^{0.333 RHR3,4} \times e^{0.435 RHR5,6,7} \times e^{-0.173 PZ} \times e^{-0.086 SRS} \times e^{0.009 AD} \times e^{0.056 HCD} \times e^{0.002 DCPM} \times e^{-0.245 CNTY 20,60,61} \quad (14)$$

where:

$N_{cr,pr}$	= predicted total crash frequency on the segment (crashes/year);
Length	= length of segment (miles);
AADT	= annual average daily traffic on the segment (veh/day);
RHR3,4	= roadside hazard rating on the segment of 3 or 4 (1 if RHR is 4 or 5; 0 otherwise);
RHR5,6,7	= roadside hazard rating on the segment of 5, 6 or 7 (1 if RHR is 6 or 7; 0 otherwise);
PZ	= presence of a passing zone in the segment (1 if present; 0 otherwise);
SRS	= presence of shoulder rumble strips in the segment (1 If present; 0 otherwise);
AD	= access density in the segment, total driveways and intersections per mile of segment length (Access Points/Mile);
HCD	= horizontal curve density in the segment, number of curves in the segment per mile (Hor. Curves/Mile);
DCPM	= total degree of curvature per mile in the segment, the sum of degree of curvature for all curves in the segment divided by segment length in miles (Degrees/100 ft/Mile); and,
CNTY20,60,61	= indicator variable for Forest (20), Venango (60), or Warren (61) counties (1 = segment is located in one of the counties; 0 otherwise)

The results presented in Table 7 show that the relationship between expected total crash frequency of two-lane rural roadway segments in engineering district 1 and the dependent variables are consistent with engineering expectations. The expected total crash frequency is positively correlated with travel volumes, roadside hazard ratings of 3 or higher, access density, horizontal curve density, and the degree of curvature per mile. The expected total crash frequency is negatively correlated with the presence of a passing zone and the presence of shoulder rumble strips. The total crash frequency in Forest, Venango and Warren counties is also generally lower than expected for similar roadway segments in the rest of engineering district 1.

For simplicity, the last term of Equation (14) is removed (and any other county or district indicator variables in other SPFs) and include them as region-specific adjustments. In this case, the $e^{-0.245 CNTY 20,60,61}$ term is removed from the SPF and included as a county-specific adjustment. Therefore, when applying the engineering district 1 SPF for total crash frequency on two-lane rural roads to roadway segments in Forest (20), Venango (60) or Warren (61) counties, the output of the SPF must then be multiplied by $e^{-0.245} = 0.78$ to account for the regional differences in the expected total crash frequency.

Table 8 provides the computed elasticities and pseudo-elasticities for the independent variables in Table 7 as calculated in Equations (10) to (12). Note that the elasticities for all continuous variables other than AADT (such as access density, horizontal curve density and degree of curvature per mile) are all a function of the value at which they are assessed. The elasticities presented in Table 8 are all provided at the mean value of these variables as provided in Table 3.

Table 8. Elasticities for Independent Variables in Two-Lane Rural Roadway SPF for Total Crash Frequency (District 1).

Variable	Total Crash Elasticity
Natural logarithm of AADT	0.587
Roadside hazard rating of 3 or 4 (1 if RHR is 3 or 4; 0 otherwise)	0.396
Roadside hazard rating of 5, 6 or 7 (1 if RHR is 5, 6 or 7; 0 otherwise)	0.545
Presence of a passing zone (1 if present; 0 otherwise)	-0.158
Presence of shoulder rumble strips (1 if present; 0 otherwise)	-0.082
Access density	0.154
Horizontal curve density	0.129
Degree of curvature per mile	0.032
County is Forest (20), Venango (60), Warren (61) (1 if yes, 0 otherwise)	-0.217

The elasticities suggest that a one percent change in AADT is associated with a 0.587 percent increase in total crash frequency on two-lane rural roadways in engineering district 1 in Pennsylvania. At the mean value of access density, a one percent increase in access density is associated with a 0.154 percent increase in total crash frequency. An increase in horizontal curve density and degree of curvature is associated with a 0.129 and 0.032 percent increase in total crash frequency, respectively. The presence of a passing zone is associated with a 15.8 percent reduction in total crash frequency while the presence of shoulder rumble strips is associated with an 8.2 percent decrease in total crash frequency. Roadside hazard ratings of 3 or 4 are associated with a 39.6 percent increase in expected total crash frequency compared to the baseline roadside hazard ratings of 1 or 2, while roadside hazard ratings of 5, 6 or 7 are associated with an even larger increase (54.5 percent) relative to the baseline. Lastly, roadways in Forest, Venango and Warren counties are associated with a 21.7 percent reduction in total crash frequency relative to other counties in engineering district 1.

The district level SPFs for total and fatal + injury crashes on two-lane rural highway segments are shown in Appendix C. The same basic procedure that is outlined above can be repeated to transform any of the SPFs presented in tabular form in Appendix C to equation form (e.g., as in Equation (14)).

Summary of SPF Recommendations

The final recommended regional SPFs for total crash frequency and fatal + injury crash frequency are shown in Table 9 below, along with the overdispersion parameter from the negative binomial regression model. These equations provide the baseline SPF for each district, which should be further modified by the county-specific adjustments provided in Table 10 to account for any differences between safety performance of two-lane rural roadway segments in each district.

Table 9. Regionalized SPFs for Two-lane Rural Highway Segments.

District 1: $N_{total} = e^{-4.946} \times L \times AADT^{0.587} \times e^{0.333 \times RHR34} \times e^{0.435 \times RHR567} \times e^{-0.173 \times PZ} \times e^{-0.086 \times SRS} \times e^{0.009 \times AD} \times e^{0.056 \times HCD} \times e^{0.002 \times DCPM}$ (15) over-dispersion parameter: 0.450 $N_{fatal\_inj} = e^{-5.554} \times L \times AADT^{0.568} \times e^{0.551 \times RHR34} \times e^{0.632 \times RHR567} \times e^{-0.183 \times PZ} \times e^{-0.123 \times SRS} \times e^{0.010 \times AD} \times e^{0.055 \times HCD} \times e^{0.002 \times DCPM}$ (16) over-dispersion parameter: 0.582
District 2: $N_{total} = e^{-5.245} \times L \times AADT^{0.649} \times e^{0.091 \times RHR4} \times e^{0.101 \times RHR567} \times e^{-0.274 \times PZ} \times e^{0.010 \times AD} \times e^{0.017 \times HCD} \times e^{0.001 \times DCPM}$ (17) over-dispersion parameter: 0.419 $N_{fatal\_inj} = e^{-5.501} \times L \times AADT^{0.600} \times e^{0.104 \times RHR4567} \times e^{-0.242 \times PZ} \times e^{0.011 \times AD} \times e^{0.021 \times HCD} \times e^{0.021 \times HCD} \times e^{0.001 \times DCPM}$ (18) over-dispersion parameter: 0.617
District 3: $N_{total} = e^{-5.345} \times L \times AADT^{0.664} \times e^{-0.136 \times PZ} \times e^{-0.145 \times SRS} \times e^{0.011 \times AD} \times e^{0.041 \times HCD} \times e^{0.001 \times DCPM}$ (19) over-dispersion parameter: 0.480 $N_{fatal\_inj} = e^{-5.936} \times L \times AADT^{0.658} \times e^{-0.132 \times PZ} \times e^{-0.182 \times SRS} \times e^{0.012 \times AD} \times e^{0.054 \times HCD} \times e^{0.001 \times DCPM}$ (20) over-dispersion parameter: 0.644
District 4: $N_{total} = e^{-5.679} \times L \times AADT^{0.718} \times e^{-0.208 \times PZ} \times e^{0.010 \times AD} \times e^{0.018 \times HCD} \times e^{0.002 \times DCPM}$ (21) over-dispersion parameter: 0.413 $N_{fatal\_inj} = e^{-6.358} \times L \times AADT^{0.725} \times e^{-0.134 \times PZ} \times e^{0.011 \times AD} \times e^{0.018 \times HCD} \times e^{0.002 \times DCPM}$ (22) over-dispersion parameter: 0.564

District 5:

$$N_{total} = e^{-5.244} \times L \times AADT^{0.655} \times e^{0.115\times \mathrm{RHR567}} \times e^{-0.140\times PZ} \times e^{0.011\times AD} \times e^{0.016\times HCD} \times e^{0.003\times DCPM} \quad (23)$$

over-dispersion parameter: 0.532

$$N_{fatal\_inj} = e^{-5.873} \times L \times AADT^{0.658} \times e^{0.129\times \mathrm{RHR567}} \times e^{-0.144\times PZ} \times e^{0.012\times AD} \times e^{0.0161\times HCD} \times e^{0.003\times DCPM} \quad (24)$$

over-dispersion parameter: 0.598

District 6:

$$N_{total} = e^{-4.826} \times L \times AADT^{0.613} \times e^{0.183\times \mathrm{RHR45}} \times e^{0.288\times \mathrm{RHR67}} \times e^{0.010\times AD} \times e^{0.048\times HCD} \times e^{0.001\times DCPM} \quad (25)$$

over-dispersion parameter: 0.533

$$N_{fatal\_inj} = e^{-5.144} \times L \times AADT^{0.589} \times e^{0.010\times AD} \times e^{0.062\times DCPM} \quad (26)$$

over-dispersion parameter: 0.659

District 8:

$$N_{total} = e^{-5.422} \times L \times AADT^{0.711} \times e^{-0.227\times PZ} \times e^{0.005\times AD} \times e^{0.034\times HCD} \times e^{0.002\times DCPM} \quad (27)$$

over-dispersion parameter: 0.529

$$N_{fatal\_inj} = e^{-6.112} \times L \times AADT^{0.716} \times e^{-0.247\times PZ} \times e^{0.005\times AD} \times e^{0.035\times HCD} \times e^{0.002\times DCPM} \quad (28)$$

over-dispersion parameter: 0.584

District 9:

$$N_{total} = e^{-6.039} \times L \times AADT^{0.734} \times e^{0.206\times \mathrm{RHR567}} \times e^{-0.167\times PZ} \times e^{-0.118\times SRS} \times e^{0.007\times AD} \times e^{0.038\times HCD} \times e^{0.002\times DCPM} \quad (29)$$

over-dispersion parameter: 0.426

$$N_{fatal\_inj} = e^{-6.510} \times L \times AADT^{0.728} \times e^{0.163\times \mathrm{RHR567}} \times e^{-0.212\times PZ} \times e^{-0.182\times SRS} \times e^{0.006\times AD} \times e^{0.041\times HCD} \times e^{0.001\times DCPM} \quad (30)$$

over-dispersion parameter: 0.495

District 10:

$$N_{total} = e^{-5.777} \times L \times AADT^{0.702} \times e^{0.132\times \mathrm{RHR4}} \times e^{0.226\times \mathrm{RHR567}} \times e^{-0.147\times PZ} \times e^{-0.123\times SRS} \times e^{0.007\times AD} \times e^{0.026\times HCD} \times e^{0.001\times DCPM} \quad (31)$$

over-dispersion parameter: 0.294

$$N_{fatal\_inj} = e^{-6.141} \times L \times AADT^{0.681} \times e^{0.106\times \mathrm{RHR4}} \times e^{0.178\times \mathrm{RHR567}} \times e^{-0.143\times PZ} \times e^{-0.125\times SRS} \times e^{0.007\times AD} \times e^{0.023\times HCD} \times e^{0.001\times DCPM} \quad (32)$$

over-dispersion parameter: 0.409

District 11: $N_{total} = e^{-4.945} \times L \times AADT^{0.571} \times e^{0.293\times \text{RHR5}} \times e^{0.327\times \text{RHR67}} \times e^{0.009\times AD} \times e^{0.029\times HCD} \times e^{0.001\times DCPM}$ (33) over-dispersion parameter: 0.496 $N_{fatal\_inj} = e^{-5.351} \times L \times AADT^{0.552} \times e^{0.265\times \text{RHR5}} \times e^{0.317\times \text{RHR67}} \times e^{0.006\times AD} \times e^{0.043\times HCD} \times e^{0.001\times DCPM}$ (34) over-dispersion parameter: 0.615
District 12: $N_{total} = e^{-4.948} \times L \times AADT^{0.630} \times e^{-0.153\times PZ} \times e^{0.015\times AD} \times e^{0.002\times DCPM}$ (35) over-dispersion parameter: 0.342 $N_{total} = e^{-5.427} \times L \times AADT^{0.615} \times e^{-0.216\times PZ} \times e^{0.016\times AD} \times e^{0.002\times DCPM}$ (36) over-dispersion parameter: 0.515
L = length of segment (miles); *AADT* = annual average daily traffic on the segment (veh/day); *RHR567* = roadside hazard rating on the segment of 5, 6 or 7 (1 if RHR is 5, 6 or 7; 0 otherwise); *RHR4* = roadside hazard rating on the segment of 4 (1 if RHR is 4; 0 otherwise); *RHR4567* = roadside hazard rating on the segment of 4, 5, 6, or 7 (1 if RHR is 4, 5, 6, or 7; 0 otherwise) *PZ* = presence of a passing zone in the segment (1 if present; 0 otherwise); *SRS* = presence of shoulder rumble strips in the segment (1 If present; 0 otherwise); *AD* = access density in the segment, total driveways and intersections per mile of segment length (Access Points/Mile); *HCD* = horizontal curve density in the segment, number of curves in the segment per mile (Hor. Curves/Mile); and, *DCPM* = total degree of curvature per mile in the segment, the sum of degree of curvature for all curves in the segment divided by segment length in miles (Degrees/100 ft/Mile).

Table 10 shows how each district SPF should be modified when considering county-level expected total and fatal + injury crash frequencies. To use the data shown in Table 10, a district-level SPF should be estimated and, if a modification is necessary, the multiplier shown for a specific county in Table 10 should be applied to the expected number of crashes obtained from the district-level model.

Table 10. County-level Modifications to District-level Two-Lane Rural Road Segment SPFs.

District	SPF	County	County-specific adjustment for total crash SPF	County-specific adjustment for fatal + injury SPF
1	Equations (15, 16)	Crawford (20), Erie (25), Mercer (43)	No modification necessary	No modification necessary
		Forest (27), Venango (60), Warren (61)	Multiply estimate by 0.78	Multiply estimate by 0.76
2	Equations (17, 18)	Cameron (12), Center (14), Clinton (18), Elk (24), Juniata (34), McKean (42)	No modification necessary	No modification necessary
		Clearfield (17)	Multiply estimate by 1.09	Multiply estimate by 1.16
		Mifflin (44), Potter (52)	Multiply estimate by 0.70	Multiply estimate by 0.70

District	SPF	County	County-specific adjustment for total crash SPF	County-specific adjustment for fatal + injury SPF
3	Equations (19, 20)	Tioga (58), Columbia (19), Northumberland (49), Snyder (54)	No modification necessary	No modification necessary
		Bradford (8)	Multiply estimate by 1.10	No modification necessary
		Lycoming (41), Montour (47)	Multiply estimate by 1.09	No modification necessary
		Sullivan (56), Union (59)	Multiply estimate by 0.86	Multiply estimate by 0.83
4	Equations (21, 22)	Lackawanna (35), Susquehanna (57), Wayne (63)	No modification necessary	No modification necessary
		Luzerne (40), Pike (51), Wyoming (65)	Multiply estimate by 1.20	Multiply estimate by 1.16
5	Equations (23, 24)	Schuylkill(53)	No modification necessary	No modification necessary
		Berks (6), Monroe (45)	Multiply estimate by 1.94	Multiply estimate by 1.71
		Carbon (13)	Multiply estimate by 1.16	Multiply estimate by 1.11
		Lehigh (39)	Multiply estimate by 1.34	Multiply estimate by 1.36
		Northampton (48)	Multiply estimate by 1.48	Multiply estimate by 1.45
6	Equations (25, 26)	Bucks (9), Chester (15), Delaware (23), Philadelphia (67)	No modification necessary	No modification necessary
		Montgomery (46)	Multiply estimate by 1.21	Multiply estimate by 1.30
8	Equations (27, 28)	Franklin (28), Cumberland (21), Lebanon (38)	No modification necessary	No modification necessary
		Adams (1), Lancaster (36)	Multiply estimate by 1.25	Multiply estimate by 1.28
		Dauphin (22), Perry (50)	Multiply estimate by 0.92	Multiply estimate by 0.91
		York(66)	Multiply estimate by 1.09	Multiply estimate by 1.10
9	Equations (29, 30)	Huntingdon (31), Somerset (55)	No modification necessary	No modification necessary
		Bedford (5), Blair (7), Cambria (11)	Multiply estimate by 1.11	Multiply estimate by 1.10
		Fulton(29)	Multiply estimate by 1.37	Multiply estimate by 1.38
10	Equations (31, 32)	Indiana (32), Jefferson (33)	No modification necessary	No modification necessary
		Armstrong (3), Clarion (16)	Multiply estimate by 1.10	Multiply estimate by 1.11
		Butler (10)	Multiply estimate by 1.19	Multiply estimate by 1.16
11	Equations (33, 34)	Lawrence (37)	No modification necessary	No modification necessary
		Allegheny (2)	Multiply estimate by 1.46	Multiply estimate by 1.33
		Beaver (4)	Multiply estimate by 1.48	Multiply estimate by 1.40
12	Equations (35, 36)	Westmoreland (64), Washington (62)	No modification necessary	No modification necessary
		Fayette(26)	Multiply estimate by 1.15	Multiply estimate by 1.22
		Greene(30)	Multiply estimate by 0.79	Multiply estimate by 0.81

Comparison with HSM SPFs

The RMSE values were also used to compare the recommended regionalized SPF (district-level with county adjustments) to the HSM SPFs for two-lane rural highways. Table 11 provides a summary of the results by county. Again, the bolded values represent the lowest RMSE for each county. The results reveal that the HSM provides better prediction (i.e., lower RMSE values) for only 3 of the 65 counties. For one of these three counties, the RMSE value is the same when using the district-level and HSM SPFs. The district-level SPFs outperform the HSM for 62 of the 65 counties based on the RMSE values. The average RMSE measured across all counties is also 2.7% smaller when applying the district-level SPFs than the HSM SPFs. Therefore, the Pennsylvania-specific district-level SPFs with county-specific adjustments demonstrate a clear benefit in predictive power over the SPF in the HSM for two-lane rural roadways segments.

Table 11. RMSE Comparison for Total Crash Frequency on Two-Lane Rural Roads – District-Level and HSM SPFs.

County	SPF Prediction RMSE		Percent Improvement	County	SPF Prediction RMSE		Percent Improvement
	District	HSM			District	HSM	
1	1.499	1.538	2.5%	35	0.921	0.932	1.2%
2	1.477	1.498	1.4%	36	1.832	1.888	3.0%
3	0.907	0.935	3.0%	37	0.899	0.960	6.4%
4	1.159	1.172	1.1%	38	1.402	1.410	0.6%
5	0.869	0.898	3.2%	39	1.670	1.672	0.1%
6	2.102	2.152	2.3%	40	1.198	1.214	1.3%
7	1.031	1.109	7.0%	41	0.679	0.693	2.0%
8	0.911	0.898	-1.4%	42	0.664	0.681	2.5%
9	1.413	1.439	1.8%	43	0.974	0.980	0.6%
10	1.049	1.070	2.0%	44	0.707	0.836	15.4%
11	0.873	0.907	3.7%	45	1.985	2.277	12.8%
12	0.542	0.565	4.1%	46	2.375	2.450	3.1%
13	1.131	1.131	0.0%	47	0.907	0.911	0.4%
14	0.833	0.865	3.7%	48	1.667	1.701	2.0%
15	1.568	1.618	3.1%	49	0.949	0.985	3.7%
16	0.799	0.806	0.9%	50	0.920	0.913	-0.8%
17	0.869	0.872	0.3%	51	1.163	1.164	0.1%
18	0.648	0.656	1.2%	52	0.478	0.513	6.8%
19	0.857	0.878	2.4%	53	1.115	1.139	2.1%
20	0.845	0.858	1.5%	54	0.881	0.933	5.6%
21	1.084	1.104	1.8%	55	0.827	0.852	2.9%
22	1.174	1.190	1.3%	56	0.551	0.558	1.3%
24	0.862	0.883	2.4%	57	0.700	0.713	1.8%
25	0.994	1.009	1.5%	58	0.766	0.787	2.7%
26	0.970	0.990	2.0%	59	0.815	0.841	3.1%
27	0.567	0.579	2.1%	60	0.789	0.793	0.5%
28	1.080	1.108	2.5%	61	0.715	0.735	2.7%
29	0.812	0.878	7.5%	62	0.952	0.970	1.9%
30	0.898	0.817	-9.9%	63	0.822	0.843	2.5%
31	0.733	0.757	3.2%	64	1.038	1.050	1.1%
32	0.822	0.833	1.3%	65	1.181	1.181	0.0%
33	0.779	0.822	5.2%	66	1.203	1.223	1.6%
34	0.621	0.627	1.0%	Average	1.010	1.038	2.7%

Two-Lane Rural Roadway Intersections SPFs

As a part of the Work Order #1 project, statewide SPFs were developed for the following five intersection forms on two-lane rural roads:

- 4-leg intersections with signal control
- 3-leg intersections with signal control
- 4-leg intersections with all-way stop control
- 4-leg intersections with minor-street stop control
- 3-leg intersections with minor-street stop control

The data collected in the Work Order #1 project were used in the present study to determine if regionalized SPFs can be developed for all five intersection forms on rural two-lane highways. The remainder of this section summarizes the statewide data available for the development of regionalized SPFs, the selection of the most appropriate regionalization level, and the final SPF recommendations.

Data Summary

A total of 683 unique intersections were included in the previous data analysis files. The distribution of these intersections based on their type was:

- 105 4-leg intersections with signal control
- 45 3-leg intersections with signal control
- 33 4-leg intersections with all-way stop control
- 86 4-leg intersections with minor-street stop control
- 414 3-leg intersections with minor-street stop control

Because eight years of crash data were available for each intersection (2005 to 2012), the analysis database consisted of 5,464 observations. Table 12 provides summary statistics for the total crashes and total fatal + injury crashes recorded for each intersection type. As expected, the total crash frequency is higher than the fatal + injury crash frequency. The signalized intersection forms have the highest mean frequency of severe (fatal + injury) crashes.

Table 12. Summary Statistics for Total and Fatal + Injury Crash Frequencies by Intersection Type for Two-Lane Rural Road Intersections.

Intersection Type	Number of observations	Mean	Standard Deviation	Minimum	Maximum
Total crash frequency					
4-leg, signalized	840	3.136	3.213	0	20
3-leg, signalized	360	1.922	2.559	0	15
4-leg, all-way stop	264	1.970	2.538	0	12
4-leg, two-way stop	688	1.637	2.312	0	15
3-leg, two-way stop	3312	1.383	2.023	0	16
ALL	5464	1.748		0	20
Fatal + Injury crash frequency					
4-leg, signalized	840	1.677	2.104	0	15
3-leg, signalized	360	1.203	1.831	0	13
4-leg, all-way stop	264	1.023	1.594	0	8
4-leg, two-way stop	688	0.920	1.663	0	11
3-leg, two-way stop	3312	0.766	1.348	0	12
ALL	5464	0.957		0	15

Table 13 to Table 17 present summary statistics for the independent variables considered in the SPF development, organized by the five intersection forms included in this report. The signalized intersections and the 3-leg, two-way stop-controlled intersection forms have the highest traffic volumes. The paved width includes the through lanes, turning lanes, and paved shoulder widths on each of the major and minor approaches; therefore, these widths vary widely within each intersection form, and when compared across the different intersection forms. The number of turn-lanes is generally higher at signalized intersections when compared to stop-controlled intersections. The posted speed limits vary considerably for all intersection types.

Table 13. Summary Statistics for 4-Leg Signalized Intersections on Two-Lane Rural Roads.

Continuous Variable	Mean	Standard Deviation	Minimum	Maximum
Total Crashes per Year	3.136	3.213	0	20
Total Fatal + Injury Crashes per Year	1.677	2.104	0	15
Major Road AADT (veh/day)	7399	4102	793	23,375
Minor Road AADT (veh/day)	3858	2432	285	13,699
Left Shoulder Total Width on Major Road (feet)	3.682	2.885	0	13
Right Shoulder Total Width on Major Road (feet)	3.637	2.885	0	10
Paved Width on Major Road (feet)	27.988	7.872	20	54
Posted Speed Limit on Major Road (mph)	40.851	9.640	25	55
Left Shoulder Total Width on Minor Road (feet)	3.061	2.407	0	10
Right Shoulder Total Width on Minor Road (feet)	3.087	2.489	0	10
Paved Width on Minor Road (feet)	24.136	5.185	19	54
Posted Speed Limit on Minor Road (mph)	39.244	9.476	25	55
Intersection Skew Angle (degree)	76.714	15.560	15	90
Categorical Variable	Description		Proportion	
Presence of exclusive left-turn lanes on major road approach	None		70.48	
	Present on one approach		22.86	
	Present on both approaches		6.67	
Presence of exclusive right-turn lanes on major road approach	None		84.76	
	Present on one approach		14.29	
	Present on both approaches		0.95	
Presence of pedestrian crosswalk on major road approach	None		74.52	
	Present on one approach		15.00	
	Present on both approaches		10.48	
Presence of intersection warning on major road approach	None		97.86	
	Present		2.14	
Presence of exclusive left-turn lane on minor road approach	None		78.10	
	Present on one approach		16.19	
	Present on both approaches		5.71	
Presence of exclusive right-turn lane on minor road approach	None		86.67	
	Present on one approach		10.48	
	Present on both approaches		2.86	
Presence of pedestrian crosswalk on major road approach	None		71.19	
	Present on one approach		18.33	
	Present on both approaches		10.48	
Presence of intersection warning on major road approach	None		95.48	
	Present		4.52	

Table 14. Summary Statistics for 3-Leg Signalized Intersections on Two-Lane Rural Roads.

Continuous Variable	Mean	Standard Deviation	Minimum	Maximum
Total Crashes per Year	1.922	2.558	0	15
Total Fatal + Injury Crash per Year	1.203	1.831	0	13
Major Road AADT (veh/day)	6710	3815	913	17,265
Minor Road AADT (veh/day)	4127	2819	324	12,501
Left Shoulder Total Width on Major Road (feet)	2.769	2.960	0	10
Right Shoulder Total Width on Major Road (feet)	2.858	3.141	0	10
Paved Width on Major Road (feet)	28.928	7.041	20	50
Posted Speed Limit on Major Road (mph)	38.722	11.072	20	55
Left Shoulder Total Width on Minor Road (feet)	2.297	1.992	0	8
Right Shoulder Total Width on Minor Road (feet)	2.386	2.011	0	8
Paved Width on Minor Road (feet)	24.739	5.139	20	42
Posted Speed Limit on Minor Road (mph)	37.833	9.005	25	55
Intersection Skew Angle (degree)	76.000	17.203	20	90

Categorical Variable	Description	Proportion
Presence of exclusive left-turn lane on major road approach	None	71.67
	Present	28.33
Presence of exclusive right-turn lane on major road approach	None	93.61
	Present	6.39
Presence of pedestrian crosswalk on major road approach	None	76.11
	Present on one approach	19.44
	Present on both approaches	4.44
Presence of exclusive left-turn lanes on minor road	None	95
	Present	5
Presence of exclusive right-turn lanes on minor road	None	93.06
	Present	6.94
Presence of pedestrian crosswalk on minor road	None	77.22
	Present on one approach	18.33
	Present on both approaches	4.44

Table 15. Summary Statistics for 4-Leg All-Way Stop Control Intersections on Two-Lane Rural Roads.

Continuous Variable	Mean	Standard Deviation	Minimum	Maximum
Total Crashes per Year	1.970	2.538	0	12
Total Fatal + Injury Crash per Year	1.023	1.594	0	8
Major Road AADT (veh/day)	3763	2745	740	11,351
Minor Road AADT (veh/day)	1973	1356	317	5959
Left Shoulder Total Width on Major Road (feet)	4.254	2.473	0	10
Right Shoulder Total Width on Major Road (feet)	4.432	2.544	0	10
Paved Width on Major Road (feet)	22.659	3.268	20	35
Posted Speed Limit on Major Road (mph)	45.436	9.089	25	55
Left Shoulder Total Width on Minor Road (feet)	2.928	1.845	0	8
Right Shoulder Total Width on Minor Road (feet)	2.932	1.865	0	8
Paved Width on Minor Road (feet)	21.098	2.325	18	32
Posted Speed Limit on Minor Road (mph)	42.746	7.107	25	55
Intersection Skew Angle (degrees)	67.727	17.314	10	90

Categorical Variable	Description	Proportion
Presence of exclusive left-turn lane on major road approach	None	96.97
	Present on both approaches	3.03
Presence of exclusive right-turn lane on major road approach	None	90.91
	Present on one approach	6.06
	Present on both approaches	3.03
Presence of pedestrian crosswalk on major road approach	None	96.97
	Present on one approach	3.03
Presence of intersection warning on major road	None	96.97
	Present	3.03
Presence of exclusive left-turn lane on minor road approach	None	96.97
	Present on one approach	3.03
Presence of exclusive right-turn lane on minor road approach	None	96.97
	Present on both approaches	3.03
Presence of pedestrian crosswalk on minor road approach	None	96.97
	Present on one approach	3.03
Presence of intersection warning on minor road	None	90.91
	Present	9.09

Table 16. Summary Statistics for 4-Leg Two-Way Stop-Controlled Intersections on Two-Lane Rural Roads.

Continuous Variable	Mean	Standard Deviation	Minimum	Maximum
Total Crashes per Year	1.637	2.312	0	15
Total Fatal + Injury Crash per Year	0.920	1.663	0	11
Major Road AADT (veh/day)	3913	2761	312	14,387
Minor Road AADT (veh/day)	1681	1278	172	8923
Left Shoulder Total Width on Major Road (feet)	3.610	2.362	0	14
Right Shoulder Total Width on Major Road (feet)	3.750	2.537	0	14
Paved Width on Major Road (feet)	23.968	6.818	20	66
Posted Speed Limit on Major Road (mph)	43.721	8.706	25	55
Left Shoulder Total Width on Minor Road (feet)	2.797	1.833	0	8
Right Shoulder Total Width on Minor Road (feet)	2.762	1.876	0	8
Paved Width on Minor Road (feet)	21.799	3.252	18	40
Posted Speed Limit on Minor Road (mph)	41.919	8.081	25	55
Skew Angle on Major Route (degree)	72.151	18.559	15	90

Categorical Variable	Description	Proportion
Presence of exclusive left-turn lane on major approach	None	96.51
	Present on one approach	2.33
	Present on both approaches	1.16
Presence of pedestrian crosswalk on major road approach	None	96.51
	Present on one approach	3.49
Presence of intersection warning on major road approach	None	99.13
	Present	0.87
Presence of exclusive left-turn lane on minor approach	None	98.84
	Present on both approaches	1.16
Presence of exclusive right-turn lane on minor approach	None	98.84
	Present on one approach	1.16
Presence of pedestrian crosswalk on minor road approach	None	93.02
	Present on one approach	6.98
Presence of intersection warning on minor road approach	None	98.55
	Present	1.45

Table 17. Summary Statistics for 3-Leg Two-Way Stop-Controlled Intersections on Two-Lane Rural Roads.

Continuous Variable	Mean	Standard Deviation	Minimum	Maximum
Total Crashes per Year	1.383	2.023	0	16
Total Fatal + Injury Crashes per Year	0.766	1.348	0	12
Major Road AADT (veh/day)	4109	2873	138	19,161
Minor Road AADT (veh/day)	1992	1734	74	14,537
Left Shoulder Total Width on Major Road (feet)	4.342	2.473	0	12
Right Shoulder Total Width on Major Road (feet)	4.356	2.449	0	11
Paved Width on Major Road (feet)	23.278	3.714	18	41
Posted Speed Limit on Major Road (mph)	46.443	8.189	15	55
Left Shoulder Total Width on Minor Road (feet)	3.201	1.939	0	12
Right Shoulder Total Width on Minor Road (feet)	3.289	2.001	0	11
Paved Width on Minor Road (feet)	21.920	3.612	16	66
Posted Speed Limit on Minor Road (mph)	44.269	8.561	20	55
Intersection Skew Angle (degree)	65.145	21.136	10	90

Categorical Variable	Description	Proportion
Presence of exclusive left-turn lane on major approach	None	94.96
	Present on one approach	5.04
Presence of exclusive right-turn lane on major approach	None	96.62
	Present on one approach	3.38
Presence of pedestrian crosswalk on major road approach	None	99.52
	Present on one approach	0.48
Presence of intersection warning on major road approach	None	99.31
	Present	0.69
Presence of exclusive left-turn lane on minor approach	None	96.11
	Present on one approach	3.89
Presence of exclusive right-turn lane on minor approach	None	95.41
	Present on one approach	4.59
Presence of pedestrian crosswalk on minor road approach	None	99.52
	Present on one approach	0.48
Presence of intersection warning on minor road approach	None	99.00
	Present	1.00

Regionalization of SPFs

Table 18 and Table 19 provide the frequency of the various intersection forms in the analysis database by county and engineering district, respectively. A review of these tables suggests that an adequate sample of various intersection forms is not available to estimate county-level intersection SPFs of any form. An adequate sample size to estimate district-level SPFs was available for engineering districts 1, 2 and 8 for the three-leg minor stop-controlled intersection form; no other intersection forms have sufficient sample size within any engineering districts to warrant district-level SPFs. For this reason, only statewide SPFs were developed for each of these intersection forms. District-specific adjustments were considered to capture any regional differences across Pennsylvania for intersections of two-lane rural highways.

Table 18. Rural Two-lane Highway County Intersections.

County	Name	3L MS	3L SIG	4L AWS	4L MS	4L SIG	Sum
1	ADAMS	3	0	0	0	4	7
2	ALLEGHENY	0	0	0	0	0	0
3	ARMSTRONG	5	0	0	0	0	5
4	BEAVER	4	0	1	0	2	7
5	BEDFORD	11	1	0	1	2	15
6	BERKS	3	1	0	2	4	10
7	BLAIR	0	0	0	0	0	0
8	BRADFORD	5	2	0	1	2	10
9	BUCKS	5	2	0	1	1	9
10	BUTLER	4	0	3	1	1	9
11	CAMBRIA	10	0	0	0	0	10
12	CAMERON	0	1	0	0	0	1
13	CARBON	3	1	0	0	1	5
14	CENTRE	5	0	1	2	3	11
15	CHESTER	0	0	8	4	3	15
16	CLARION	4	0	1	5	6	16
17	CLEARFIELD	12	0	1	2	3	18
18	CLINTON	2	1	1	0	0	4
19	COLUMBIA	6	0	0	1	1	8
20	CRAWFORD	15	2	0	0	5	22
21	CUMBERLAND	6	1	1	5	4	17
22	DAUPHIN	2	1	0	3	2	8
24	ELK	7	0	0	0	2	9
25	ERIE	9	1	0	1	1	12
26	FAYETTE	4	2	0	1	0	7
27	FOREST	5	0	0	1	0	6
28	FRANKLIN	13	2	2	2	1	20
29	FULTON	9	0	0	3	1	13
30	GREENE	3	0	0	1		4
31	HUNTINGDON	12	1	1	2	3	19
32	INDIANA	17	0	1	4	1	23
33	JEFFERSON	4	1	0	0	4	9
34	JUNIATA	0	0	0	2	0	2
35	LACKAWANNA	3	2	0	1	4	10
36	LANCASTER	8	0	0	0	2	10
37	LAWRENCE	10	0	2	5	5	22
38	LEBANON	6	1	0	0	4	11
39	LEHIGH	2	1	0	0	0	3
40	LUZERNE	1	0	1	1	3	6
41	LYCOMING	12	0	0	1	0	13
42	MCKEAN	19	4	1	1	1	26
43	MERCER	5	2	0	2	3	12
44	MIFFLIN	1	0	0	0	0	1
45	MONROE	10	1	0	0	2	13
46	MONTGOMERY	0	0	0	0	0	0
47	MONTOUR	0	0	0	1	1	2
48	NORTHAMPTON	1	0	0	0	2	3
49	NORTHUMBERLAND	3	0	0	1	3	7
50	PERRY	10	0	3	3	0	16
51	PIKE	3	1	0	2	1	7
52	POTTER	8	1	0	3	1	13
53	SCHUYLKILL	7	1	1	4	0	13
54	SNYDER	2	2	1	0	0	5

County	Name	3L MS	3L SIG	4L AWS	4L MS	4L SIG	Sum
55	SOMERSET	4	4	0	0	1	9
56	SULLIVAN	7	1	0	0	1	9
57	SUSQUEHANNA	16	1	0	0	2	19
58	TIOGA	10	1	0	0	2	13
59	UNION	2	0	0	0	2	4
60	VENANGO	12	1	0	2	0	15
61	WARREN	7	1	0	1	1	10
62	WASHINGTON	21	0	0	2	1	24
63	WAYNE	12	0	1	3	4	20
64	WESTMORELAND	10	0	2	2	0	14
65	WYOMING	6	0	0	1	2	9
66	YORK	8	0	0	5	0	13
Total		356	37	20	74	82	683
3L MS = 3-leg intersection with stop-control on minor approach; 3L SIG = 3-leg signalized intersection; 4L AWS = 4-leg intersection with all-way stop-control; 4L MS = 4-leg intersection with stop-control on minor approach; 4L SIG = 4-leg signalized intersection							

Table 19. Rural Two-lane District Intersections.

District	3L MS	3L SIG	4L AWS	4L MS	4L SIG	Sum
1	53	7	0	7	10	78
2	54	7	4	10	10	87
3	47	6	1	5	12	74
4	41	4	2	8	16	75
5	26	5	1	6	9	52
6	5	2	8	5	4	30
8	56	5	6	18	17	110
9	46	6	1	6	7	75
10	34	1	5	10	12	72
11	14	0	3	5	7	40
12	38	2	2	6	1	61
Total	414	45	33	86	105	754

Therefore, for the two-lane rural highway intersection types, the research team recommends using **statewide SPFs** because the number of each intersection type in each district is too few to estimate regional SPFs. District-specific adjustments were considered, but found to not be statistically valid.

For 3-leg minor stop-controlled intersections, the presence of "STOP Except Right Turns" signs was identified using the PennDOT Sign Inventory. Only 15 of the 414 intersections in the analysis database had these signs, which was not sufficient to estimate a separate SPF for intersections with this sign. However, Appendix I contains a procedure to adjust the estimate of the 3-leg minor stop-controlled intersection SPF to estimate crash frequencies for intersections with this sign installed.

<u>Summary of SPF Recommendations</u>

The total and fatal + injury SPFs for at-grade intersections on two-lane rural highways are shown in Appendix D. For brevity, a detailed interpretation of these models is not provided, but proceeds in a manner consistent with the discussion in the two-lane rural highway segment section above.

A summary of the final recommendations for total and fatal+injury SPFs for intersections on two-lane rural highways are shown in Table 20 below.

Table 20. Regionalized SPFs for Two-lane Rural Highway Intersections.

Intersection Type	Total and Fatal+Injury SPF
4-leg Signalized	$N_{Total} = e^{-5.353} \times AADT_{major}^{0.313} \times AADT_{minor}^{0.250} \times e^{0.025 PSL_{major}} \times e^{0.014 PSL_{minor}} \times e^{0.216 ERT_{major}}$ $Overdispersion = 0.579$ (37) $N_{FI} = e^{-4.960} \times AADT_{major}^{0.202} \times AADT_{minor}^{0.209} \times e^{0.028 PSL_{major}} \times e^{0.018 PSL_{minor}} \times e^{0.388 ERT_{major}}$ $Overdispersion = 0.892$ (38)
3-leg Signalized	$N_{Total} = e^{-6.813} \times AADT_{major}^{0.451} \times AADT_{minor}^{0.349} \times e^{0.020 PSL_{major}} \times e^{-0.433 Walk_{major}} \times e^{-0.345 Walk_{minor}}$ $Overdispersion = 0.982$ (39) $N_{FI} = e^{-6.981} \times AADT_{major}^{0.452} \times AADT_{minor}^{0.287} \times e^{0.026 PSL_{major}} \times e^{-0.605 Walk_{major}} \times e^{-0.413 Walk_{minor}}$ $Overdispersion = 1.114$ (40)
4-leg All-way stop-controlled	$N_{Total} = e^{-6.581} \times AADT_{major}^{0.680} \times AADT_{minor}^{0.064} \times e^{0.028 PSL_{major}}$ $Overdispersion = 1.283$ (41) $N_{FI} = e^{-7.541} \times AADT_{major}^{0.639} \times AADT_{minor}^{0.134} \times e^{0.029 PSL_{major}}$ $Overdispersion = 1.522$ (42)
4-leg minor-street stop-controlled	$N_{Total} = e^{-6.359} \times AADT_{major}^{0.528} \times AADT_{minor}^{0.275} \times e^{0.007 Skew}$ $Overdispersion = 1.348$ (43) $N_{FI} = e^{-6.156} \times AADT_{major}^{0.512} \times AADT_{minor}^{0.176} \times e^{0.008 Skew}$ $Overdispersion = 2.597$ (44)
3-leg minor-street stop-controlled	$N_{Total} = e^{-6.337} \times AADT_{major}^{0.479} \times AADT_{minor}^{0.362} \times e^{-0.330 ELT_{major}} \times e^{0.507 ERT_{major}}$ $Overdispersion = 1.117$ (45) $N_{FI} = e^{-6.457} \times AADT_{major}^{0.439} \times AADT_{minor}^{0.343} \times e^{-0.267 ELT_{major}} \times e^{0.560 ERT_{major}}$ $Overdispersion = 1.810$ (46)
$AADT_{major}$ = major road average annual daily traffic (veh/day) $AADT_{minor}$= minor road average annual daily traffic (veh/day) PSL_{major} = posted speed limit on the major road (mph) PSL_{minor} = posted speed limit on the minor road (mph) ELT_{major} = exclusive left turn lane on the major road (1 = present; 0 = not present) ERT_{major} = exclusive right turn lane on the major road (1 = present; 0 = not present) $Walk_{major}$ = pedestrian crosswalk on the major road (1 = present; 0 = not present) $Walk_{minor}$ = pedestrian crosswalk on the minor road (1 = present; 0 = not present) Skew = intersection skew angle (90 – angle) [degrees]	

Comparison with HSM SPFs

RMSE values were also used to compare the recommended regionalized SPFs (statewide) to the HSM SPFs for at-grade intersections on two-lane rural highways. Since SPFs are not available in the HSM for 4-leg all-way stop-controlled or 3-leg signalized intersections, crash frequency predictions (and RMSE values) are not possible using the HSM. For these two intersection types, the proposed statewide models facilitate predictions of safety performance for intersections in Pennsylvania that would not otherwise be possible.

Table 21 to Table 23 provides RMSE comparisons for the three intersection forms that are available in the HSM for two-lane rural highways (4-leg signalized, 4-leg minor stop-controlled and 3-leg signalized intersections). For the 4-leg signalized intersections, the statewide SPFs provide lower RMSE values for 39 of the 45 counties that had intersections of this type. The RMSE measured across all counties is also 28.8% smaller when applying the statewide SPFs when compared to the HSM SPFs. For the 4-leg minor approach stop-controlled intersections, the statewide SPFs provide lower RMSE values for 31 of the 40 counties that had intersections of this type. The RMSE measured across all counties is also 37.2% smaller when applying the statewide SPFs than the HSM SPFs. For the 3-leg signalized intersections, the statewide SPFs provide lower RMSE values for 47 of the 58 counties that had intersections of this type. The RMSE measured across all counties is also 17.2% smaller when applying the statewide SPFs than the HSM SPFs. Therefore, the Pennsylvania-specific statewide SPFs demonstrate a clear benefit in predictive power over the SPF in the HSM for intersections on two-lane rural highways.

Table 21. RMSE Comparison for Total Crash Frequency at 4-Leg Signalized Intersections on Two-Lane Rural Roads – Statewide and HSM SPFs.

County	SPF Prediction RMSE		Percent Improvement	County	SPF Prediction RMSE		Percent Improvement
	Statewide	HSM			Statewide	HSM	
1	3.901	3.876	-0.6%	35	2.340	3.114	24.9%
4	3.837	3.470	-10.6%	36	3.876	6.700	42.1%
5	1.917	4.314	55.6%	37	2.188	3.791	42.3%
6	5.118	4.415	-15.9%	38	2.682	5.287	49.3%
8	2.289	4.033	43.2%	40	2.038	3.479	41.4%
9	2.393	4.486	46.7%	42	2.427	4.490	45.9%
10	2.320	2.332	0.5%	43	2.401	2.653	9.5%
13	2.980	3.164	5.8%	45	2.436	2.276	-7.0%
14	1.688	5.278	68.0%	47	1.309	2.449	46.5%
15	2.995	4.387	31.7%	48	4.739	3.632	-30.5%
16	2.078	3.007	30.9%	49	2.753	2.720	-1.2%
17	2.213	3.242	31.7%	51	3.077	7.674	59.9%
19	1.889	4.841	61.0%	52	1.323	4.747	72.1%
20	3.559	3.895	8.6%	55	2.190	2.483	11.8%
21	3.327	3.659	9.1%	56	1.541	2.977	48.2%
22	1.161	3.576	67.5%	57	1.526	4.076	62.6%
24	1.227	4.866	74.8%	58	2.197	2.878	23.7%
25	2.269	2.287	0.8%	59	2.333	5.429	57.0%
28	1.672	3.606	53.6%	61	1.831	3.002	39.0%

29	4.711	6.744	30.1%	62	2.214	3.872	42.8%
31	1.920	2.697	28.8%	63	3.151	3.586	12.1%
32	1.570	5.557	71.7%	65	5.135	5.820	11.8%
33	2.550	3.763	32.2%	Average	2.864	4.020	28.8%

Table 22. RMSE Comparison for Total Crash Frequency at 4-Leg Minor Stop-Controlled Intersections on Two-Lane Rural Roads – Statewide and HSM SPFs.

County	SPF Prediction RMSE		Percent Improvement	County	SPF Prediction RMSE		Percent Improvement
	Statewide	HSM			Statewide	HSM	
5	0.998	1.529	34.7%	34	1.288	2.767	53.5%
6	1.176	1.810	35.0%	35	1.768	1.746	-1.3%
8	1.074	2.259	52.5%	37	1.682	3.068	45.2%
9	2.453	3.551	30.9%	40	1.125	1.400	19.6%
10	1.925	1.773	-8.6%	41	1.168	1.268	7.9%
14	1.251	2.904	56.9%	42	1.266	1.190	-6.4%
15	2.722	3.596	24.3%	43	1.956	3.394	42.4%
16	1.585	4.831	67.2%	47	1.665	6.585	74.7%
17	2.327	4.017	42.1%	49	1.329	3.769	64.7%
19	2.128	3.433	38.0%	50	4.003	3.362	-19.1%
21	1.924	2.806	31.4%	51	2.367	1.952	-21.3%
22	3.751	4.656	19.4%	52	1.557	2.772	43.8%
25	4.630	3.898	-18.8%	53	3.741	3.689	-1.4%
26	2.488	5.772	56.9%	60	1.345	2.936	54.2%
27	1.011	1.485	31.9%	61	1.868	2.618	28.6%
28	1.314	2.394	45.1%	62	3.042	9.191	66.9%
29	1.611	1.541	-4.5%	63	0.675	0.950	28.9%
30	1.510	1.704	11.4%	64	1.548	1.499	-3.3%
31	1.670	2.494	33.0%	65	1.704	3.091	44.9%
32	1.749	2.932	40.3%	66	2.411	4.498	46.4%
				Average	2.208	3.516	37.2%

Table 23. RMSE Comparison for Total Crash Frequency at 3-Leg Signalized Intersections on Two-Lane Rural Roads – Statewide and HSM SPFs.

County	SPF Prediction RMSE		Percent Improvement	County	SPF Prediction RMSE		Percent Improvement
	Statewide	HSM			Statewide	HSM	
1	2.216	3.123	29.0%	36	3.488	4.247	17.9%
3	1.892	2.111	10.4%	37	1.583	1.860	14.9%
4	3.032	2.770	-9.5%	38	1.947	2.169	10.2%
5	1.387	1.537	9.8%	39	2.870	3.000	4.3%
6	5.143	3.885	-32.4%	40	1.539	1.684	8.6%
8	1.830	1.852	1.2%	41	1.040	1.103	5.7%
9	2.576	3.559	27.6%	42	1.516	1.707	11.2%
10	1.698	1.462	-16.1%	43	1.227	1.670	26.5%
11	1.521	2.590	41.3%	44	1.771	2.668	33.6%
13	2.000	2.127	6.0%	45	3.775	4.911	23.1%
14	1.318	1.254	-5.1%	48	2.303	5.430	57.6%
16	1.430	1.541	7.2%	49	1.615	3.550	54.5%
17	1.083	1.117	3.0%	50	1.420	1.826	22.2%
18	0.696	0.671	-3.7%	51	1.426	1.712	16.7%
19	1.274	1.746	27.0%	52	0.926	0.920	-0.7%
20	1.373	1.430	4.0%	53	1.496	2.105	28.9%
21	1.628	2.859	43.1%	54	1.153	1.794	35.7%
22	1.368	1.471	7.0%	55	1.509	1.496	-0.9%
24	1.787	2.867	37.7%	56	1.389	1.371	-1.3%
25	3.470	3.889	10.8%	57	1.480	1.557	4.9%
26	1.817	1.741	-4.4%	58	1.821	1.729	-5.3%
27	1.259	1.513	16.8%	59	2.074	5.672	63.4%
28	2.120	2.228	4.8%	60	1.074	1.162	7.6%
29	0.735	0.740	0.7%	61	1.438	1.594	9.8%
30	1.587	1.977	19.7%	62	1.568	1.617	3.0%
31	1.326	1.777	25.4%	63	1.430	2.243	36.2%
32	1.583	1.871	15.4%	64	2.159	2.456	12.1%
33	1.420	1.917	25.9%	65	2.265	3.218	29.6%
35	1.102	1.084	-1.7%	66	2.480	2.803	11.5%
				Average	1.854	2.240	17.2%

Rural Multilane Roadway Segment SPFs

This section describes the development of SPFs for rural multilane roadway segments. The remainder of this section summarizes the data available for the development of regionalized SPFs, the selection of the most appropriate regionalization level, and the final SPF recommendations.

Data Summary

The roadway inventory file for the rural multilane highway segments was created by combining PennDOT's RMS data files with data collected by the research team using PennDOT's video photolog software and Google Earth images. Each of these data elements were previously described in the Data Collection section.

The HSM separates rural multilane highway segments into 4-lane undivided and 4-lane divided roadways. The PennDOT RMS data codes were used to identify each of these roadway forms as shown in Table 24. The resulting database consisted of a total of 1,380 unique roadway segments, which covered a total of 643.49 miles of roadway multilane roadways. Of these, 18 segments represented rural multilane highways with more than two travel lanes per direction (i.e., more than four lanes total). Since rural multilane segment SPFs in the HSM are developed only for four-lane segments, these 18 segments were removed from the analysis database and only the remaining 1,362 unique segments were considered. Because five years of crash data were available for each segment (2010 to 2014), the analysis database consisted of a total of 6,810 observations.

Table 24. PennDOT RMS Data Codes Used to Identify Rural Multilane Roadway Segment Types.

Roadway Form	PennDOT Data Codes
Four-lane undivided	Number of lanes = 2 Divisor type = 1 or 4 Center turn lane presence = 0
Four-lane divided	Number of lanes = 2 Divisor type = 2, 3, 5, 7 or 8

Table 25 provides summary statistics for total crashes, fatal, injury, and PDO crashes, traffic volumes, and the roadway and roadside characteristics for the 6,810 observations that were used for modeling. As shown in Table 25, there are more injury and PDO crashes than fatal crashes per segment. The rural multilane roadway segments have higher traffic volumes than two-lane rural roadway segments, as expected. The categorical variables are summarized in the lower half of Table 25. The majority of the segments have roadside hazard ratings of 3, 4 or 5. Fewer than 2 percent of the segments have horizontal curve warning pavement markings.

Table 25. Crash, Traffic Volume, and Site Characteristic Data Summary for Rural Multilane Highway Segments.

Variables	Mean	Standard Deviation	Minimum	Maximum
Total crashes per year	0.783	1.266	0	19
Total fatal crashes per year	0.016	0.126	0	1
Total injury crashes per year	0.368	0.752	0	8
Total property-damage only (PDO) crashes per year	0.392	0.784	0	13
Average annual daily traffic (veh/day)	5810	2825	238	19,182
Segment length (miles)	0.443	0.141	0.044	0.756
Posted speed limit (mph)	50.312	6.235	20	65
Left paved shoulder width (feet)	4.720	3.879	0	12
Right paved shoulder width (feet)	4.778	3.862	0	14
Access density (access points and intersections per mile)	7.196	6.314	0	39.63964
Degree of curve per mile	13.753	30.618	0	374.988
Roadside hazard rating of right-hand roadside (1 to 7)	1		0.81	
	2		4.63	
	3		38.84	
	4		41.48	
	5		11.09	
	6		1.84	
	7		1.32	
Presence of centerline rumble strips or left-hand shoulder rumble strips	Yes		21.8	
	No		78.2	
Presence of right-hand shoulder rumble strips	Yes		44.1	
	No		55.9	
Presence of curve pavement warning marker	Yes		1.2	
	No		98.8	
Presence of a media barrier on the segment	Yes		47.8	
	No		52.2	

Regionalization of SPFs

Table 26 shows the four-lane divided and four-lane divided rural multilane highway segment mileage for all 67 counties in the Commonwealth. Clearly, the development of SPFs for these two highway types was not possible due to the relatively low mileage in each county. Even if sufficient roadway mileage did exist, the research team found that separate SPFs for 4-lane undivided and 4-lane divided roadways would be difficult to estimate due to the inconsistent coding of divided and undivided roadway segments in the RMS database. Instead, only a single SPF form was considered that can be applied to both divided and undivided roadway segments.

Considering the combined mileage of multilane rural highway segments, only Westmoreland County has more than the minimum 50 miles of rural multilane highways required to estimate a county-level SPF. Therefore, adequate sample sizes do not exist to estimate county-level SPFs for the Commonwealth. Table 27 provides the four-lane divided and four-lane undivided segment mileage within each engineering district. Again, separate SFPs for 4-lane undivided and 4-lane divided roadways is not possible due to the low roadway mileage of each type within each district. Therefore, a single SPF form is considered at the district level. With the exception of engineering districts 6 and 11, there appears to be an adequate sample to consider SPFs at the engineering district level for rural multilane highways. Note, however, that the mileage within each engineering district is relatively small (the largest district has just over 100 miles of rural multilane highways) so district-level SPFs are not expected to include many independent variables.

Table 26. Rural Multilane Highway County Segment Mileage.

County	Name	Four-lane undivided	Four-lane divided	County	Name	Four-lane undivided	Four-lane divided
1	ADAMS	1.2	7	35	LACKAWANNA	22	8
2	ALLEGHENY	0	3	36	LANCASTER	0.8	0
3	ARMSTRONG	0.5	4	37	LAWRENCE	0.3	4
4	BEAVER	0	7	38	LEBANON	11	32
5	BEDFORD	18	11	39	LEHIGH	0.2	0
6	BERKS	0.0	3	40	LUZERNE	5	0
7	BLAIR	3	4	41	LYCOMING	1.0	0
8	BRADFORD	1	0	42	MCKEAN	0	0
9	BUCKS	0.6	1.0	43	MERCER	2	16
10	BUTLER	32	1.3	44	MIFFLIN	1.5	6
11	CAMBRIA	3	20	45	MONROE	1.7	6
12	CAMERON	0	0	46	MONTGOMERY	0.0	0
13	CARBON	0	0	47	MONTOUR	0.7	4
14	CENTRE	0	8	48	NORTHAMPTON	0.6	1.5
15	CHESTER	0.3	3	49	NORTHUMBERLAND	6	1.3
16	CLARION	0	0	50	PERRY	7	26
17	CLEARFIELD	1.3	14	51	PIKE	2	0.2
18	CLINTON	0	0	52	POTTER	0.0	0
19	COLUMBIA	3	0.7	53	SCHUYLKILL	10	25
20	CRAWFORD	8	0.8	54	SNYDER	0	22
21	CUMBERLAND	3	0.4	55	SOMERSET	0	0.5
22	DAUPHIN	1.3	7	56	SULLIVAN	0	0
23	DELAWARE	0	0	57	SUSQUEHANNA	0	0
24	ELK	4	0	58	TIOGA	0	0
25	ERIE	18	17	59	UNION	2	5
26	FAYETTE	1.5	36	60	VENANGO	6	1.5
27	FOREST	0	0	61	WARREN	0	7
28	FRANKLIN	1.7	1.1	62	WASHINGTON	0	6
29	FULTON	0	1.3	63	WAYNE	0	0.9
30	GREENE	0	3	64	WESTMORELAND	4	50
31	HUNTINGDON	3	0	65	WYOMING	4	7
32	INDIANA	16	7	66	YORK	0	0
33	JEFFERSON	3	0.9	67	PHILADELPHIA	0	0
34	JUNIATA	0	4	Total		211	393

Table 27. Rural Multilane Highway District Segment Mileage.

District	Four-lane undivided	Four-lane divided
1	19	35
2	40	37
3	21	23
4	21	58
5	44	20
6	18	35
8	13	35
9	19	73
10	8	6
11	0	14
12	7	57
Total	211	393

Based on the number of observations within each regional level and the RMSE values that were available for different levels of regionalized SPFs, the research team recommends using **statewide SPFs with district-specific adjustments** for rural multilane roadway segments. This regionalization level was found to provide the most accurate estimates of crash frequency compared to district-level SPFs.

Summary of SPF Recommendations

The total and fatal + injury SPFs for rural multilane highway segments are provided in Appendix E. For brevity, a detailed interpretation of these models is not provided here. However, the same procedure used to interpret the two-lane rural roadway segment SPFs can be applied to these models to interpret their results.

The recommended statewide SPFs are shown in Table 28.

Table 28. Statewide SPFs for Rural Multilane Highway Segments.

$N_{Total} = e^{-4.571} \times \mathrm{L} \times AADT^{0.587} \times e^{0.097\times\mathrm{Barrier}} \times e^{0.002\times\mathrm{DCPM}} \times e^{0.188\times\mathrm{RRHR4}} \times e^{0.386\times\mathrm{RRHR567}} \times e^{0.023\times\mathrm{AD}} \times e^{-0.143\times\mathrm{PSL4550}} \times e^{-0.385\times\mathrm{PSL55p}} \times e^{-0.184\times\mathrm{CRS}} \times e^{-0.188\times\mathrm{SRS}}$ (47) over-dispersion parameter: 0.790
$N_{FI} = e^{-4.048} \times \mathrm{L} \times AADT^{0.424} \times e^{0.002\times\mathrm{DCPM}} \times e^{0.186\times\mathrm{RRHR4}} \times e^{0.431\times\mathrm{RRHR567}} \times e^{0.029\times\mathrm{AD}} \times e^{-0.281\times\mathrm{PSL55p}} \times e^{-0.259\times\mathrm{CRS}} \times e^{-0.131\times\mathrm{SRS})}$ (48) over-dispersion parameter: 0.929
Barrier = presence of a median barrier on the segment (1 = present; 0 otherwise) DCPM = total degree of curvature per mile in the segment, the sum of degree of curvature for all curves in the segment divided by segment length in miles (Degrees/100 ft/Mile). RRHR4 – indicator for roadside hazard rating of the right-hand side of the segment is 4 (1 if RHRR = 4; 0 otherwise) RRHR567 – indicator for roadside hazard rating on the right-hand side of the segment is 5, 6 or 7 (1 if RRHR = 5, 6, or 7; 0 otherwise) AD = access density along the segment (driveways plus intersections per mile) PSL4550 – indicator for posted speed limit of 45 or 50 mph (1 = posted speed limit is 45 or 50 mph on segment; 0 otherwise) PSL55p – indicator for posted speed limit of 55 mph or greater (1 = posted speed limit is 55 mph or greater on segment; 0 otherwise) CRS – indicator for presence of a centerline rumble strip (undivided road) or shoulder rumble strip on the left-hand side (divided road) (1 = centerline or left-hand shoulder rumble strip present; 0 otherwise) SRS – indicator for presence of a right-hand shoulder rumble strip (1 = right-hand shoulder rumble strip present; 0 otherwise)

The district-level modifications to the statewide SPF are shown in Table 29. To use the modification factors, it is recommended that the statewide SPF be estimated using the equations shown above, and the multiplicative factors shown in Table 29 be used to modify the expected number of crashes from the statewide total and fatal+injury SPFs.

Table 29. District Adjustment Factors for Total and Fatal+Injury Crashes on Multilane Rural Highway Segments.

District	District-specific adjustment for total crash SPF	District-specific adjustment for fatal + injury SPF
1	No modification necessary	No modification necessary
2	Multiply estimate by 1.25	Multiply estimate by 1.36
3	Multiply estimate by 0.82	No modification necessary
4	No modification necessary	No modification necessary
5	Multiply estimate by 1.25	Multiple estimate by 1.36
6	No modification necessary	No modification necessary
8	No modification necessary	No modification necessary
9	No modification necessary	No modification necessary
10	No modification necessary	No modification necessary
11	Multiply estimate by 1.21	Multiply estimate by 1.35
12	Multiply estimate by 1.21	Multiply estimate by 1.35

Comparison with HSM SPFs

RMSE values were also used to compare the recommended regionalized SPFs (statewide) to the HSM SPFs on rural multilane highway segments. The RMSE comparisons are provided in Table 30 and Table 31 for 4-lane undivided and 4-lane divided roadway types, respectively. For 4-lane undivided roadways, the statewide RMSE values are lower for 34 of the 41 counties with this roadway type. The overall RMSE measured across all counties is also 5.1% smaller when applying the statewide model when compared to the model provided in the HSM. For 4-lane divided roadways, the RMSE values are lower for 31 of the 46 counties with this roadway type. The overall RMSE measured across all counties is also 4.1% smaller when applying the statewide model as compared to the model provided in the HSM. Therefore, the Pennsylvania-specific statewide SPFs demonstrate a clear benefit in predictive power over the SPF in the HSM for rural multilane highway segments.

Table 30. RMSE Comparison for Total Crash Frequency on 4-Lane Undivided Rural Multilane Highway Segments – Statewide and HSM SPFs.

County	SPF Prediction RMSE		Percent Improvement	County	SPF Prediction RMSE		Percent Improvement
	Statewide	HSM			Statewide	HSM	
1	2.353	2.416	2.6%	35	0.864	0.864	0.0%
3	0.495	0.647	23.5%	36	0.445	0.261	-70.5%
5	1.422	1.574	9.7%	37	5.432	5.767	5.8%
7	0.797	0.877	9.1%	38	0.936	0.953	1.8%
8	0.482	0.489	1.4%	39	1.349	1.387	2.7%
9	1.801	2.054	12.3%	40	0.926	1.010	8.3%
10	1.307	1.354	3.5%	41	0.901	0.974	7.5%
11	0.869	0.858	-1.3%	43	2.473	2.603	5.0%
15	0.211	0.345	38.8%	44	1.954	2.146	8.9%
17	0.590	0.571	-3.3%	45	0.809	0.902	10.3%
19	0.460	0.471	2.3%	47	0.475	0.497	4.4%
20	1.094	1.148	4.7%	48	2.299	2.410	4.6%
21	1.078	1.095	1.6%	49	0.683	0.789	13.4%
22	0.972	1.113	12.7%	50	0.802	1.292	37.9%
24	1.829	1.423	-28.5%	51	3.188	3.409	6.5%
25	0.895	0.901	0.7%	53	1.082	1.080	-0.2%
26	1.927	1.969	2.1%	59	0.720	1.169	38.4%
28	2.214	2.236	1.0%	60	1.017	1.074	5.3%
31	0.775	0.867	10.6%	64	1.339	1.256	-6.6%
32	0.745	0.866	14.0%	65	0.828	0.846	2.1%
33	1.189	1.224	2.9%	Average	1.185	1.249	5.1%

Table 31. RMSE Comparison for Total Crash Frequency on 4-Lane Divided Rural Multilane Highway Segments – Statewide and HSM SPFs.

County	SPF Prediction RMSE		Percent Improvement	County	SPF Prediction RMSE		Percent Improvement
	Statewide	HSM			Statewide	HSM	
1	0.731	0.802	8.9%	33	0.846	0.832	-1.7%
2	1.105	0.910	-21.4%	34	1.009	1.049	3.8%
3	0.678	0.668	-1.5%	35	0.857	0.820	-4.5%
4	1.060	1.045	-1.4%	37	0.977	0.925	-5.6%
5	1.041	1.179	11.7%	38	0.904	0.889	-1.7%
6	2.277	2.317	1.7%	43	1.206	1.309	7.9%
7	0.821	0.877	6.4%	44	1.555	1.648	5.6%
9	0.744	0.807	7.8%	45	1.773	1.841	3.7%
10	0.866	0.778	-11.3%	47	1.553	1.487	-4.4%
11	1.270	1.278	0.6%	48	3.805	4.055	6.2%
14	0.953	0.982	3.0%	49	1.567	1.655	5.3%
15	0.643	0.636	-1.1%	50	0.865	0.912	5.2%
17	0.820	0.846	3.1%	51	0.215	0.139	-54.7%
19	0.750	0.774	3.1%	53	1.991	2.051	2.9%
20	0.504	0.594	15.2%	54	0.617	0.618	0.2%
21	2.366	2.748	13.9%	55	0.857	0.972	11.8%
22	2.636	2.864	8.0%	59	0.905	0.955	5.2%
25	0.702	0.724	3.0%	60	1.287	1.411	8.8%
26	0.937	1.002	6.5%	61	0.765	0.659	-16.1%
28	2.074	2.516	17.6%	62	1.774	2.040	13.0%
29	0.611	0.611	0.0%	63	1.054	1.084	2.8%
30	1.106	1.016	-8.9%	64	1.316	1.345	2.2%
32	0.628	0.622	-1.0%	65	1.159	1.286	9.9%
				Average	1.227	1.280	4.1%

Rural Multilane Intersection SPFs

This section describes the development of SPFs for rural multilane highway intersections. The remainder of this section summarizes the data available for the development of regionalized SPFs, the selection of the most appropriate regionalization level, and the final SPF recommendations.

<u>Data Summary</u>

Roadway inventory files for rural multilane intersections were created by combining PennDOT's RMS data files with data collected by the research team using PennDOT's video photolog software and Google Earth images. These data were previously described in the Data Collection section. A total of 168 unique intersections were identified in the data analysis file. The distribution of these intersections based on their type was:

- 45 4-leg intersections with signal control
- 44 4-leg intersections with minor-street stop control
- 79 3-leg intersections with minor-street stop control

Because five years of crash data were available for each intersection (2010 to 2014), the analysis database consisted of 840 observations. These data were appended to the roadway inventory files to develop the analysis files. Table 32 provides summary statistics for total crashes and fatal + injury crashes for each intersection type in the analysis database. As expected, the total crash frequency is higher than the fatal + injury crash frequency. The signalized intersection forms have the highest frequency of fatal + injury crashes.

Table 32. Summary Statistics for Total and Fatal + Injury Crash Frequencies by Intersection Type for Rural Multilane Highway Intersections.

Intersection Type	Number of observations	Mean	Standard Deviation	Minimum	Maximum
Total crash frequency					
4-leg, signalized	225	2.498	2.047	0	11
4-leg, two-way stop	220	1.205	1.394	0	8
3-leg, two-way stop	395	0.977	1.360	0	12
ALL	840	1.444		0	12
Fatal + Injury crash frequency					
4-leg, signalized	225	1.347	1.351	0	8
4-leg, two-way stop	220	0.673	0.952	0	5
3-leg, two-way stop	395	0.552	0.942	0	7
ALL	840	0.796		0	8

Table 33 to Table 35 present summary statistics for the independent variables considered in the SPF development, stratified by the three intersection forms included in this report. The 4-leg signalized intersection form has the highest traffic volumes. The signalized intersection also tends to have more exclusive turn lanes, particularly exclusive right-turn lanes. The posted speed limits vary considerably for all intersection types.

Table 33. Summary Statistics for 4-leg Signalized Intersection on Rural Multilane Roadways.

Continuous Variable	Mean	Standard Deviation	Minimum	Maximum
Total Crashes per Year	2.498	2.047	0	11
Total Fatal + Injury Crashes per Year	1.347	1.351	0	8
Major Road AADT (veh/day)	7174	2977	2570	18653
Minor Road AADT (veh/day)	3064	2335	105	11692
Left Shoulder Paved Width on Major Road (feet)	3.156	3.523	0	10
Right Shoulder Paved Width on Major Road (feet)	6.400	3.079	0	10
Paved Width on Major Road (feet)	34.778	7.276	21	53
Posted Speed Limit on Major Road (mph)	46.889	5.619	35	55
Left Shoulder Total Width on Minor Road (feet)	1.600	2.440	0	8
Right Shoulder Total Width on Minor Road (feet)	3.333	3.427	0	10
Paved Width on Minor Road (feet)	27.356	6.896	18	49
Posted Speed Limit on Minor Road (mph)	43.000	7.500	25	55

Categorical Variable	Description	Proportion
Presence of exclusive left-turn lanes on major road approach	None	0.47
	Present on at least one approach	0.53
Presence of exclusive right-turn lanes on major road approach	None	0.67
	Present on at least one approach	0.33
Presence of pedestrian crosswalk on major road approach	None	0.78
	Present on at least one approach	0.22
Presence of exclusive left-turn lane on minor road approach	None	0.60
	Present on at least one approach	0.40
Presence of exclusive right-turn lane on minor road approach	None	0.69
	Present on at least one approach	0.31
Presence of pedestrian crosswalk on major road approach	None	0.78
	Present on at least one approach	0.22

Table 34. Summary Statistics for 4-leg Minor Approach Stop-controlled Intersection on Rural Multilane Roadways.

Continuous Variable	Mean	Standard Deviation	Minimum	Maximum
Total Crashes per Year	1.205	1.394	0	8
Total Fatal + Injury Crashes per Year	0.673	0.952	0	5
Major Road AADT (veh/day)	5192	2897	934	13019
Minor Road AADT (veh/day)	1224	1288	103	5821
Left Shoulder Paved Width on Major Road (feet)	1.818	2.730	0	8
Right Shoulder Paved Width on Major Road (feet)	7.000	2.464	0	11
Paved Width on Major Road (feet)	34.500	7.928	20	70
Posted Speed Limit on Major Road (mph)	50.227	6.921	35	55
Left Shoulder Total Width on Minor Road (feet)	1.818	2.549	0	10
Right Shoulder Total Width on Minor Road (feet)	1.909	2.776	0	10
Paved Width on Minor Road (feet)	24.932	7.511	16	49
Posted Speed Limit on Minor Road (mph)	40.000	7.246	25	55

Categorical Variable	Description	Proportion
Presence of exclusive left-turn lanes on major road approach	None	0.45
	Present on at least one approach	0.55
Presence of exclusive right-turn lanes on major road approach	None	0.86
	Present on at least one approach	0.14
Presence of pedestrian crosswalk on major road approach	None	0.98
	Present on at least one approach	0.02
Presence of exclusive left-turn lane on minor road approach	None	0.95
	Present on at least one approach	0.05
Presence of exclusive right-turn lane on minor road approach	None	0.86
	Present on at least one approach	0.14
Presence of pedestrian crosswalk on major road approach	None	0.98
	Present on at least one approach	0.02

Table 35. Summary Statistics for 3-leg Minor Approach Stop-controlled Intersection on Rural Multilane Roadways.

Continuous Variable	Mean	Standard Deviation	Minimum	Maximum
Total Crashes per Year	0.977	1.360	0	12
Total Fatal + Injury Crashes per Year	0.552	0.942	0	7
Major Road AADT (veh/day)	6104	2780	685	16123
Minor Road AADT (veh/day)	1682	2039	28	13882
Left Shoulder Paved Width on Major Road (feet)	2.177	3.121	0	12
Right Shoulder Paved Width on Major Road (feet)	6.924	3.291	0	14
Paved Width on Major Road (feet)	34.772	6.290	24	57
Posted Speed Limit on Major Road (mph)	49.810	6.590	25	55
Left Shoulder Total Width on Minor Road (feet)	1.380	2.151	0	10
Right Shoulder Total Width on Minor Road (feet)	1.873	2.793	0	10
Paved Width on Minor Road (feet)	25.215	6.257	18	44
Posted Speed Limit on Minor Road (mph)	42.532	8.648	20	55
Categorical Variable	Description		Proportion	
Presence of exclusive left-turn lanes on major road approach	None		0.53	
	Present on at least one approach		0.47	
Presence of exclusive right-turn lanes on major road approach	None		0.86	
	Present on at least one approach		0.14	
Presence of exclusive left-turn lane on minor road approach	None		0.81	
	Present on at least one approach		0.19	
Presence of exclusive right-turn lane on minor road approach	None		0.78	
	Present on at least one approach		0.22	

Regionalization of SPFs

For the regionalization of rural multilane intersections, only statewide SPFs are considered since there are fewer than 50 intersections available in Pennsylvania for the 4-leg signalized and 4-leg minor stop-controlled intersection forms, and only 79 intersections available in Pennsylvania for the 3-leg minor stop-controlled intersection form. Therefore, for the rural multilane highway intersection types, the research team recommends using **statewide SPFs** because the number of each intersection type in each district is too few to estimate regional SPFs. District-level adjustments were considered but not found statistically valid.

Summary of SPF Recommendations

The total and fatal+injury SPFs for rural multilane highway intersections are provided in Appendix F. For brevity, a detailed interpretation of these models in not provided here. However, the same procedure used for the two-lane rural roadway segment SPFs can be applied to these models to interpret their results. A summary of the recommended total and fatal+injury SPFs for intersections on rural multilane highways are shown in Table 36 below.

Table 36. Rural Multilane Highway Intersection SPFs.

Intersection Type	Total and Fatal+Injury Safety Performance Functions
3-leg minor stop-controlled	$N_{total} = e^{-8.072} \times MajorAADT^{0.509} \times \mathrm{MinorAADT}^{0.509}$ (49) over-dispersion parameter: 0.187 $N_{fatal\_inj} = e^{-7.830} \times MajorAADT^{0.459} \times \mathrm{MinorAADT}^{0.459}$ (50) over-dispersion parameter: 0.441
4-leg minor stop-controlled	$N_{total} = e^{-4.342} \times MajorAADT^{0.334} \times \mathrm{MinorAADT}^{0.264}$ (51) over-dispersion parameter: 0.381 $N_{fatal\_inj} = e^{-3.248} \times MajorAADT^{0.217} \times \mathrm{MinorAADT}^{0.152}$ (52) over-dispersion parameter: 0.413
4-leg signalized	$N_{total} = e^{-3.563} \times MajorAADT^{0.389} \times \mathrm{MinorAADT}^{0.134}$ (53) over-dispersion parameter: 0.203 $N_{fatal\_inj} = e^{-3.301} \times MajorAADT^{0.291} \times \mathrm{MinorAADT}^{0.133}$ (54) over-dispersion parameter: 0.227
MajorAADT = average annual daily traffic on the major street (veh/day) MinorAADT = average annual daily traffic on the minor street (veh/day)	

Comparison with HSM SPFs

RMSE values were also used to compare the recommended regionalized SPFs (statewide) to the HSM SPFs for rural multilane highway intersections. Due to the small sample size of intersections of each type within each county, individual county comparisons were not very meaningful. Instead, the overall RMSE measured across all counties was used to compare the statewide and HSM SPF performance. A summary of these values are provided in Table 37. The results show that the statewide SPFs outperform the HSM SPFs for all intersection types. For 3-leg minor approach stop-controlled intersections, the average RMSE value is 18.6% smaller when applying the statewide SPFs than the HSM SPFs. For 4-leg minor approach stop-controlled intersections, the average RMSE value is 12.5% smaller when applying the statewide SPFs than the HSM SPFs. For the 4-leg signalized intersections, the average RMSE value is 62.0% smaller for the statewide SPFs than the HSM SPFs. Therefore, the Pennsylvania-specific statewide SPFs demonstrate a clear benefit in predictive power over the SPFs in the HSM for intersections on rural multilane highways.

Table 37. RMSE Comparison for Intersections on Rural Multilane Highways– Statewide and HSM SPFs.

	Statewide RMSE	HSM RMSE	Percent Improvement
3-leg minor stop-controlled	1.134	1.393	18.6%
4-leg minor stop-controlled	1.116	1.276	12.5%
4-leg signalized	1.946	5.116	62.0%

Urban-Suburban Arterial Roadway Segment SPFs

This section of the report describes the development of SPFs for urban-suburban arterial roadway segments. The remainder of this section summarizes the data available for the development of regionalized SPFs, the selection of the most appropriate regionalization level, and the final SPF recommendations.

Data Summary

The roadway inventory file for the urban-suburban arterial roadway segments was created by combining PennDOT's RMS data files with data collected by the research team using PennDOT's video photolog software and Google Earth images. These data were previously described in the Data Collection section.

The HSM breaks urban-suburban arterial segments into five forms:

- Two-lane undivided
- Four-lane undivided
- Four-lane divided
- Two-lane with center turn lanes
- Four-lane with center turn lanes

The PennDOT RMS data codes were used to identify each of these roadway forms, and are shown in Table 38. The resulting database consisted of a total of 16,780 unique roadway segments, which covered 7,075.84 miles. Because five years of crash data were available for each unique roadway segment, the database consisted of 83,900 observations after the crash and roadway inventory files were appended.

Table 38. PennDOT RMS Data Codes Used to Identify Urban-Suburban Arterial Roadway Segment Types.

Roadway Form	PennDOT Data Codes
Two-lane undivided	Number of lanes = 2 Divisor type = 0 Center turn lane presence = 0
Four-lane undivided	Number of lanes = 2 Divisor type = 1 or 4 Center turn lane presence = 0
Four-lane divided	Number of lanes = 2 Divisor type = 2, 3, 5, 7 or 8
Two-lane undivided with center turn lane	Number of lanes = 2 Divisor type = 0 Center turn lane presence = 1
Four-lane undivided with center turn lane	Number of lanes = 2 Divisor type = 1 or 4 Center turn lane presence = 1

Table 39 provides summary statistics for total crashes, fatal, injury, and PDO crashes, traffic volumes, and the roadway characteristics included in the analysis database. As shown, injury and PDO crashes are much more frequent than fatal crashes. The traffic volumes vary considerably. About 10 percent of the segments have either center turn lanes or parking lanes.

Table 39. Crash, Traffic Volume, and Site Characteristic Data Summary for Urban-Suburban Arterial Segments.

Variables	Mean	Standard Deviation	Minimum	Maximum
Total crashes per year	2.488	3.166	0	61
Total fatal crashes per year	0.019	0.140	0	2
Total injury crashes per year	1.320	1.996	0	28
Total property-damage only (PDO) crashes per year	1.110	1.602	0	35
Average annual daily traffic (veh/day)	9376	4537	165	34726
Segment length (miles)	0.428	0.161	0.002	1.663
Posted speed limit (mph)	39.301	8.063	15	65
Left paved shoulder width (feet)	2.609	3.107	0	20
Right paved shoulder width (feet)	2.675	3.176	0	22
Lane width (feet)	13.716	3.688	4.5	46
Categorical Variables	Category		Proportion	
Presence of center turn lanes	Yes		0.10	
	No		0.90	
Presence of parking lanes	Yes		0.09	
	No		0.91	
Presence of physical median barrier	Yes		0.17	
	No		0.83	

As will be discussed in the next section, SPFs were only developed for three roadway types for the urban-suburban arterials due to sample size issues. These three types were:

- Two-lane undivided arterials
- Four-lane undivided arterials
- Four-lane divided arterials

Summary statistics for each of these roadway types are provided in Table 40 to Table 42. As shown in these tables, traffic volumes are quite similar across the three roadway types. Parking is generally provided on 6-11% of the segments (based on the type) and center left turn lanes are provided on 6-14% of the segments (based on the type). Note that the presence of center turn lanes are included as an independent variable and thus incorporate into the models of 2-lane and 4-lane undivided roadway segments.

Table 40. Summary Statistics for 2-lane Undivided Urban Suburban Arterials.

Variables	Mean	Standard Deviation	Minimum	Maximum
Total Crashes Per Year	2.420	2.859	0	33
Total Fatal + Injury Crashes Per Year	1.267	1.807	0	20
Average Annual Daily Traffic (veh/fay)	9312	4705	165	31487
Segment Length (miles)	0.436	0.158	0.002	0.758
Posted Speed Limit (mph)	38	8	15	60
Left Paved Shoulder Width (feet)	2.863	2.834	0	15
Right Paved Shoulder Width (feet)	2.953	2.912	0	22
Lane Width (feet)	13.894	4.043	5.5	46
Categorical variables	Category		Proportion	
Presence Of Center Turn Lanes	Yes		0.10	
	No		0.90	
Presence Of Parking Lanes	Yes		0.11	
	No		0.89	

Table 41. Summary Statistics for 4-lane Undivided Urban Suburban Arterials.

Variables	Mean	Standard Deviation	Minimum	Maximum
Total crashes per year	3.009	4.008	0	61
Total fatal + injury crashes per year	1.735	2.612	0	28
Average annual daily traffic (veh/day)	9169	3843	300	33076
Segment length (miles)	0.408	0.166	0.007	1.117
Posted speed limit (mph)	39	7	20	65
Left paved shoulder width (feet)	1.227	2.698	0	14
Right paved shoulder width (feet)	1.263	2.804	0	18
Lane width (feet)	13.631	3.197	5.5	35
Categorical Variables	Category		Proportion	
Presence of center turn lanes	Yes		0.14	
	No		0.86	
Presence of parking lanes	Yes		0.09	
	No		0.91	

Table 42. Summary Statistics for 4-lane Divided Urban Suburban Arterial.

Variables	Mean	Standard Deviation	Minimum	Maximum
Total crashes per year	2.232	3.161	0	36
Total fatal + injury crashes per year	1.207	1.947	0	21
Average annual daily traffic (veh/day)	9758	4565	800	34726
Segment length (miles)	0.422	0.164	0.020	1.663
Posted speed limit (mph)	44	8	25	55
Left paved shoulder width (feet)	3.065	3.828	0	20
Right paved shoulder width (feet)	3.083	3.853	0	15
Lane width (feet)	13.244	2.805	4.5	31.5
Categorical Variables	Category		Proportion	
Presence of center turn lanes	Yes		0.06	
	No		0.94	
Presence of parking lanes	Yes		0.04	
	No		0.96	
Presence of physical median barrier	Yes		0.83	
	No		0.17	

Regionalization of SPFs

Table 43 shows the urban-suburban highway segment mileage for all 67 counties in the Commonwealth broken into the five roadway forms provided in the HSM. Of the five roadway forms, the two-lane undivided with center turn lanes and four-lane undivided with center turn lane types have the lowest mileage within Pennsylvania. Estimating SPFs for these roadway types at a regional level is not feasible. Although there are some counties with significant mileage of two-lane undivided, four-lane undivided and four-lane divided urban-suburban arterial segments, most counties do not have the minimum roadway mileage to estimate county-level SPFs for each of the other three roadway types. In fact, several counties (Bedford, Cameron, Fulton, Pike and Potter) have no urban-suburban arterials, while many others have very few miles of any urban-suburban arterial type.

Table 44 provides the segment mileage within each engineering district among the five urban-suburban arterial roadway forms. Again, separate SFPs for two-lane undivided with center turn lanes and four-lane undivided with center turn lanes are generally not feasible at the district-level. However, there is sufficient mileage within each engineering district to estimate district-level SPFs for two-lane undivided roadways at the district level. For four-lane undivided roadways, districts 2, 3, 9, 10 and 12 do not have the required 50 miles necessary to estimate district-level SPFs. For four-lane divided roadways, districts 2, 3 and 9 do not have the required 50 miles necessary to estimate district-level SPFs.

Table 43. Urban-Suburban Arterial County Segment Mileage.

County	Name	Two-lane undivided	Four-lane undivided	Four-lane divided	Two-lane undivided with center turn lane	Four-lane undivided with center turn lane
1	ADAMS	39	0.2	0.3	4	0
2	ALLEGHENY	398	172	161	17	10
3	ARMSTRONG	39	0	11	5	0
4	BEAVER	105	16	65	0.4	0
5	BEDFORD	0	0	0	0	0
6	BERKS	98	25	47	1	0
7	BLAIR	39	10	30	10	3
8	BRADFORD	12	0	0	2	0
9	BUCKS	296	95	80	48	32
10	BUTLER	66	23	14	9	5
11	CAMBRIA	78	8	13	4	2
12	CAMERON	0	0	0	0	0
13	CARBON	12	0	10	0	0
14	CENTRE	42	15	10	17	7
15	CHESTER	223	30	61	19	6
16	CLARION	10	0	1	1	0
17	CLEARFIELD	31	2	1	18	0
18	CLINTON	7	1	1	2	0
19	COLUMBIA	28	1	5	10	0
20	CRAWFORD	30	4	12	0	2
21	CUMBERLAND	79	13	17	13	6
22	DAUPHIN	84	30	47	20	9
23	DELAWARE	158	86	74	10	13
24	ELK	5	4	0	1	2
25	ERIE	93	62	28	4	9
26	FAYETTE	42	12	33	2	2
27	FOREST	0	0	0	0	0
28	FRANKLIN	44	6	1	14	0.4
29	FULTON	0	0	0	0	0
30	GREENE	6	0	4	0	0
31	HUNTINGDON	7	0	1	2	0
32	INDIANA	16	3	32	3	2
33	JEFFERSON	11	0	0	2	0
34	JUNIATA	0	0	0	0	0
35	LACKAWANNA	99	21	20	9	4
36	LANCASTER	196	19	15	36	9
37	LAWRENCE	28	5	5	3	0
38	LEBANON	33	3	1	11	0
39	LEHIGH	100	22	43	0	0
40	LUZERNE	130	68	36	9	7
41	LYCOMING	60	15	17	8	0
42	MCKEAN	5	0	0	1	0
43	MERCER	56	15	12	2	6
44	MIFFLIN	23	1	0.4	7	1
45	MONROE	48	2	9	0	0
46	MONTGOMERY	334	106	46	32	9
47	MONTOUR	8	1	1	5	0
48	NORTHAMPTON	105	9	9	0	0
49	NORTHUMBERLAND	35	12	3	3	0.4
50	PERRY	8	0	0	5	0
51	PIKE	0	0	0	0	0
52	POTTER	0	0	0	0	0

County	Name	Two-lane undivided	Four-lane undivided	Four-lane divided	Two-lane undivided with center turn lane	Four-lane undivided with center turn lane
53	SCHUYLKILL	52	4	23	0	0
54	SNYDER	8	4	4	0	1
55	SOMERSET	19	0	5	3	0
56	SULLIVAN	0	0	0	0	0
57	SUSQUEHANNA	2	0	0	0	0
58	TIOGA	0	0	0	0	0
59	UNION	6	5	9	1	2
60	VENANGO	23	5	9	4	0
61	WARREN	25	0	12	1	0
62	WASHINGTON	123	13	23	2	1
63	WAYNE	11	0	0	3	0
64	WESTMORELAND	162	24	106	5	3
65	WYOMING	0	0	2	0	0
66	YORK	146	11	22	17	1
67	PHILADELPHIA	111	118	86	11	16
Total		4049	1103	1276	418	170

Table 44. Urban-Suburban Arterial District Segment Mileage.

District	Two-lane undivided	Four-lane undivided	Four-lane divided	Two-lane undivided with center turn lane	Four-lane undivided with center turn lane
1	227	87	72	12	16
2	113	24	12	46	9
3	157	37	40	28	4
4	242	89	58	21	11
5	415	63	142	1	0
6	1120	435	347	120	76
8	629	82	103	121	25
9	142	19	49	19	5
10	141	25	57	20	7
11	530	194	231	21	10
12	333	49	165	10	6
Total	4049	1103	1276	418	170

Based on these data, SPFs were only developed for 2-lane undivided roads, 4-lane undivided roads and 4-lane divided roads. The presence of center two-way left-turn lanes were incorporated within the SPFs for 2-lane undivided roads and 4-lane undivided roads as an indicator variable. Therefore, crash frequency estimates can be obtained for the 3-lane undivided roads with a center two-way left-turn lane and 5-lane undivided roads with a center two-way left-turn lane roadway types using the 2-lane undivided road and 4-lane undivided road SPFs, respectively.

Based on the regionalization process and amount of available data for each roadway type, the research team recommends using **district-level SPFs with county-specific adjustments** for the two-lane undivided roadway type and **statewide SPFs with**

district-specific adjustments for the four-lane undivided and four-lane divided roadway types.

Summary of SPF Recommendations

In the HSM, SPFs for urban-suburban arterial segments are provided based on the following collision types:

- Single-vehicle collisions
- Multiple-vehicle non-driveway collisions
- Multiple-vehicle driveway-related collisions

The expected crash frequency for each of these roadway types is then summed to determine the total crash frequency on urban-suburban arterial segments. Using the data available from PennDOT's crash data files, it was not possible to develop different collision type SPFs in the same way as the HSM. Instead, the research team created a single SPF that estimates the frequency of all three collision types combined. These SPFs are easier to use, since only one equation is required.

The total and fatal+injury SPFs for each urban-suburban arterial segment type are provided in Appendix G. For brevity, a detailed interpretation of these models is not provided here. However, the same procedure used for the two-lane rural roadway segment SPFs can be applied to these models to interpret their results. Table 45 provides the district-level SPFs for two-lane undivided urban-suburban arterials, while Table 46 provides the county-specific adjustments for this roadway type.

Table 45. District SPFs for Two-lane Undivided Urban-Suburban Arterial Segments.

District 1:

$$N_{total} = e^{-6.000} \times L \times AADT^{0.854} \times e^{-0.230\times \text{PSL35}} \times e^{-0.478\times \text{PSL40}} \times e^{-0.634\times \text{PSL45\_65}} \quad (55)$$

over-dispersion parameter: 0.420

$$N_{fatal\_inj} = e^{-6.825} \times L \times AADT^{0.883} \times e^{-0.332\times \text{PSL35}} \times e^{-0.545\times \text{PSL40}} \times e^{-0.660\times \text{PSL45\_65}} \quad (56)$$

over-dispersion parameter: 0.438

District 2:

$$N_{total} = e^{-5.621} \times L \times AADT^{0.807} \times e^{-0.606\times \text{PSL40\_65}} \times e^{0.230\times \text{CTL}} \quad (57)$$

over-dispersion parameter: 0.359

$$N_{fatal\_inj} = e^{-7.520} \times L \times AADT^{0.943} \times e^{-0.610\times \text{PSL40\_65}} \times e^{0.115\times \text{CTL}} \quad (58)$$

over-dispersion parameter: 0.282

District 3:

$$N_{total} = e^{-6.321} \times L \times AADT^{0.884} \times e^{-0.529\times \text{PSL40\_65}} \quad (59)$$

over-dispersion parameter: 0.513

$$N_{fatal\_inj} = e^{-7.321} \times L \times AADT^{0.920} \times e^{-0.476\times \text{PSL40\_65}} \quad (60)$$

over-dispersion parameter: 0.514

District 4:

$$N_{total} = e^{-7.089} \times L \times AADT^{1.015} \times e^{-0.493\times \text{PSL35}} \times e^{-0.801\times \text{PSL40\_65}} \quad (61)$$

over-dispersion parameter: 0.402

$$N_{fatal\_inj} = e^{-8.713} \times L \times AADT^{1.124} \times e^{-0.500\times \text{PSL35}} \times e^{-0.823\times \text{PSL40\_65}} \quad (62)$$

over-dispersion parameter: 0.440

District 5:

$$N_{total} = e^{-6.162} \times L \times AADT^{0.900} \times e^{-0.407\times \text{PSL35}} \times e^{-0.515\times \text{PSL40}} \times e^{-0.877\times \text{PSL45\_65}} \times e^{0.156\times \text{Parking\_Lane}} \quad (63)$$

over-dispersion parameter: 0.340

$$N_{fatal\_inj} = e^{-7.170} \times L \times AADT^{0.943} \times e^{-0.403\times \text{PSL35}} \times e^{-0.491\times \text{PSL40}} \times e^{-0.863\times \text{PSL45\_65}} \times e^{0.082\times \text{Parking\_Lane}} \quad (64)$$

over-dispersion parameter: 0.393

District 6:

$$N_{total} = e^{-5.004} \times L \times AADT^{0.774} \times e^{-0.247\times\mathrm{PSL35}} \times e^{-0.376\times\mathrm{PSL40}} \times e^{-0.474\times\mathrm{PSL45\_65}} \times e^{0.180\times\mathrm{CTL}} \times e^{0.183\times\mathrm{Parking\_Lane}} \quad (65)$$

over-dispersion parameter: 0.364

$$N_{fatal\_inj} = e^{-5.773} \times L \times AADT^{0.787} \times e^{-0.261\times\mathrm{PSL35}} \times e^{-0.445\times\mathrm{PSL40}} \times e^{-0.550\times\mathrm{PSL45\_65}} \times e^{0.242\times\mathrm{CTL}} \times e^{0.257\times\mathrm{Parking\_Lane}} \quad (66)$$

over-dispersion parameter: 0.393

District 8:

$$N_{total} = e^{-5.872} \times L \times AADT^{0.846} \times e^{-0.140\times\mathrm{PSL35}} \times e^{-0.295\times\mathrm{PSL40}} \times e^{-0.572\times\mathrm{PSL45_{65}}} \times e^{0.163\times\mathrm{CTL}} \times e^{0.326\times\mathrm{Parking\_Lane}} \quad (67)$$

over-dispersion parameter: 0.369

$$N_{fatal\_inj} = e^{-6.902} \times L \times AADT^{0.885} \times e^{-0.169\times\mathrm{PSL35}} \times e^{-0.299\times\mathrm{PSL40}} \times e^{-0.588\times\mathrm{PSL45\_65}} \times e^{0.243\times\mathrm{CTL}} \times e^{0.326\times\mathrm{Parking\_Lane}} \quad (68)$$

over-dispersion parameter: 0.435

District 9:

$$N_{total} = e^{-5.290} \times L \times AADT^{0.791} \times e^{-0.332\times\mathrm{PSL35}} \times e^{-0.741\times\mathrm{PSL40\_65}} \quad (69)$$

over-dispersion parameter: 0.266

$$N_{fatal\_inj} = e^{-6.828} \times L \times AADT^{0.876} \times e^{-0.188\times\mathrm{PSL35}} \times e^{-0.570\times\mathrm{PSL40\_65}} \quad (70)$$

over-dispersion parameter: 0.349

District 10:

$$N_{total} = e^{-6.679} \times L \times AADT^{0.936} \times e^{-0.328\times\mathrm{PSL40\_65}} \quad (71)$$

over-dispersion parameter: 0.503

$$N_{fatal\_inj} = e^{-6.915} \times L \times AADT^{0.889} \times e^{-0.343\times\mathrm{PSL40\_65}} \quad (72)$$

over-dispersion parameter: 0.581

District 11:
$$N_{total} = e^{-6.289} \times L \times AADT^{0.892} \times e^{-0.229\times \text{PSL35}} \times e^{-0.408\times \text{PSL40}} \times e^{-0.564\times \text{PSL45\_65}} \times e^{0.307\times \text{Parking\_Lane}} \quad (73)$$ over-dispersion parameter: 0.562 $$N_{fatal\_inj} = e^{-7.343} \times L \times AADT^{0.930} \times e^{-0.249\times \text{PSL35}} \times e^{-0.415\times \text{PSL40}} \times e^{-0.557\times \text{PSL45\_65}} \times e^{0.271\times \text{Parking\_Lane}} \quad (74)$$ over-dispersion parameter: 0.551
District 12: $$N_{total} = e^{-6.212} \times L \times AADT^{0.886} \times e^{-0.206\times \text{PSL35}} \times e^{-0.328\times \text{PSL40\_65}} \quad (75)$$ over-dispersion parameter: 0.424 $$N_{total} = e^{-6.293} \times L \times AADT^{0.827} \times e^{-0.173\times \text{PSL35}} \times e^{-0.354\times \text{PSL40\_65}} \quad (76)$$ over-dispersion parameter: 0.444
L = segment length (miles) AADT = average annual daily traffic (veh/day) PSL35 = indicator variable for speed limits of 35 mph (1 = speed limit of 35 mph; 0 otherwise) PSL40 = indicator variable for speed limits of 40 mph (1 = speed limit of 40 mph; 0 otherwise) PSL45_65 = indicator variable for speed limits of 45 to 65 mph (1 = speed limit of 45 to 65 mph; 0 otherwise) PSL40_65 = indicator variable for speed limits of 40 to 65 mph (1 = speed limit of 45 to 65 mph; 0 otherwise) CTL = indicator variable for presence of center two-lane left-turn lane (1 = present; 0 otherwise) Parking_Lane = indicator variable for presence of parking lane (1 = present; 0 otherwise)

Table 46. County Adjustments for Two-lane Undivided Urban-suburban Arterial Segments.

District	SPF	County	County-specific adjustments for total crash SPF	County-specific adjustments for fatal + injury SPF
1	Equations (55, 56)	Crawford (20), Forest (27), Warren (61)	No modification necessary	No modification necessary
		Erie (25)	Multiply estimate by 1.27	Multiply estimate by 1.22
		Mercer (43)	Multiply estimate by 1.30	Multiply estimate by 1.30
		Venango (60)	Multiply estimate by 1.13	No modification necessary
2	Equations (57, 58)	Cameron (12), Center (14), Clinton (18), Elk (24), Juniata (34), Mckean (42), Mifflin (44), Potter (52)	No modification necessary	No modification necessary
		Clearfield (17)	Multiply estimate by 0.73	Multiply estimate by 0.79

District	SPF	County	County-specific adjustments for total crash SPF	County-specific adjustments for fatal + injury SPF
3	Equations (59, 60)	Bradford (8), Montour (47), Snyder (54), Sullivan (56), Tioga (58), Union (59)	No modification necessary	No modification necessary
		Columbia (19)	Multiply estimate by 1.13	No modification necessary
		Lycoming (41)	Multiply estimate by 1.23	Multiply estimate by 1.15
		Northumberland (49)	Multiply estimate by 0.87	Multiply estimate by 0.84
4	Equations (61, 62)	Lackawanna (35), Luzerne (40), Pike (51), Susquehanna (57), Wayne (63), Wyoming (65)	No modification necessary	No modification necessary
5	Equations (63, 64)	Carbon (13), Schuylkill (53)	No modification necessary	No modification necessary
		Berks (6), Northampton (48)	Multiply estimate by 1.43	Multiply estimate by 1.34
		Lehigh (39)	Multiply estimate by 1.59	Multiply estimate by 1.50
		Monroe (45)	Multiply estimate by 1.33	Multiply estimate by 1.30
6	Equations (65, 66)	Bucks (9)	Multiply estimate by 0.90	Multiply estimate by 0.86
		Chester (15)	Multiply estimate by 0.84	Multiply estimate by 0.73
		Delaware (23),	Multiply estimate by 1.06	Multiply estimate by 1.13
		Montgomery (46)	No modification necessary	No modification necessary
		Philadelphia (67)	Multiply estimate by 1.36	Multiply estimate by 1.99
8	Equations (67, 68)	Dauphin (22), Franklin (28), Perry (50), Lebanon (38)	No modification necessary	No modification necessary
		Adams (1)	Multiply estimate by 0.84	Multiply estimate by 0.78
		Cumberland (21)	Multiply estimate by 1.13	No modification necessary
		Lancaster (36)	Multiply estimate by 1.09	Multiply estimate by 1.07
		York (66)	Multiply estimate by 1.16	Multiply estimate by 1.15
9	Equations (69, 70)	Bedford (5), Cambria (11), Fulton (29), Huntingdon (31), Somerset (55)	No modification necessary	No modification necessary
		Blair (7)	Multiply estimate by 1.12	No modification necessary
10	Equations (71, 72)	Butler (10), Clarion (16), Indiana (32), Jefferson (33)	No modification necessary	No modification necessary
		Armstrong (3)	Multiply estimate by 0.70	Multiply estimate by 0.64
11	Equations (73, 74)	Allegheny (2), Lawrence (37)	No modification necessary	No modification necessary
		Beaver (4)	Multiply estimate by 0.84	Multiply estimate by 0.80
12	Equations (75, 76)	Fayette (26), Greene (30)	No modification necessary	No modification necessary
		Washington (62)	Multiply estimate by 0.84	Multiply estimate by 0.76
		Westmoreland (64)	Multiply estimate by 0.90	Multiply estimate by 0.82

On four-lane undivided urban-suburban arterial segments, statewide SPFs with district-level adjustments are recommended. The statewide models are shown in Table 47, with district adjustment factors provided in Table 48.

Table 47. Four-lane Undivided Urban-suburban Arterial SPFs.

$$N_{total} = e^{-3.487} \times L \times AADT^{0.645} \times e^{-0.262\times \text{PSL35}} \times e^{-0.555\times \text{PSL40}} \times e^{-0.804\times \text{PSL45\_65}} \times e^{0.388\times \text{CTL}} \quad (77)$$

over-dispersion parameter: 0.911

$$N_{fatal\_inj} = e^{-3.909} \times L \times AADT^{0.651} \times e^{-0.482\times \text{PSL35}} \times e^{-0.826\times \text{PSL40}} \times e^{-1.095\times \text{PSL45\_65}} \times e^{0.440\times \text{CTL}} \quad (78)$$

over-dispersion parameter: 0.991

L = segment length (miles)
AADT = average annual daily traffic (veh/day)
PSL35 = indicator variable for speed limits of 35 mph (1 = speed limit of 35 mph; 0 otherwise)
PSL40 = indicator variable for speed limits of 40 mph (1 = speed limit of 40 mph; 0 otherwise)
PSL45_65 = indicator variable for speed limits of 45 to 65 mph (1 = speed limit of 45 to 65 mph; 0 otherwise)
PSL40_65 = indicator variable for speed limits of 40 to 65 mph (1 = speed limit of 45 to 65 mph; 0 otherwise)
CTL = indicator variable for presence of center two-lane left-turn lane (1 = present; 0 otherwise)
Parking_Lane = indicator variable for presence of parking lane (1 = present; 0 otherwise)

Table 48. Four-lane Undivided Urban-suburban Arterial District Modification Factors.

District	District-specific adjustments for total crash SPF	District-specific adjustments for fatal + injury SPF
1	Multiply estimate by 0.86	Multiply estimate by 0.90
2	Multiply estimate by 0.73	Multiply estimate by 0.64
3	Multiply estimate by 0.80	Multiply estimate by 0.76
4	No modification necessary	No modification necessary
5	Multiply estimate by 1.42	Multiply estimate by 1.39
6	No modification necessary	No modification necessary
8	Multiply estimate by 1.11	Multiply estimate by 1.07
9	Multiply estimate by 0.73	Multiply estimate by 0.64
10	Multiply estimate by 0.57	Multiply estimate by 0.55
11	No modification necessary	No modification necessary
12	No modification necessary	No modification necessary

On four-lane divided urban-suburban arterial segments, statewide SPFs with district-level adjustments are recommended. The statewide models are shown in Table 49, with district adjustment factors provided in Table 50.

Table 49. Four-lane Divided Urban-suburban Arterial SPFs.

$$N_{total} = e^{-5.044} \times L \times AADT^{0.747} \times e^{-0.126\times\text{PSL35}} \times e^{-0.283\times\text{PSL40}} \times e^{-0.479\times\text{PSL45}} \times e^{-0.912\times\text{PSL50\_65}} \times e^{0.155\times\text{barrier}} \times e^{0.501\times\text{CTL}} \quad (79)$$

over-dispersion parameter: 0.994

$$N_{fatal\_inj} = e^{-5.344} \times L \times AADT^{0.732} \times e^{-0.275\times\text{PSL35}} \times e^{-0.446\times\text{PSL40}} \times e^{-0.722\times\text{PSL45}} \times e^{-1.172\times\text{PSL50\_65}} \times e^{0.129\times\text{barrier}} \times e^{0.544\times\text{CTL}} \quad (80)$$

over-dispersion parameter: 1.120

L = segment length (miles)
AADT = average annual daily traffic (veh/day)
PSL35 = indicator variable for speed limits of 35 mph (1 = speed limit of 35 mph; 0 otherwise)
PSL40 = indicator variable for speed limits of 40 mph (1 = speed limit of 40 mph; 0 otherwise)
PSL45 = indicator variable for speed limits of 45 mph (1 = speed limit of 45 mph; 0 otherwise)
PSL50_65 = indicator variable for speed limits of 50 to 65 mph (1 = speed limit of 50 to 65 mph; 0 otherwise)
CTL = indicator variable for presence of center two-lane left-turn lane (1 = present; 0 otherwise)
Barrier = indicator variable for presence of median barrier (1 = present; 0 otherwise)

Table 50. Four-lane Divided Urban-suburban Arterial District Modification Factors.

District	District-specific adjustment for total crash SPF	District-specific adjustment for fatal + injury SPF
1	No modification necessary	No modification necessary
2	No modification necessary	No modification necessary
3	Multiply estimate by 0.87	Multiply estimate by 0.81
4	Multiply estimate by 1.29	Multiply estimate by 1.27
5	Multiply estimate by 1.65	Multiply estimate by 1.74
6	Multiply estimate by 1.17	Multiply estimate by 1.25
8	Multiply estimate by 1.33	Multiply estimate by 1.25
9	No modification necessary	No modification necessary
10	No modification necessary	No modification necessary
11	Multiply estimate by 1.05	No modification necessary
12	No modification necessary	No modification necessary

Comparison with HSM SPFs

RMSE values were also used to compare the recommended regionalized SPFs (statewide) to the HSM SPFs for urban-suburban arterial segments. Crash frequency predictions were computed using the proposed regionalized SPFs and the HSM SPFs for each of the following roadway types:

- Two-lane undivided
- Two-lane with center turn lanes
- Four-lane undivided
- Four-lane divided
- Four-lane with center turn lanes

The two-lane undivided regionalized SPF was applied to two-lane arterials with center turn lanes; in this case, an indicator variable was used to consider the impacts of the center turn lanes. A similar procedure was repeated for four-lane arterials with center turn lanes. The RMSE summaries are presented in Table 51 to Table 55. As shown, the regionalized SPFs outperform the HSM SPFs in all cases. For two-lane undivided arterials, the regionalized SPFs show better performance in 56 of the 57 counties with this roadway type and a 22.3% improvement on the average RMSE value measured across all counties. For two-lane undivided arterials with center turn lanes, the regionalized SPFs show better performance in 42 of the 49 counties with this roadway type and an overall improvement of 20.1% on the average RMSE value measured across all counties. The regionalized SPFs perform better for 34 of 45 counties and demonstrate an overall RMSE improvement of 13.8% on average for 4-lane undivided urban-suburban arterials. The regionalized SPFs also perform better than the HSM SPFs for 43 of 52 counties, with an average RMSE improvement of 13.0% overall, for 4-lane divided urban-suburban arterials. Finally, for two-lane arterials with center turn lanes, the regionalized SPFs outperform the HSM SPFs for 21 of 29 counties, with an overall RMSE improvement of 18.5% across the entire state. Therefore, the Pennsylvania-specific regionalized SPFs demonstrate a clear benefit in predictive power over the HSM SPF for urban-suburban arterial segments.

Table 51. RMSE Comparison for Total Crash Frequency on 2-Lane Undivided Urban-Suburban Arterials – District-Level and HSM SPFs.

County	SPF Prediction RMSE		Percent Improvement	County	SPF Prediction RMSE		Percent Improvement
	District	HSM			District	HSM	
1	1.771	2.238	20.9%	35	2.571	3.584	28.3%
2	2.28	2.697	15.5%	36	2.253	2.741	17.8%
3	0.985	1.082	9.0%	37	2.162	2.665	18.9%
4	1.640	1.838	10.8%	38	2.153	3.009	28.4%
6	3.106	4.265	27.2%	39	3.428	4.852	29.3%
7	1.549	1.861	16.8%	40	2.065	2.778	25.7%
8	1.494	1.779	16.0%	41	1.651	1.917	13.9%
9	2.099	2.473	15.1%	42	1.106	1.344	17.7%
10	2.005	2.345	14.5%	43	1.507	1.87	19.4%
11	1.427	1.813	21.3%	44	1.035	1.114	7.1%
13	2.094	2.387	12.3%	45	2.686	3.56	24.6%
14	1.834	2.086	12.1%	46	2.553	3.136	18.6%
15	2.186	2.556	14.5%	47	2.139	2.78	23.1%
16	1.783	2.094	14.9%	48	2.601	3.502	25.7%
17	1.160	1.289	10.0%	49	1.410	1.607	12.3%
18	1.259	1.751	28.1%	50	1.968	0.949	-107.4%
19	2.226	2.864	22.3%	53	1.698	2.087	18.6%
20	1.199	1.43	16.2%	54	1.300	1.511	14.0%
21	2.313	3.071	24.7%	55	1.437	1.725	16.7%
22	2.453	2.935	16.4%	57	1.363	1.754	22.3%
23	2.822	3.874	27.2%	59	1.247	1.543	19.2%
24	1.336	1.47	9.1%	60	1.539	1.787	13.9%
25	2.298	2.838	19.0%	61	1.352	1.477	8.5%
26	1.413	1.792	21.1%	62	1.476	1.716	14.0%
28	2.170	3.027	28.3%	63	1.455	1.726	15.7%
30	1.279	1.465	12.7%	64	1.709	1.938	11.8%
31	0.928	1.11	16.4%	66	2.563	3.393	24.5%
32	2.273	2.887	21.3%	67	3.744	5.778	35.2%
33	1.221	1.381	11.6%	Average	2.263	2.912	22.3%

Table 52. RMSE Comparison for Total Crash Frequency on 2-Lane Urban-Suburban Arterials With Center Turn Lanes – District-Level and HSM SPFs.

County	SPF Prediction RMSE		Percent Improvement	County	SPF Prediction RMSE		Percent Improvement
	District	HSM			District	HSM	
1	2.209	2.380	7.2%	32	2.743	3.605	23.9%
2	3.576	4.189	14.6%	33	1.908	1.946	2.0%
3	1.191	1.319	9.7%	35	2.361	3.172	25.6%
4	1.644	1.809	9.1%	36	4.261	5.455	21.9%
6	1.158	0.384	-201.6%	37	2.008	2.632	23.7%
7	1.702	2.062	17.5%	38	2.878	3.600	20.1%
8	2.100	1.503	-39.7%	40	3.071	3.639	15.6%
9	3.193	4.005	20.3%	41	2.136	2.265	5.7%
10	3.391	3.970	14.6%	42	2.257	1.168	-93.2%
11	2.163	2.917	25.8%	43	1.608	2.096	23.3%
14	1.901	2.111	9.9%	44	1.698	2.427	30.0%
15	2.492	2.640	5.6%	46	3.040	3.901	22.1%
16	3.037	3.800	20.1%	47	2.445	2.734	10.6%
17	1.701	2.071	17.9%	49	1.580	1.701	7.1%
18	2.283	3.788	39.7%	50	2.098	1.403	-49.5%
19	2.194	2.029	-8.1%	55	1.781	1.878	5.2%
21	3.803	4.683	18.8%	59	1.353	2.572	47.4%
22	3.144	4.071	22.8%	60	1.225	1.181	-3.7%
23	3.617	4.926	26.6%	61	1.238	1.412	12.3%
24	1.930	2.360	18.2%	62	3.773	4.906	23.1%
25	2.325	2.767	16.0%	63	3.150	3.281	4.0%
26	2.915	3.499	16.7%	64	3.916	4.835	19.0%
28	2.292	2.698	15.0%	66	2.540	2.926	13.2%
30	1.178	0.881	-33.7%	67	5.062	7.550	33.0%
31	1.685	1.936	13.0%	Average	2.967	3.716	20.2%

Table 53. RMSE Comparison for Total Crash Frequency on 4-Lane Undivided Urban-Suburban Arterials – Statewide and HSM SPFs.

County	SPF Prediction RMSE		Percent Improvement	County	SPF Prediction RMSE		Percent Improvement
	Statewide	HSM			Statewide	HSM	
1	1.015	1.129	10.1%	35	2.779	3.677	24.4%
2	4.296	4.829	11.0%	36	6.080	7.127	14.7%
4	1.775	1.599	-11.0%	37	1.516	1.845	17.8%
6	3.721	4.385	15.1%	38	2.296	2.599	11.7%
7	1.414	1.397	-1.2%	39	5.371	6.416	16.3%
8	1.994	2.099	5.0%	40	3.115	3.617	13.9%
9	3.448	3.700	6.8%	41	2.744	3.282	16.4%
10	1.704	1.775	4.0%	43	1.875	2.039	8.0%
11	2.226	2.505	11.1%	44	0.691	0.183	-277.6%
14	2.271	2.424	6.3%	45	2.074	2.779	25.4%
15	2.579	2.315	-11.4%	46	3.370	3.796	11.2%
17	1.939	2.388	18.8%	47	0.600	0.723	17.0%
18	0.837	0.875	4.3%	48	4.679	5.416	13.6%
19	1.839	2.192	16.1%	49	1.247	0.977	-27.6%
20	1.096	1.242	11.8%	53	2.814	3.614	22.1%
21	2.268	2.787	18.6%	54	1.690	1.650	-2.4%
22	2.963	3.061	3.2%	59	1.826	0.832	-119.5%
23	4.174	5.219	20.0%	60	2.063	2.277	9.4%
24	1.911	1.271	-50.4%	62	2.733	2.962	7.7%
25	2.423	2.811	13.8%	64	2.285	2.722	16.1%
26	1.636	1.440	-13.6%	66	3.898	4.938	21.1%
28	3.693	4.376	15.6%	67	4.689	5.711	17.9%
32	1.103	1.297	15.0%	Average	3.589	4.167	13.9%

Table 54. RMSE Comparison for Total Crash Frequency on 4-Lane Divided Urban-Suburban Arterials– Statewide and HSM SPFs.

County	SPF Prediction RMSE		Percent Improvement	County	SPF Prediction RMSE		Percent Improvement
	Statewide	HSM			Statewide	HSM	
1	1.069	1.166	8.3%	32	1.557	1.590	2.1%
2	2.989	3.486	14.3%	35	2.836	3.231	12.2%
3	0.880	0.749	-17.5%	36	3.354	3.736	10.2%
4	1.834	1.834	0.0%	37	2.081	2.498	16.7%
6	2.933	3.466	15.4%	38	1.791	2.005	10.7%
7	2.502	3.146	20.5%	39	4.130	4.938	16.4%
9	3.657	4.805	23.9%	40	2.972	3.246	8.4%
10	3.454	4.398	21.5%	41	1.412	1.601	11.8%
11	2.053	2.552	19.6%	43	1.944	2.151	9.6%
13	2.237	2.290	2.3%	44	0.817	0.403	-102.7%
14	2.452	2.963	17.2%	45	2.956	4.093	27.8%
15	2.545	2.791	8.8%	46	3.625	4.301	15.7%
16	1.052	1.236	14.9%	47	1.494	1.605	6.9%
17	0.712	0.709	-0.4%	48	3.709	4.529	18.1%
18	1.640	2.210	25.8%	49	1.243	1.328	6.4%
19	1.374	1.497	8.2%	53	2.088	1.825	-14.4%
20	1.777	1.800	1.3%	54	2.266	2.658	14.7%
21	3.684	3.868	4.8%	55	1.556	1.624	4.2%
22	2.857	3.247	12.0%	59	1.678	1.831	8.4%
23	3.515	3.924	10.4%	60	1.425	1.387	-2.7%
24	1.160	1.295	10.4%	61	1.272	1.034	-23.0%
25	3.586	4.203	14.7%	62	1.507	1.585	4.9%
26	1.710	2.019	15.3%	64	1.963	2.131	7.9%
28	2.127	2.835	25.0%	65	1.757	2.328	24.5%
30	2.512	3.076	18.3%	66	3.897	4.934	21.0%
31	0.768	0.654	-17.4%	67	4.010	3.929	-2.1%
				Average	2.920	3.356	13.0%

Table 55. RMSE Comparison for Total Crash Frequency on 4-Lane Urban-Suburban Arterials With Center Turn Lanes– Statewide and HSM SPFs.

County	SPF Prediction RMSE		Percent Improvement	County	SPF Prediction RMSE		Percent Improvement
	Statewide	HSM			Statewide	HSM	
2	3.628	4.807	24.5%	32	2.072	1.089	-90.3%
7	2.295	2.622	12.5%	35	3.085	4.145	25.6%
9	4.653	5.357	13.1%	36	4.708	4.814	2.2%
10	2.701	2.613	-3.4%	40	3.554	4.736	25.0%
11	3.148	3.990	21.1%	43	3.523	4.705	25.1%
14	3.530	4.636	23.9%	44	0.860	0.464	-85.3%
15	2.971	4.227	29.7%	46	3.912	4.442	11.9%
20	2.459	2.606	5.6%	49	0.736	0.491	-49.9%
21	4.696	5.541	15.2%	54	3.194	3.851	17.1%
22	3.691	3.210	-15.0%	59	1.944	2.356	17.5%
23	3.135	3.969	21.0%	62	3.581	6.942	48.4%
24	2.046	2.774	26.2%	64	3.072	4.646	33.9%
25	3.126	3.802	17.8%	66	3.616	2.394	-51.0%
26	3.495	1.016	-244.0%	67	4.814	7.092	32.1%
28	2.056	1.328	-54.8%	Average	3.825	4.693	18.5%

Urban-Suburban Arterial Intersection SPFs

This section describes the development of SPFs for urban-suburban arterial intersections. The remainder of this section summarizes the data available for the development of regionalized SPFs, the selection of the most appropriate regionalization level, and the final SPF recommendations.

Data Summary

Roadway inventory files for urban-suburban arterial intersections were created by combining PennDOT's RMS data files with data collected by the research team using PennDOT's video photolog software and Google Earth images. These data were previously described in the Data Collection section. A total of 4,472 unique intersections were identified in the data analysis file. The distribution of these intersections based on their type was:

- 2,117 4-leg intersections with signal control
- 396 4-leg intersections with minor-street stop control
- 46 4-leg intersections with all-way stop control
- 651 3-leg intersection with signal control
- 1,262 3-leg intersections with minor-street stop control

Because five years of crash data were available for each intersection (2010 to 2014), the analysis database consisted of 22,360 observations, after appending the roadway inventory and crash data files. Table 56 provides summary statistics for total crashes and fatal + injury crashes for each intersection type in the analysis database. As expected, the total crash frequency is higher than the fatal + injury crash frequency. The signalized intersection forms have the highest frequency of fatal + injury crashes.

Table 56. Summary Statistics for Total and Fatal + Injury Crash Frequencies by Intersection Type for Urban-Suburban Arterial Intersections

Intersection Type	Number of observations	Mean	Standard Deviation	Minimum	Maximum
Total crash frequency					
4-leg, signalized	10585	3.190	3.036	0	54
3-leg, signalized	3255	2.159	2.186	0	22
4-leg, all-way stop	230	1.204	1.429	0	6
4-leg, two-way stop	1980	1.308	1.547	0	10
3-leg, two-way stop	6310	1.007	1.348	0	13
ALL	22360	2.237		0	54
Fatal + Injury crash frequency					
4-leg, signalized	10585	1.816	2.036	0	27
3-leg, signalized	3255	1.167	1.406	0	10
4-leg, all-way stop	230	0.522	0.855	0	5
4-leg, two-way stop	1980	0.663	0.981	0	7
3-leg, two-way stop	6310	0.523	0.881	0	10
ALL	22360	1.241		0	27

Table 57 to Table 61 present summary statistics for the independent variables considered in the SPF development for the five intersection forms included in the analysis. The signalized intersections have the highest traffic volumes. The paved width includes the through lanes, turning lanes, and paved shoulder widths on each of the major and minor street approaches; therefore, these widths vary widely within each intersection form, and when compared across the different intersection forms. The posted speed limits vary considerably for all intersection types.

Table 57. Summary Statistics for 3-leg Minor Approach Stop-controlled Intersection on Urban-Suburban Arterials.

Continuous Variable	Mean	Standard Deviation	Minimum	Maximum
Total Crashes per Year	1.007	1.348	0	13
Total Fatal + Injury Crashes per Year	0.523	0.881	0	10
Major Road AADT (veh/day)	8745	4681	785	31871
Minor Road AADT (veh/day)	2771	2456	38	18621
Left Shoulder Paved Width on Major Road (feet)	2.883	2.645	0	12
Right Shoulder Paved Width on Major Road (feet)	3.355	2.866	0	15
Paved Width on Major Road (feet)	32.270	7.748	14	75
Posted Speed Limit on Major Road (mph)	39.303	8.219	25	55
Left Shoulder Total Width on Minor Road (feet)	1.498	2.069	0	13
Right Shoulder Total Width on Minor Road (feet)	1.582	2.197	0	13
Paved Width on Minor Road (feet)	25.884	6.317	12	63
Posted Speed Limit on Minor Road (mph)	37.084	7.998	15	55

Categorical Variable	Description	Proportion
Presence of exclusive left-turn lanes on major road approach	None	0.94
	Present on at least one approach	0.06
Presence of exclusive right-turn lanes on major road approach	None	0.99
	Present on at least one approach	0.01
Presence of pedestrian crosswalk on major road approach	None	0.96
	Present on at least one approach	0.04
Presence of exclusive left-turn lane on minor road approach	None	0.99
	Present on at least one approach	0.01
Presence of exclusive right-turn lane on minor road approach	None	0.99
	Present on at least one approach	0.01
Presence of pedestrian crosswalk on major road approach	None	0.97
	Present on at least one approach	0.03
Presence of No U-turn Sign on major road approach	None	0.9992
	Present on at least one approach	0.0008

Table 58. Summary Statistics for 3-leg Signalized Intersections on Urban Suburban Arterials.

Continuous Variable	Mean	Standard Deviation	Minimum	Maximum
Total Crashes per Year	2.159	2.186	0	22
Total Fatal + Injury Crashes per Year	1.167	1.406	0	10
Major Road AADT (veh/day)	12125	4456	1628	30985
Minor Road AADT (veh/day)	6407	3288	45	18911
Left Shoulder Paved Width on Major Road (feet)	1.937	2.865	0	12
Right Shoulder Paved Width on Major Road (feet)	2.536	3.252	0	13
Paved Width on Major Road (feet)	35.045	9.027	15	73
Posted Speed Limit on Major Road (mph)	36.935	7.632	20	55
Left Shoulder Total Width on Minor Road (feet)	1.717	2.624	0	15
Right Shoulder Total Width on Minor Road (feet)	2.063	2.890	0	15
Paved Width on Minor Road (feet)	30.751	8.136	11	80
Posted Speed Limit on Minor Road (mph)	35.891	7.769	15	55
Categorical Variable	**Description**		**Proportion**	
Presence of exclusive left-turn lanes on major road approach	None		0.62	
	Present on at least one approach		0.38	
Presence of exclusive right-turn lanes on major road approach	None		0.84	
	Present on at least one approach		0.16	
Presence of pedestrian crosswalk on major road approach	None		0.55	
	Present on at least one approach		0.45	
Presence of exclusive left-turn lane on minor road approach	None		0.72	
	Present on at least one approach		0.28	
Presence of exclusive right-turn lane on minor road approach	None		0.80	
	Present on at least one approach		0.20	
Presence of pedestrian crosswalk on major road approach	None		0.54	
	Present on at least one approach		0.46	
Presence of No U-turn Sign on major road approach	None		0.9985	
	Present on at least one approach		0.0015	

Table 59. Summary Statistics 4-leg Minor Approach Stop-controlled Intersections on Urban-Suburban Arterials.

Continuous Variable	Mean	Standard Deviation	Minimum	Maximum
Total Crashes per Year	1.308	1.547	0	10
Total Fatal + Injury Crashes per Year	0.663	0.981	0	7
Major Road AADT (veh/day)	8206	3962	916	25105
Minor Road AADT (veh/day)	2377	2019	62	17480
Left Shoulder Paved Width on Major Road (feet)	2.442	2.687	0	11
Right Shoulder Paved Width on Major Road (feet)	2.859	2.870	0	10
Paved Width on Major Road (feet)	32.278	7.788	20	60
Posted Speed Limit on Major Road (mph)	38.687	8.368	25	55
Left Shoulder Total Width on Minor Road (feet)	1.000	1.728	0	10
Right Shoulder Total Width on Minor Road (feet)	1.116	1.917	0	11
Paved Width on Minor Road (feet)	25.467	5.740	16	48
Posted Speed Limit on Minor Road (mph)	37.285	8.245	20	55
Categorical Variable	**Description**		**Proportion**	
Presence of exclusive left-turn lanes on major road approach	None		0.88	
	Present on at least one approach		0.12	
Presence of exclusive right-turn lanes on major road approach	None		0.98	
	Present on at least one approach		0.02	
Presence of pedestrian crosswalk on major road approach	None		0.90	
	Present on at least one approach		0.10	
Presence of exclusive left-turn lane on minor road approach	None		0.98	
	Present on at least one approach		0.02	
Presence of exclusive right-turn lane on minor road approach	None		0.98	
	Present on at least one approach		0.02	
Presence of pedestrian crosswalk on major road approach	None		0.90	
	Present on at least one approach		0.10	
Presence of No U-turn Sign on major road approach	None		0.997	
	Present on at least one approach		0.003	

Table 60. Summary Statistics 4-leg All-way Stop-controlled Intersections on Urban-Suburban Arterials.

Continuous Variable	Mean	Standard Deviation	Minimum	Maximum
Total Crashes per Year	1.204	1.429	0	6
Total Fatal + Injury Crashes per Year	0.522	0.855	0	5
Major Road AADT (veh/day)	6499	3321	1622	15733
Minor Road AADT (veh/day)	3365	1858	773	8359
Left Shoulder Paved Width on Major Road (feet)	1.804	1.756	0	6
Right Shoulder Paved Width on Major Road (feet)	2.435	2.967	0	17
Paved Width on Major Road (feet)	28.870	5.827	20	46
Posted Speed Limit on Major Road (mph)	36.739	6.201	25	45
Left Shoulder Total Width on Minor Road (feet)	1.457	1.818	0	6
Right Shoulder Total Width on Minor Road (feet)	1.478	1.758	0	6
Paved Width on Minor Road (feet)	26.261	5.451	14	46
Posted Speed Limit on Minor Road (mph)	37.174	5.785	25	55
Categorical Variable	Description		Proportion	
Presence of exclusive left-turn lanes on major road approach	None		0.98	
	Present on at least one approach		0.02	
Presence of pedestrian crosswalk on major road approach	None		0.85	
	Present on at least one approach		0.15	
Presence of exclusive right-turn lane on minor road approach	None		0.98	
	Present on at least one approach		0.02	
Presence of pedestrian crosswalk on major road approach	None		0.87	
	Present on at least one approach		0.13	

Table 61. Summary Statistics for 4-leg Signalized Intersections on Urban-Suburban Arterials.

Continuous Variable	Mean	Standard Deviation	Minimum	Maximum
Total Crashes per Year	3.190	3.036	0	54
Total Fatal + Injury Crashes per Year	1.816	2.036	0	27
Major Road AADT (veh/day)	11867	4456	1877	68000
Minor Road AADT (veh/day)	6602	3531	132	21532
Left Shoulder Paved Width on Major Road (feet)	1.645	2.711	0	14
Right Shoulder Paved Width on Major Road (feet)	2.427	3.295	0	18
Paved Width on Major Road (feet)	35.466	9.031	18	98
Posted Speed Limit on Major Road (mph)	36.649	7.903	25	55
Left Shoulder Total Width on Minor Road (feet)	1.189	2.114	0	15
Right Shoulder Total Width on Minor Road (feet)	1.675	2.694	0	18
Paved Width on Minor Road (feet)	31.517	8.748	10	84
Posted Speed Limit on Minor Road (mph)	35.368	7.648	15	55
Categorical Variable	**Description**		**Proportion**	
Presence of exclusive left-turn lanes on major road approach	None		0.46	
	Present on at least one approach		0.54	
Presence of exclusive right-turn lanes on major road approach	None		0.81	
	Present on at least one approach		0.19	
Presence of pedestrian crosswalk on major road approach	None		0.35	
	Present on at least one approach		0.65	
Presence of exclusive left-turn lane on minor road approach	None		0.60	
	Present on at least one approach		0.40	
Presence of exclusive right-turn lane on minor road approach	None		0.84	
	Present on at least one approach		0.16	
Presence of pedestrian crosswalk on major road approach	None		0.35	
	Present on at least one approach		0.65	
Presence of No U-turn Sign on major road approach	None		0.9991	
	Present on at least one approach		0.0009	

<u>Regionalization of SPFs</u>

Table 62 and Table 63 shows the frequency of the various intersection forms in the analysis database by county and engineering district, respectively. An adequate sample size does not exist to estimate county-level SPFs for 4-leg all-way stop and 4-leg minor stop-controlled intersections. Only a handful of counties have sufficient sample size to develop county-level SPFs for the other intersections forms. Therefore, county-level SPFs are not expected to be reliable. At the district level, sufficient sample size will exist to develop district-level SPFs for the 3-leg minor stop-controlled intersection if adjacent districts 1 and 2 and adjacent districts 9 and 10 are combined. For 3-leg signalized intersections and 4-leg minor stop-controlled intersections, only 4 districts have sufficient sample size for the development of district-level SPFs. No districts have sufficient sample size for the development of district-level SPFs for 4-leg all-way stop-controlled intersections. Finally, sufficient sample size exists for the development of district-level SPFs for 4-leg signalized intersections.

Table 62. Urban-Suburban Arterial County Intersections.

County	Name	3L MS	3L SIG	4L AWS	4L MS	4L SIG	Sum
1	ADAMS	12	5	0	1	5	23
2	ALLEGHENY	144	97	7	8	116	372
3	ARMSTRONG	20	2	0	9	11	42
4	BEAVER	56	10	1	11	28	106
5	BEDFORD	0	0	0	0	0	0
6	BERKS	42	23	1	15	63	144
7	BLAIR	13	9	0	4	27	53
8	BRADFORD	6	2	0	0	6	14
9	BUCKS	69	42	6	17	164	298
10	BUTLER	13	11	0	3	26	53
11	CAMBRIA	32	22	0	4	23	81
12	CAMERON	0	0	0	0	0	0
13	CARBON	7	3	0	3	4	17
14	CENTRE	13	4	0	0	19	36
15	CHESTER	46	35	9	25	98	213
16	CLARION	3	0	0	1	2	6
17	CLEARFIELD	13	2	0	2	16	33
18	CLINTON	3	3	2	0	6	14
19	COLUMBIA	10	5	0	4	11	30
20	CRAWFORD	16	1	0	3	15	35
21	CUMBERLAND	15	19	1	7	45	87
22	DAUPHIN	15	10	0	9	43	77
23	DELAWARE	45	30	2	17	184	278
24	ELK	3	1	0	1	1	6
25	ERIE	10	9	1	9	48	77
26	FAYETTE	20	2	0	6	20	48
27	FOREST	0	0	0	0	0	0
28	FRANKLIN	11	3	0	5	23	42
29	FULTON	0	0	0	0	0	0
30	GREENE	2	2	0	1	5	10
31	HUNTINGDON	5	0	0	0	1	6
32	INDIANA	5	1	0	8	18	32
33	JEFFERSON	8	0	0	3	6	17
34	JUNIATA	0	0	0	0	0	0
35	LACKAWANNA	33	12	1	17	44	107
36	LANCASTER	42	18	1	11	98	170
37	LAWRENCE	7	4	1	3	12	27
38	LEBANON	3	1	0	1	18	23
39	LEHIGH	32	14	1	13	66	126
40	LUZERNE	57	26	5	13	53	154
41	LYCOMING	20	3	0	8	21	52
42	MCKEAN	1	0	1	0	2	4
43	MERCER	15	5	3	8	31	62
44	MIFFLIN	8	4	0	1	8	21
45	MONROE	19	17	0	3	14	53
46	MONTGOMERY	51	58	2	25	213	349
47	MONTOUR	4	0	0	1	4	9
48	NORTHAMPTON	24	12	0	16	49	101
49	NORTHUMBERLAND	9	9	0	6	14	38
50	PERRY	0	1	0	0	0	1

County	Name	3L MS	3L SIG	4L AWS	4L MS	4L SIG	Sum
51	PIKE	0	0	0	0	0	0
52	POTTER	0	0	0	0	0	0
53	SCHUYLKILL	25	4	0	6	21	56
54	SNYDER	5	2	0	3	5	15
55	SOMERSET	3	3	0	3	11	20
56	SULLIVAN	0	0	0	0	0	0
57	SUSQUEHANNA	2	0	0	1	0	3
58	TIOGA	0	0	0	0	0	0
59	UNION	5	2	0	0	6	13
60	VENANGO	6	6	0	2	11	25
61	WARREN	9	3	0	1	9	22
62	WASHINGTON	55	16	1	17	44	133
63	WAYNE	9	4	0	3	2	18
64	WESTMORELAND	96	17	0	32	63	208
65	WYOMING	1	0	0	0	1	2
66	YORK	48	16	0	23	64	151
67	PHILADELPHIA	16	41	0	3	199	259
sum		1,262	651	46	396	2,117	4,472

Table 63. Urban-Suburban Arterial District Intersections.

District	3L MS	3L SIG	4L AWS	4L MS	4L SIG	Sum
1	56	24	4	23	114	221
2	41	14	3	4	52	114
3	59	23	0	22	67	171
4	102	42	6	34	100	284
5	149	73	2	56	217	497
6	227	206	19	87	858	1397
8	146	73	2	57	296	574
9	53	34	0	11	62	160
10	49	14	0	24	63	150
11	207	111	9	22	156	505
12	173	37	1	56	132	399
Total	1262	651	46	396	2117	4472

Based on the regionalization process and amount of available data for each urban-suburban arterial intersection type, the research team recommends using **district-level SPFs with county-specific adjustments** for 3-leg minor stop-controlled intersections. **Statewide SPFs with district-specific adjustments** are recommended for 3-leg signalized intersections, 4-leg signalized intersections and 4-leg minor stop-controlled intersections.

Preliminary models suggest that reliable SPFs are not possible with the available data for 4-leg all-way stop-controlled intersections. Instead, the research team recommends using the 4-leg minor stop-controlled intersection SPF and an adjustment factor to obtain crash frequency estimates for 4-leg all-way stop-controlled intersections. This process is described in Appendix I. Also included in Appendix I is an adjustment to the 4-leg signalized intersection SPF that can provide an estimate for crash frequency of 5-leg signalized intersections on urban-suburban arterials. Appendix I also includes an adjustment to the 3-leg minor stop-controlled intersection SPF that can provide an estimate of crash frequency for 3-leg minor stop controlled intersections with "STOP Except Right Turns" signs.

Summary of SPF Recommendations

The total and fatal+injury crash SPFs estimation for each intersection form is provided in Appendix H. For brevity, a detailed interpretation of these models is not provided. However, the same procedure used for the two-lane rural roadway segment SPFs can be applied to these models to interpret the results.

For the three-leg intersections with stop-control on the minor street, district-level SPFs are recommended, and are shown in Table 64. The county adjustment factors are shown in Table 65.

Table 64. District SPFs for Three-leg Intersections with Minor Street Stop Control.

District 1 & District 2:

$$N_{total} = e^{-6.758} \times MajorAADT^{0.538} \times MinorAADT^{0.188} \times e^{0.210\times \text{MajPSL40p}} \times e^{0.356\times \text{MinPSL40p}} \quad (81)$$

over-dispersion parameter: 0.286

$$N_{fatal\_inj} = e^{-7.447} \times MajorAADT^{0.557} \times MinorAADT^{0.150} \times e^{0.551\times \text{MajPSL40p}} \quad (82)$$

over-dispersion parameter: 0.0000057

District 3:

$$N_{total} = e^{-8.382} \times MajorAADT^{0.532} \times MinorAADT^{0.391} \times e^{0.344\times \text{MajPSL40p}} \times e^{0.327\times \text{MinPSL40p}} \quad (83)$$

over-dispersion parameter: 0.193

$$N_{fatal\_inj} = e^{-10.660} \times MajorAADT^{0.638} \times MinorAADT^{0.451} \times e^{0.522\times \text{MajPSL40p}} \times e^{0.486\times \text{MinPSL40p}} \quad (84)$$

over-dispersion parameter: 0.119

District 4:

$$N_{total} = e^{-8.655} \times MajorAADT^{0.662} \times MinorAADT^{0.362} \quad (85)$$

over-dispersion parameter: 0.166

$$N_{fatal\_inj} = e^{-10.980} \times MajorAADT^{0.884} \times MinorAADT^{0.323} \quad (86)$$

over-dispersion parameter: 0.049

District 5:

$$N_{total} = e^{-6.255} \times MajorAADT^{0.403} \times MinorAADT^{0.350} \times e^{0.293\times \text{MajPSL40p}} \quad (87)$$

over-dispersion parameter: 0.342

$$N_{fatal\_inj} = e^{-8.088} \times MajorAADT^{0.549} \times MinorAADT^{0.321} \times e^{0.392\times \text{MajPSL40p}} \quad (88)$$

over-dispersion parameter: 0.406

District 6:

$$N_{total} = e^{-6.729} \times MajorAADT^{0.423} \times MinorAADT^{0.373} \times e^{0.131\times \text{MajPSL40p}} \quad (89)$$

over-dispersion parameter: 0.397

$$N_{fatal\_inj} = e^{-9.186} \times MajorAADT^{0.575} \times MinorAADT^{0.432} \quad (90)$$

over-dispersion parameter: 0.449

District 8: $N_{total} = e^{-8.417} \times MajorAADT^{0.623} \times MinorAADT^{0.334} \times e^{0.236 \times \text{MinPSL40p}}$ (91) over-dispersion parameter: 0.272 $N_{fatal\_inj} = e^{-10.217} \times MajorAADT^{0.722} \times MinorAADT^{0.357} \times e^{0.267 \times \text{MinPSL40p}}$ (92) over-dispersion parameter: 0.263
District 9 & 10: $N_{total} = e^{-7.090} \times MajorAADT^{0.550} \times MinorAADT^{0.244}$ (93) over-dispersion parameter: 0.482 $N_{fatal\_inj} = e^{-8.011} \times MajorAADT^{0.642} \times MinorAADT^{0.162}$ (94) over-dispersion parameter: 0.456
District 11: $N_{total} = e^{-9.485} \times MajorAADT^{0.787} \times MinorAADT^{0.288} \times e^{0.153 \times \text{MajPSL40p}} \times e^{0.139 \times \text{MinPSL40p}}$ (95) over-dispersion parameter: 0.407 $N_{fatal\_inj} = e^{-10.899} \times MajorAADT^{0.913} \times MinorAADT^{0.229} \times e^{0.309 \times \text{MajPSL40p}}$ (96) over-dispersion parameter: 0.452
District 12: $N_{total} = e^{-9.022} \times MajorAADT^{0.826} \times MinorAADT^{0.169} \times e^{0.245 \times \text{MajPSL40p}}$ (97) over-dispersion parameter: 0.440 $N_{fatal\_inj} = e^{-10.305} \times MajorAADT^{0.870} \times MinorAADT^{0.193} \times e^{0.351 \times \text{MajPSL40p}}$ (98) over-dispersion parameter: 0.364
MajorAADT = major road average annual daily traffic (veh/day) MinorAADT = minor road average annual daily traffic (veh/day) MajPSL40p = indicator for posted speed limit of 40 mph or greater on major road (1 = present; 0 otherwise) MinPSL40p = indicator for posted speed limit of 40 mph or greater on minor road (1 = present; 0 otherwise)

To apply the county adjustment factors for total and fatal+injury crashes, the expected number of crashes should be estimated using the appropriate district-level SPF in Table 65, and the total or fatal+injury adjustment for a specific county should then be multiplied by the expected crash frequency from the district SPF.

Table 65. County Adjustment Factors for Three-leg Intersections with Minor Street Stop Control.

District	SPF	County	District-specific adjustments to total crash SPF	District-specific adjustments to fatal + injury SPF
1	Equations (81, 82)	All counties in district 1	No modification necessary	No modification necessary
2	Equations (81, 82)	All counties in district 2	No modification necessary	No modification necessary
3	Equations (83, 84)	All counties in district 3	No modification necessary	No modification necessary
4	Equations (85, 86)	All counties in district 4	No modification necessary	No modification necessary
5	Equations (87, 88)	All counties in district 5	No modification necessary	No modification necessary
6	Equations (89, 90)	All counties in district 6	No modification necessary	No modification necessary
8	Equations (91, 92)	All counties in district 8	No modification necessary	No modification necessary
9	Equations (93, 94)	All counties in district 9	No modification necessary	No modification necessary
10	Equations (93, 94)	All counties in district 10	No modification necessary	No modification necessary
11	Equations (95, 96)	Allegheny (2), Lawrence (37)	No modification necessary	No modification necessary
		Beaver (4)	Multiply estimate by 1.46	Multiply estimate by 1.56
12	Equations (97, 98)	All counties in district 12	No modification necessary	No modification necessary

A statewide SPF with district-level adjustment factors is recommended for three-leg signalized intersections. The total and fatal+injury crash SPFs are shown in Table 66, and the district adjustment factors are shown in Table 67. To apply the district-specific adjustments, the statewide SPF should be estimated first and the result multiplied by the district-level adjustment.

Table 66. Three-leg Signalized Intersection SPF for Urban-suburban Arterials.

$$N_{total} = e^{-5.113} \times MajorAADT^{0.393} \times MinorAADT^{0.219} \times e^{0.097\times \text{ELTMaj}} \times e^{0.110\times \text{ELTMin}} \times e^{0.131\times \text{MajPSL30\_35}} \times e^{0.346\times \text{MajPSL40p}} \quad (99)$$

over-dispersion parameter: 0.385

$$N_{fatal\_inj} = e^{-5.677} \times MajorAADT^{0.381} \times MinorAADT^{0.247} \times e^{0.115\times \text{ELTMaj}} \times e^{0.181\times \text{MajPSL40p}} \quad (100)$$

over-dispersion parameter: 0.458

MajorAADT = major road average annual daily traffic (veh/day)
MinorAADT = minor road average annual daily traffic (veh/day)
ELTMaj = indicator variable for exclusive left-turn lane on the major street approach (1 = present; 0 otherwise)
ELTMin = indicator variable for exclusive left-turn lane on the minor street approach (1 = present; 0 otherwise)
MajPSL30_35 = indicator for posted speed limit of 30 or 35 mph on major road (1 = present; 0 otherwise)
MajPSL40p = indicator for posted speed limit of 40 mph or more on major road (1 = present; 0 otherwise)

Table 67. Three-leg Signalized Intersection SPF Adjustment Factors for Urban-suburban Arterials.

District	District-specific adjustments for total crash SPF	District-specific adjustments for fatal + injury SPF
1	No modification necessary	No modification necessary
2	No modification necessary	No modification necessary
3	Multiply estimate by 0.87	Multiply estimate by 0.81
4	No modification necessary	No modification necessary
5	Multiply estimate by 1.18	Multiply estimate by 1.12
6	No modification necessary	No modification necessary
8	Multiply estimate by 0.87	Multiply estimate by 0.81
9	Multiply estimate by 0.87	Multiply estimate by 0.81
10	No modification necessary	No modification necessary
11	Multiply estimate by 1.18	Multiply estimate by 1.12
12	No modification necessary	No modification necessary

A statewide SPF with district-level adjustment factors is also recommended for 4-leg minor stop-controlled intersections. The total and fatal+injury crash SPFs are shown in Table 68, and the district adjustment factors are shown in Table 69. To apply the district-specific adjustments, the statewide SPF should be estimated first and the result multiplied by the district-level adjustment.

Table 68. Four-leg Minor-Stop Controlled Intersection SPF for Urban-suburban Arterials.

$$N_{total} = e^{-6.909} \times MajorAADT^{0.530} \times MinorAADT^{0.279} \times e^{0.183 \times \text{MajPSL40\_45}} \times e^{0.356 \times \text{MajPSL50\_55}} \times e^{0.131 \times \text{MinPSL40p}} \quad (101)$$

over-dispersion parameter: 0.387

$$N_{total} = e^{-8.223} \times MajorAADT^{0.585} \times MinorAADT^{0.296} \times e^{0.132 \times \text{MajPSL40\_45}} \times e^{0.396 \times \text{MajPSL50\_55}} \times e^{0.169 \times \text{MinPSL40p}} \quad (102)$$

over-dispersion parameter: 0.368

MajorAADT = major road average annual daily traffic (veh/day)
MinorAADT = minor road average annual daily traffic (veh/day)
MajPSL40_45 = indicator for posted speed limit of 40 or 45 mph on major road (1 = present; 0 otherwise)
MajPSL50_55 = indicator for posted speed limit of 50 or 55 mph on major road (1 = present; 0 otherwise)
MinPSL40p = indicator for posted speed limit of 40 mph or more on minor road (1 = present; 0 otherwise)

Table 69. Four-leg Minor-Stop Controlled Intersection SPF Adjustment Factors for Urban-suburban Arterials.

District	District-specific instructions for total crash SPF	District-specific instructions for fatal + injury SPF
1	No modification necessary	No modification necessary
2	No modification necessary	No modification necessary
3	No modification necessary	No modification necessary
4	No modification necessary	No modification necessary
5	Multiply estimate by 1.44	Multiply estimate by 1.44
6	Multiply estimate by 1.16	Multiply estimate by 1.14
8	Multiply estimate by 1.44	Multiply estimate by 1.44
9	No modification necessary	No modification necessary
10	No modification necessary	No modification necessary
11	No modification necessary	No modification necessary
12	No modification necessary	No modification necessary

A statewide SPF with district-level adjustment factors is recommended for 4-leg signalized intersections. The total and fatal+injury crash SPFs are shown in Table 70, and the district adjustment factors are shown in Table 71. To apply the district-specific adjustments, the statewide SPF should be estimated first and the result multiplied by the district-level adjustment.

Table 70. Four-leg Signalized Intersection SPF for Urban-suburban Arterials.

$$N_{total} = e^{-5.501} \times MajorAADT^{0.403} \times MinorAADT^{0.316} \times e^{0.053\times \text{ELTMaj}} \times e^{0.126\times \text{ERTMaj}} \times e^{0.056\times \text{ELTMin}} \times e^{0.045\times \text{ERTMin}} \times e^{0.101\times \text{MajPSL40\_45}} \times e^{0.290\times \text{MajPSL50\_55}} \times e^{0.075\times \text{MinPSL35p}} \quad (103)$$

over-dispersion parameter: 0.356

$$N_{fatal\_inj} = e^{-6.374} \times MajorAADT^{0.411} \times MinorAADT^{0.363} \times e^{0.130\times \text{ELTMaj}} \times e^{0.053\times \text{ELTMin}} \times e^{0.226\times \text{MajPSL50\_55}} \quad (104)$$

over-dispersion parameter: 0.432

MajorAADT = major road average annual daily traffic (veh/day)
MinorAADT = minor road average annual daily traffic (veh/day)
ELTMaj = indicator variable for exclusive left-turn lane on the major street approach (1 = present; 0 otherwise)
ERTMaj = indicator variable for exclusive right-turn lane on the major street approach (1 = present; 0 otherwise)
ELTMin = indicator variable for exclusive left-turn lane on the minor street approach (1 = present; 0 otherwise)
ERTMin = indicator variable for exclusive right-turn lane on the minor street approach (1 = present; 0 otherwise)
MajPSL40_45 = indicator for posted speed limit of 40 or 45 mph on major road (1 = present; 0 otherwise)
MajPSL50_55 = indicator for posted speed limit of 50 or 55 mph on major road (1 = present; 0 otherwise)
MinPSL35p = indicator for posted speed limit of 35 mph or more on minor road (1 = present; 0 otherwise)

Table 71. Four-leg Signalized Intersection SPF Adjustment Factors for Urban-suburban Arterials.

District	District-specific instructions for total crash SPF	District-specific instructions for fatal + injury SPF
1	Multiply estimate by 0.78	Multiply estimate by 0.74
2	Multiply estimate by 0.78	Multiply estimate by 0.74
3	Multiply estimate by 0.71	Multiply estimate by 0.64
4	Multiply estimate by 1.11	Multiply estimate by 1.09
5	No modification necessary	No modification necessary
6	No modification necessary	No modification necessary
8	Multiply estimate by 0.88	Multiply estimate by 0.79
9	Multiply estimate by 0.88	Multiply estimate by 0.79
10	Multiply estimate by 0.71	Multiply estimate by 0.64
11	Multiply estimate by 0.96	Multiply estimate by 0.83
12	Multiply estimate by 0.78	Multiply estimate by 0.74

Comparison with HSM SPFs

RMSE values were also used to compare the recommended regionalized SPFs to the HSM SPFs for at-grade intersections on urban-suburban arterials. Due to the small sample size of intersections of each type within each county, individual county comparisons were not meaningful. Instead, the overall RMSE measured across all counties was used to compare the statewide to the HSM SPF performance. A summary of these values is provided in Table 72. As shown, regionalized SPFs for all intersection forms outperform the HSM SPFs. Therefore, the Pennsylvania-specific regionalized SPFs demonstrate a clear benefit in predictive power over the HSM SPFs for at-grade urban-suburban arterials.

Table 72. RMSE Comparison for Intersections on Urban-Suburban Arterials – Statewide and HSM SPFs.

	Statewide RMSE	HSM RMSE	Percent Improvement
3-leg minor stop-controlled	1.225	1.347	9.1%
3-leg signalized	2.07	2.171	4.7%
4-leg minor stop-controlled	1.44	1.54	6.5%
4-leg signalized	2.785	2.918	4.6%

Additional CMFs for urban-suburban roadway segments

As described in the Data and Data Structures section, the Penn State research team collected additional data for a 500-mile sample of the urban-suburban arterial roadway network. These additional data included:

- Presence of medians
- Presence of median openings
- Presence of left-turn and no U-turn signs at median openings
- Roadside hazard ratings
- Presence and degree of curvature of horizontal curves

This additional data collection included 530 segments of 2-lane undivided roadways, 179 segments of 4-lane undivided roadways and 306 segments of 4-lane divided roadways. Since 5 years of crash data were available for each segment, this resulted in analysis databases of 2650 total observations for of 2-lane undivided roadways, 895 total observations for 4-lane undivided roadways and 1530 total observations for 4-lane divided roadways. Summary statistics for each of these roadway types are provided in Table 73 to Table 75.

Table 73. Summary Statistics 2-Lane Undivided Urban-Suburban Arterials From 500-Mile Database.

Variables	Mean	Standard Deviation	Minimum	Maximum
Total crashes per year	2.419	2.391	0	17
Total fatal + injury crashes per year	1.089	1.349	0	9
Average annual daily traffic (veh/day)	10770	4557	1612	29077
Segment length (miles)	0.474	0.153	0	0.752
Posted speed limit (mph)	41.085	6.863	25	55
Left paved shoulder width (feet)	2.955	2.536	0	9
Right paved shoulder width (feet)	3.060	2.607	0	13
Lane width (feet)	12.899	3.363	6	27
Left roadside hazard rating (1 to 7)	5.774	0.837	3	7
Right roadside hazard rating (1 to 7)	5.409	0.820	2	7
Degree of curvature per mile (ft/mile)	48.772	84.948	0	536.999
Average curve radius in the segment (ft)	713.645	1038.187	0	9854.301
Categorical Variables	Category		Proportion	
Presence of center turn lanes	Yes		0.08	
	No		0.92	
Presence of parking lanes	Yes		0.03	
	No		0.97	

Table 74. Summary Statistics 4-Lane Undivided Urban-Suburban Arterials from 500-Mile Database.

Variables	Mean	Standard Deviation	Minimum	Maximum
Total crashes per year	3.411	4.976	0	61
Total fatal + injury crashes per year	1.597	2.532	0	28
Average annual daily traffic (veh/day)	10406	4096	300	33076
Segment length (miles)	0.430	0.150	0	0.736
Posted speed limit (mph)	40.084	5.030	25	55
Left paved shoulder width (feet)	0.888	2.358	0	10
Right paved shoulder width (feet)	0.777	2.130	0	11
Lane width (feet)	12.405	1.938	10	20
Left roadside hazard rating (1 to 7)	6.827	0.471	4	7
Right roadside hazard rating (1 to 7)	5.911	0.868	4	7
Degree of curvature per mile (ft/mile)	26.927	44.795	0	257.317
Average curve radius in the segment (ft)	670.860	755.742	0	4991.752
Categorical Variables	Category		Proportion	
Presence of center turn lanes	Yes		0.11	
	No		0.89	
Presence of parking lanes	Yes		0.01	
	No		0.99	

Table 75. Summary Statistics 4-Lane Divided Urban-Suburban Arterials from 500-Mile Database.

Variables	Mean	Standard Deviation	Minimum	Maximum
Total crashes per year	2.405	2.789	0	18
Total fatal + injury crashes per year	1.114	1.551	0	13
Average annual daily traffic (veh/day)	11499	4661	1911	28706
Segment length (miles)	0.454	0.152	0	0.864
Posted speed limit (mph)	44.706	5.922	35	55
Left paved shoulder width (feet)	2.925	3.951	0	14
Right paved shoulder width (feet)	3.098	4.128	0	15
Lane width (feet)	12.542	2.208	10	32
Left roadside hazard rating (1 to 7)	6.307	1.099	4	7
Right roadside hazard rating (1 to 7)	5.232	0.981	3	7
Degree of curvature per mile (ft/mile)	27.382	84.150	0	1006.962
Average curve radius in the segment (ft)	937.968	931.973	0	4000.372
Categorical Variables	Category		Proportion	
Presence of center turn lanes	Yes		0.01	
	No		0.99	
Presence of barrier	Yes		0.79	
	No		0.21	

Median presence was initially used to confirm the categorization of roadway types using PennDOT's RMS data codes. While the roadway types were fairly consistent between the manual data collection and PennDOT's RMS data codes, there were differences observed. For example, several roadway segments coded as having a divisor type of 0 (no divisor) were found to have a median when viewing the online video photolog. Due to these and other discrepancies in the data, the research team decided to omit this variable from consideration to maintain consistency with the rest of the urban-suburban arterial data files used for SPF development. For this reason, the presence of median openings and presence of left-turn and no U-turn signs at median openings were not considered for CMF development.

A preliminary assessment of the manually collected data revealed that there was little variability in the roadside hazard ratings along urban-suburban arterial segments, which is reasonable since roadsides are fairly similar on this roadway type. Therefore, roadside hazard rating was not found to have a significant effect on safety performance on urban-suburban arterials.

To assess the impact of the degree of curvature on the safety performance of urban-suburban arterial segments, additional statistical models were developed using the data available in the limited 500-mile analysis database. The models considered were based on the statewide SPFs developed using the entire database, but were modified when necessary due to data limitations or unreliable model estimates. In each model, horizontal curvature was included as the degree of curvature per mile (similar to the two-lane rural and rural multilane highway segment SPFs). The statistical model outputs are included in Appendix J.

For both 4-lane undivided roadway segments and 4-lane divided roadway segments, the degree of curvature variable was not statistically significant in models of total crash frequency and fatal + injury crash frequency. This suggests that horizontal curvature is not significantly associated with crash frequency on these roadway types. This is likely the results of limited variability in curve design parameters on multilane urban-suburban arterial segments. For 2-lane undivided roadways, the degree of curvature variable was statistically significant in both models; however, the magnitude of the coefficient is very low in both cases. For total crash frequency, the degree of curvature coefficient is 0.000523. This suggests that the expected total crash frequency increases by just 0.05 percent for each unit increase in the degree of curvature per mile. For fatal + injury crash frequency, the degree of curvature coefficient is even smaller at 0.0003867. This suggests that the expected frequency of fatal + injury crashes are expected to increase by just 0.04 percent for each unit increase in the degree of curvature per mile. Since the magnitude of the result is small, this suggests that the presence of horizontal curves on 2-lane urban-suburban arterials is not practically significant, except on sharp horizontal curves with very large degree of curvature values.

SUMMARY AND RECOMMENDATIONS FOR IMPLEMENTATION

In this project, Pennsylvania-specific regionalized SPFs were developed for rural two-lane highway, rural multilane highway, and urban-suburban arterial segments and intersections. These SPFs were developed in a manner consistent with the first edition of the AASHTO HSM, but are representative of Pennsylvania conditions (e.g., drivers, climate, and crash reporting thresholds). The level of regionalization recommended is based on the data available and differs for each roadway segment and intersection type. All recommended SPFs were based on RMSE values, which were used as a means to compare the predictive power of the crash frequency models to the reported crash frequencies. A summary of the regionalization levels recommended from this research project is provided in Table 76.

The SPFs developed in the present study can be used in various steps of the project development process. Examples of their use for new or major reconstruction projects include:

- Alternatives analysis: the SPFs can be used to compare the safety performance of two or more alternatives. Comparing the frequency of total or fatal+injury crashes can be used to derive the benefits of different design alternatives, and compared to the cost to construct the alternatives.
- Design exceptions: when geometric design criteria cannot comply with established standards, the SPFs developed in the present study can be used to quantify the expected difference in safety performance between the proposed condition (with the non-conforming criteria) and the standard condition (conforming criteria).

In addition to new or major reconstruction, the SPFs developed in the present study can also be used to manage the existing roadway network. Examples include:

- Identification of sites with potential for safety improvement: the SPFs can be used to estimate the expected crash frequency of roadway segments or intersections within a jurisdiction. When combined with the historical, reported crashes (via the empirical Bayes method), sites with excess crash frequency can be identified. These sites are candidates for safety improvement.
- Traffic safety countermeasure evaluation: the SPFs can be used to evaluate safety countermeasure implementation by estimating the expected number of crashes that would have occurred had countermeasures not been implemented. This requires that historical, reported crash data be used with the predictive models (empirical Bayes method) to compare the reported crash after the site(s) were treated with a countermeasure to the predicted crash frequency had the site not been treated with the countermeasure.

Table 76. Summary of Regionalization Levels for SPFs Developed

SPF Type		Regionalization level
Two-lane rural roadway segments		District-level with county-specific adjustments
Two-lane rural roadway intersections	3-leg intersections with minor-street stop control	Statewide
	4-leg intersections with minor-street stop control	Statewide
	4-leg intersections with all-way stop control	Statewide
	3-leg intersections with signal control	Statewide
	4-leg intersections with signal control	Statewide
Rural multilane highway segments		Statewide with district-specific adjustments
Rural multilane highway intersections	3-leg intersections with minor-street stop control	Statewide
	4-leg intersections with minor-street stop control	Statewide
	4-leg intersections with signal control	Statewide
Urban-suburban arterial segments	Two-lane undivided arterials	District-level with county-specific adjustments
	Four-lane undivided arterials	Statewide with district-specific adjustments
	Four-lane divided arterials	Statewide with district-specific adjustments
Urban-suburban arterial intersections	3-leg intersections with minor-street stop control	District-level with county-specific adjustments
	4-leg intersections with minor-street stop control	Statewide with district-specific adjustments
	3-leg signalized intersections	Statewide with district-specific adjustments
	4-leg signalized intersections	Statewide with district-specific adjustments
	4-leg all-way stop-controlled intersections	Statewide with district-specific adjustments (adjustment to 4-leg intersections with minor-street stop control)
	5-leg signalized intersections	Statewide with district-specific adjustments (adjustment to 4-leg signalized intersections)

APPENDIX A

VIDEO PHOTOLOG DATA COLLECTION INSTRUCTIONAL GUIDE

The Video Log system is used by PennDOT to describe the automated collection of panoramic roadway imagery. This online system is beneficial because data collectors can see visual images of roadway conditions without having to drive into the field. In this way, fewer man-hours are required to collect field data that can be obtained visually. In this project, the video log system is used to collect various pieces of information, including: 1) roadside hazard ratings (RHR) of roadway segments; 2) intersection lane configurations (e.g., presence of left- or right-turn lanes on intersection approaches) at intersections; and, 3) verify the presence and type of traffic control that exists at these intersections (e.g., two-way vs. all-way vs. signal control).

This document will demonstrate how to collect the data needed for this project using State Route 3009 in Bedford County as an example. Prior to demonstrating the methods to collect the data of interest to the present study, the procedure necessary to access the PennDOT video log system is described.

Step 1: Access the PennDOT Online Video Log system at the following link:
http://www.dot7.state.pa.us/VideoLog/Open.aspx
Internet Explorer will likely display a "pop-up blocker" for state.pa.us – allow this to display.

Step 2. After gaining access to the Pennsylvania Video Log Application, click "I Accept" (Figure A1).

Figure A1. Screenshot of *"I Accept"* Icon

Step 3. In the "Select Area of Interest" box that is shown in Figure A2, select "route segment". Click "Generate Map" when finished.

Figure A2. Screenshot for Select Area of Interest

Step 4. In the “County” and “Select a State Route” boxes shown in Figure A3, select Bedford County and SR 3009 as shown in Figures A4 and A5, respectively. Be sure to choose “Entire Route” when selecting the State Route as this will begin the video log at the first segment within the county.

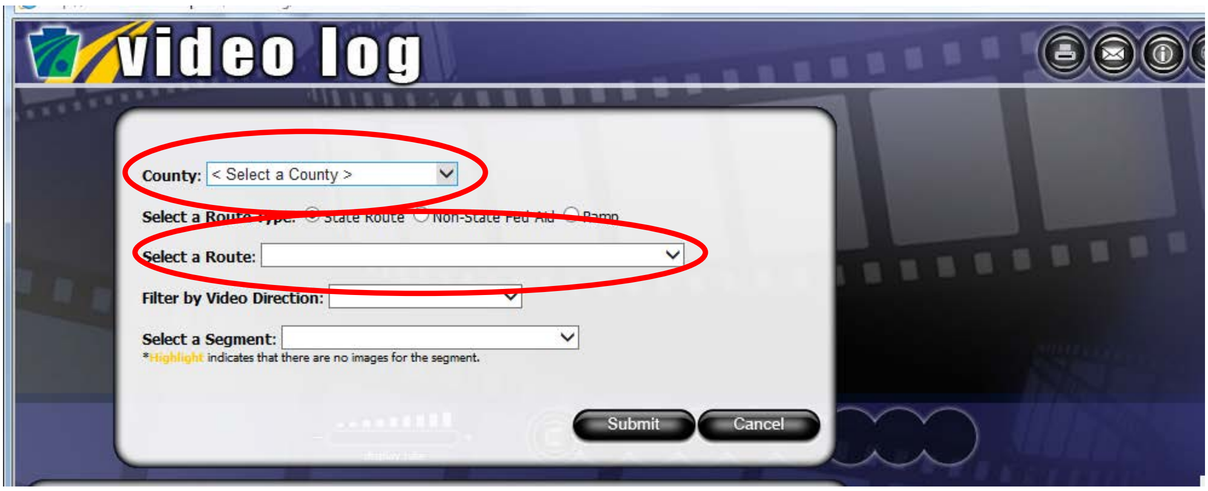

Figure A3. Select a County and Select a Route Screen Capture

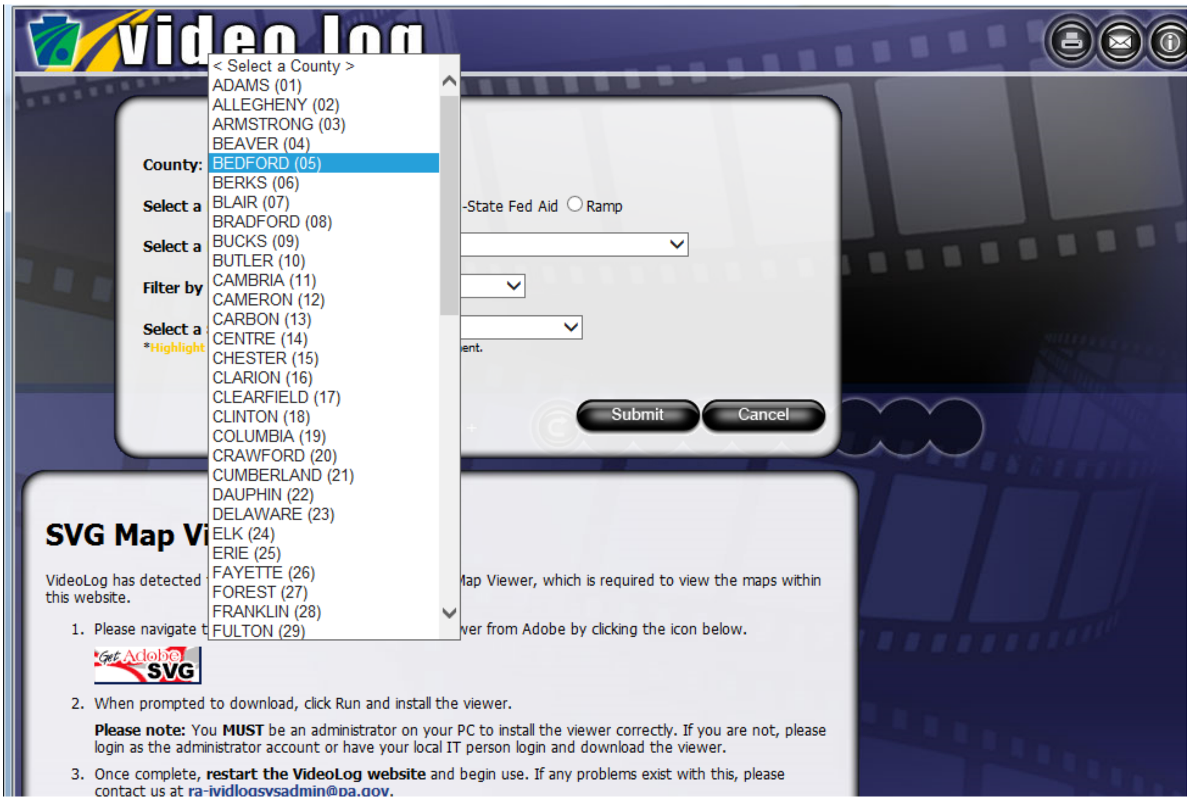

Figure A4. Selecting Bedford County

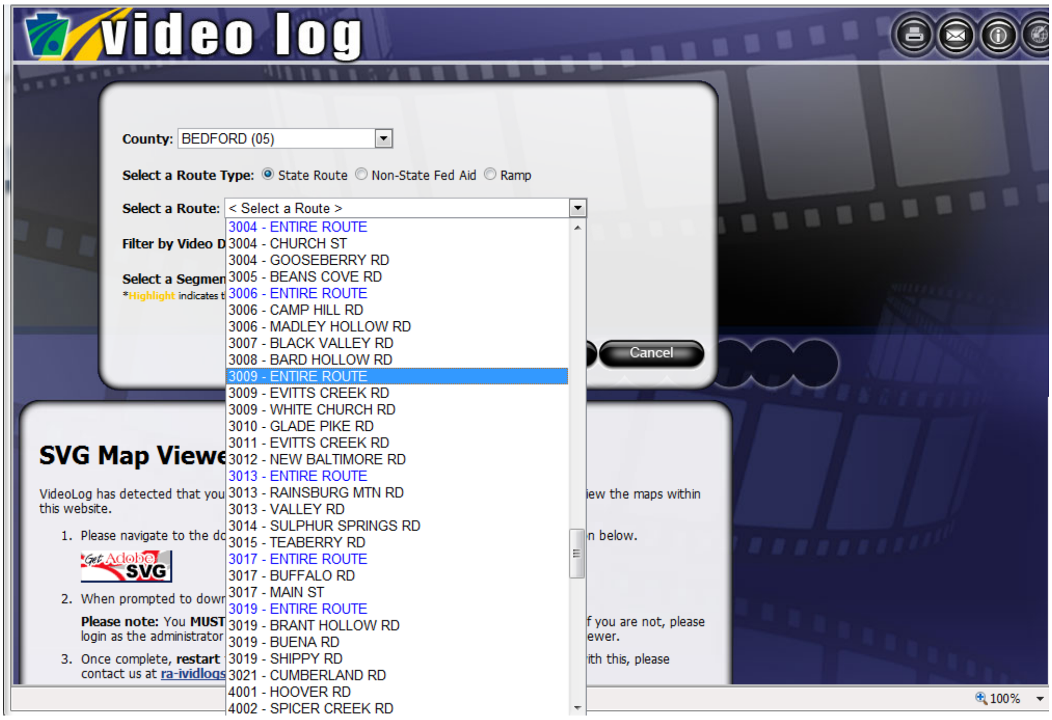

Figure A5. Selecting SR 3009

Step 5. When you gain access to the video log, click "***Activate Map***" (see Figure A6). A map will appear that provides a localized area map of the subject route, SR 3009 (see Figure A7). If you are using a computer that has not yet accessed the Pennsylvania Video Log application, you will need to install a map function 

(see Figure A8), which has a link just below the video log picture.

Figure A6. The "*Activate Map*" Icon

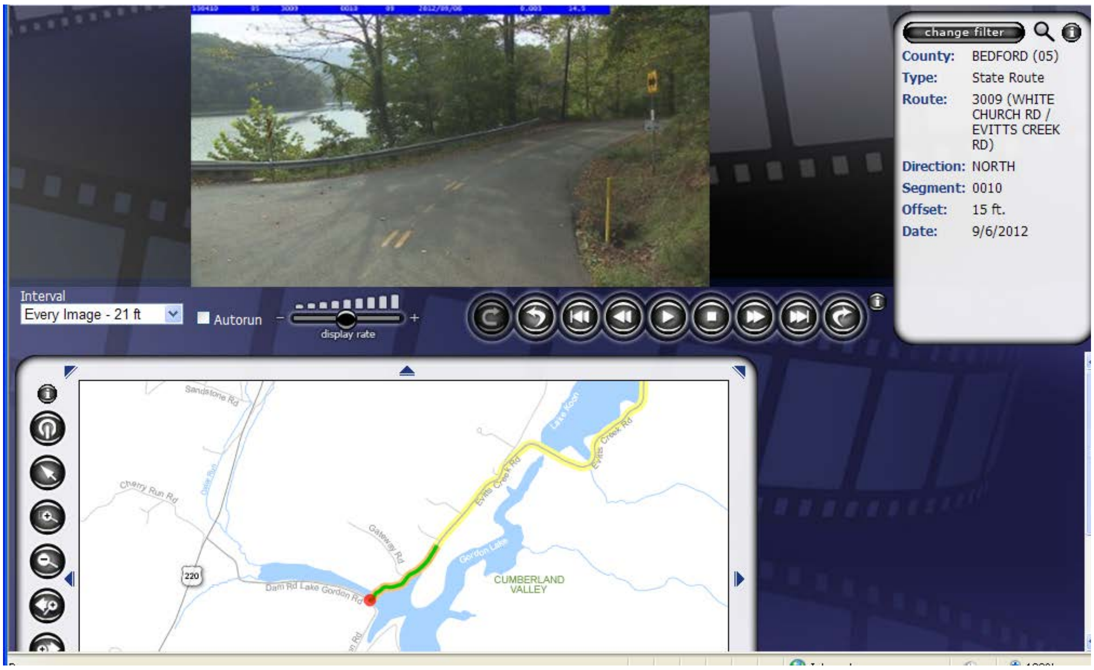

Figure A7. Screenshot for "*Show-up Map*" to locate beginning point for SR 3009

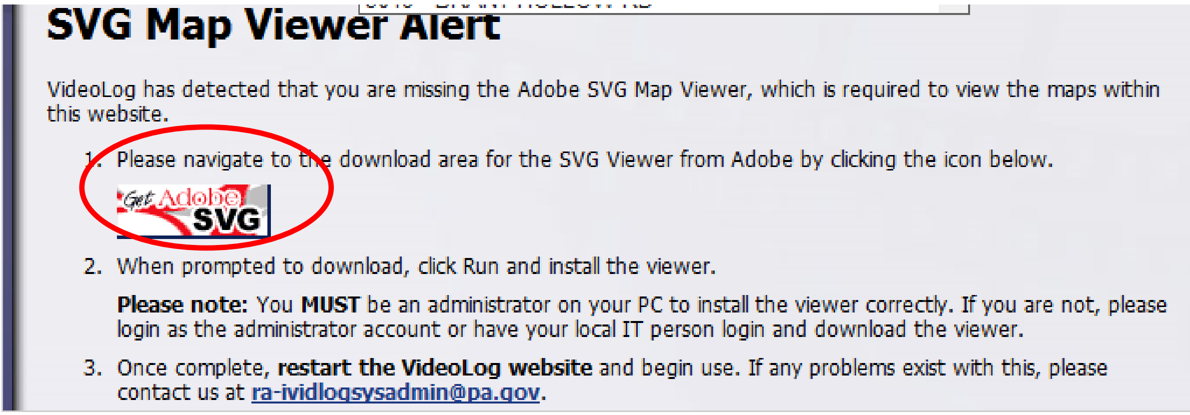

Figure A8. Screenshot for installing a map plug-in

The data that will be collected from the video log system are now described.

Roadside Hazard Rating (RHR)

The roadside hazard rating (RHR) is a qualitative characterization of the crash potential for roadside designs on two-lane highways. These estimates are made by visually inspecting a segment of roadway and assigning it a value based on the guidelines provided in Zegeer et al (1986). In this system, a seven-point categorical scale is used to describe the potential hazards, ranging from 1 (least hazardous) to 7 (more hazardous). For this project, we will utilize the PennDOT online video log system to estimate the RHR on some state-owned roadway segments. A detailed description of roadside design features that "map" to each of the seven RHR categories are shown below, as are example graphics illustrating each rating category (Torbic et al, 2009):

Rating = 1

- Wide clear zones greater than or equal to 9 m (30 ft) from the pavement edge line.
- Side slope flatter than 1V:4H (Vertical:Horizontal).
- Recoverable (*meaning: the driver of a vehicle that departs the roadway section should be able to recover the vehicle and steer back onto the roadway*).

Figure A9. Typical Roadway with Roadside Hazard Rating Equal to 1.

Rating = 2

- Clear zone between 6 and 7.5 m (20 and 25 ft) from pavement edge line.
- Side slope about 1V:4H.
- Recoverable.

Figure A10. Typical Roadway with Roadside Hazard Rating Equal to 2.

Rating = 3

- Clear zone about 3 m (10 ft) from the pavement edge line.
- Side slope about 1V:3H or 1V:4H.
- Rough roadside surface.
- Marginally recoverable.

Figure A11. Typical Roadway with Roadside Hazard Rating Equal to 3.

Rating = 4

- Clear zone between 1.5 and 3 m (5 to 10 ft) from pavement edgeline.
- Side slope about 1V:3H or 1V:4H.
- May have guardrail 1.5 to 2 m [5 to 6.5 ft] from pavement edgeline.
- May have exposed trees, poles, or other objects (about 3 m or 10 ft from pavement edgeline).
- Marginally forgiving, but increased chance of a reportable roadside collision.

Figure A12. Typical Roadway with Roadside Hazard Rating Equal to 4.

Rating = 5

- Clear zone between 1.5 and 3 m (5 to 10 ft) from pavement edgeline.
- Side slope about 1V:3H.
- May have guardrail 0 to 1.5 m [0 to 5 ft] from pavement edgeline.
- May have rigid obstacles or embankment within 2 to 3 m (6.5 to 10 ft) of pavement edgeline.
- Virtually non-recoverable.

Figure A13. Typical Roadway with Roadside Hazard Rating Equal to 5.

Rating = 6

- Clear zone less than or equal to 1.5 m (5 ft).
- Side slope about 1V:2H.
- No guardrail.
- Exposed rigid obstacles within 0 to 2 m (0 to 6.5 ft) of the pavement edgeline.
- Non-recoverable.

Figure A14. Typical Roadway with Roadside Hazard Rating Equal to 6.

Rating = 7

- Clear zone less than or equal to 1.5 m (5 ft).
- Side slope 1:2 or steeper.
- Cliff or vertical rock cut.
- No guardrail.
- Non-recoverable with high likelihood of severe injuries from roadside collision.

Figure A15. Roadway with Roadside Hazard Rating Equal to 7.

Example

Again, consider State Route 3009 in Bedford County as an example. In this example, as in most segments, the roadside hazard rating (RHR) will be different for the two directions of travel within the segment limits. As such, data collectors should estimate the average of the RHR within the segment (i.e., produce only a single RHR measure per segment). Figures A9 through A15 were used to assign a RHR for each segment. Figures A16, A17 and Table A1 show the process used to determine that SR 3009, Segment 0010 is category 6.

Figure A16. Video Log for SR 3009, Segment 0010.

Figure A17. Video Log for SR 3009 Segment 0010.

Table A1. The checklist of RHR for SR 3009 Segment 0010.

SR. 3009 seg. 0010 RHR						
	clear zone	side slope	Cliff or Vertical Rock	Guardrail	Rigid Obstacles	Recoverable
Rating 1	>=9 m(30 ft)	Flatter than 1:4			No	Yes
Rating 2	6-7.5 m(20-25 ft)	1:4		No	No	Yes
Rating 3	3 m(10 ft)	1:3 or 1:4	No		Rough roadside surface	Marginally
Rating 4	1.5-3 m(5-10 ft)			Allowable(1.5-2m[5-6.5ft])	About 3m(10ft)	Marginally forgiving
Rating 5		1:3		Allowable(0-1.5m[0-5ft])	2-3m(6.5-10ft)	Virtually non-recoverable
Rating 6	<=1.5 m(5 ft)	1:2		N/A	0-2m(0-6.5ft)	No
Rating 7		1:2 or steeper	Yes		N/A	No(high likelihood of injure)

SR 3009 segment 0010 is an example of a "severe" roadside. An example of a more forgiving roadside is shown in Figures A18 through A20, which is SR 3009, Segment 0090 in Bedford County. This example also illustrates how the RHR can change within the limits of a segment. Figure A18 shows how the RHR from both sides of the segment are averaged, while Figures A19 and A20 show how the RHR is averaged over the length of the segment. This process resulted in Segment 0090 being assigned a RHR of 3.

Figure A18. Video log for segment 0090 (1)

Figure A19. Video log for Segment 0090 (2)

Figure A20. Video log for Segment 0090 (3)

<u>**Intersection Lane Configurations and Verification of Traffic Control**</u>

The video log intersection data collection effort will be used to identify the presence of left or right-turn lanes on intersection approaches, and the type of traffic control present at intersections. For this project, we are only interested in the intersections of two state owned roads. Therefore, you should verify (using Google Maps or some other tool) that the intersection you observe in the video log is another state owned road.

The intersection control types considered in this research are: two-way stop control, all-way stop control, and signalized intersection control. Consider the intersection of SR 3009 with SR 3011 which is located within Segment 0150 in Bedford County. This is a two-way stop-controlled intersection that has no left turn lane or right turn lane.

Figure A21. Intersection Data Collection and Traffic Control

Other Segment-level Data

In the roadway segment data files, the following additional data will be collected and entered into the appropriate columns of the datafile:

- Presence of passing zones
- Presence of centerline or shoulder rumble strips
- Presence of horizontal curve warning pavement markings
- Presence of intersection warning pavement markings
- Presence of aggressive driving "dots"
- Number of driveways and intersections that are not considered the intersection of state-owned roadways.

An example of a passing zone on a two-lane highway is shown in Figure A22. Examples of shoulder (left panel) and centerline (left panel) rumble strips are shown in Figure A23. Figure A24 (left panel) shows an example of a horizontal curve warning pavement marking and the right panel of Figure A24 shows an example of intersection warning pavement markings. Aggressive driving "dots" are shown in Figure A25.

Figure A22. Example of passing zones.

Figure A23. Example of centerline rumble strips (left panel) and shoulder rumble strips (right panel).

Figure A24. Example of horizontal curve warning pavement marking (left panel) and intersection warning pavement marking (right panel).

Figure A25. Example of aggressive driving "dots" sign and pavement markings.

APPENDIX B

GOOGLE EARTH DATA COLLECTION INSTRUCTIONAL GUIDE

Google Earth is a virtual and geographic program where the 3D terrain and roadway features can be detected using detailed aerial maps. Specific tools within the Google Earth programs allow for a relatively precise way to measure linear distances and angles. For this project, Google Earth provides a useful and straightforward way to collect: 1) the geometric parameters describing horizontal curves; and, 2) the skew angle of intersections of two state owned roads.

The Google Earth tool is freely available online at: http://www.google.com/earth/index.html.

The low resolution of aerial imagery available for rural areas might result in variability in the definition of these horizontal curves among various data collectors. In an effort to alleviate this issue, we will also make use of PennDOT's video log system (available at: http://www.dot7.state.pa.us/VideoLog/Open.aspx) to help define the curve limits from a driver's perspective.

Horizontal Curve Data Collection

The geometric data that we are interested in for each horizontal curve includes: 1) the length of the curve (i.e., its arc length); and, 2) the radius of the curve. The following sections describe the specific processes used to collect this horizontal curve data.

Step 1: Drawing the route path in Google Earth

Since every state-owned route is coded in PennDOT's roadway files at the segment-level, horizontal curve data are defined within the segment boundaries. For each segment, we are interested in the number of horizontal curves that exist, and the radius and arc length of each. Before locating the starting and ending points for segments, we must first draw a path along a given route using Google Earth.

At the top of the order panel, click the "***Add Path***" icon (see Figure B1) . A window will appear to create a new path (see Figure B2). Give the path a name (e.g., SR 3009 in this example) and draw a path along the roadway of interest. This is done by clicking at points along the roadway to create nodes for the path. The nodes should be placed at fairly regular intervals (~500 ft) on straight sections, and should be placed much closer on horizontal curves to capture the curve geometry. After you have finished creating the path, click "***Ok***". **NOTE**: based on the way roadway segments are numbered in the PennDOT system, paths should be created from west to east and from south to north (i.e., direction of increasing segment).

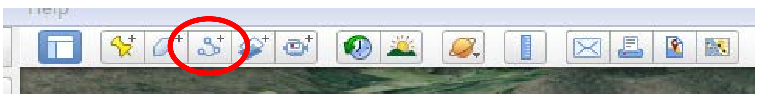

Figure B1. *"Add Path"* Icon

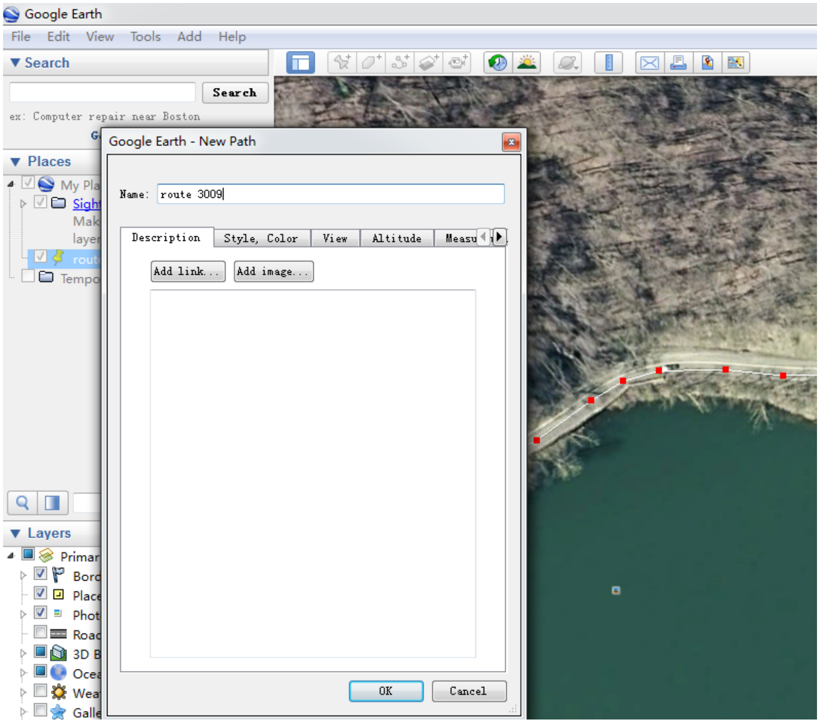

Figure B2. Screenshot for Adding Path

Step 2: Locating the starting and ending point for each segment

We must now determine the starting and ending point of each segment using the PennDOT roadway database. In Table B1, there are 18 contiguous segments on State Route (SR) 3009 in Bedford County. The first segment is 0010 while the last is 0180. The segment length in feet is provided in the fourth column, while a mileage-based segment length is shown in the fifth column. The cumulative length column is a measure of the roadway length within the county beginning at the western- or southern-most county boundary. Adjacent cumulative length values represent the beginning and ending mileposts for each segment along the route, which will be needed to use the Google Earth tool that is described in this document.

First and foremost, we need to find the beginning point for the entire route. Take segment 0010 in Bedford County as an example. When you gain access to the video log, which was illustrated in the video log sheet, a map will appear that provides a localized area map of the subject route, SR 3009 (see Figure B3). This will help you locate the starting point for the entire route. To find all the necessary locations on the Google Earth image, we will use the built-in ruler to add each segment length to the start point. Click ***"Show Ruler"***  (see Figure B4), and change the unit of length to "Feet", as shown in Figure B5.

Table B1. Length of Segments in PennDOT Profile

CNTY	SR	SEG	LENGTH(ft)	LENGTH(mi)	Begin Milepost	End Milepost	Cumulative length(mi)	SPEED	LANES	COUNTY
5	3009	10	2472	0.468182	0	0.468182	0.468182	55	2	BEDFORD
5	3009	20	2769	0.524432	0.468182	0.992614	0.992614	55	2	BEDFORD
5	3009	30	1271	0.240720	0.992614	1.233333	1.233333	55	2	BEDFORD
5	3009	40	3918	0.742045	1.233333	1.975379	1.975379	55	2	BEDFORD
5	3009	50	2929	0.554735	1.975379	2.530114	2.530114	55	2	BEDFORD
5	3009	60	1387	0.262689	2.530114	2.792803	2.792803	55	2	BEDFORD
5	3009	70	2577	0.488068	2.792803	3.280871	3.280871	55	2	BEDFORD
5	3009	80	2508	0.475000	3.280871	3.755871	3.755871	55	2	BEDFORD
5	3009	90	3015	0.571023	3.755871	4.326894	4.326894	55	2	BEDFORD
5	3009	100	2029	0.384280	4.326894	4.711174	4.711174	55	2	BEDFORD
5	3009	110	1963	0.371780	4.711174	5.082955	5.082955	55	2	BEDFORD
5	3009	120	2592	0.490909	5.082955	5.573864	5.573864	55	2	BEDFORD
5	3009	130	1937	0.366856	5.573864	5.940720	5.940720	55	2	BEDFORD
5	3009	140	1744	0.330303	5.940720	6.271023	6.271023	55	2	BEDFORD
5	3009	150	2312	0.437879	6.271023	6.708902	6.708902	55	2	BEDFORD
5	3009	160	1794	0.339773	6.708902	7.048674	7.048674	55	2	BEDFORD
5	3009	170	3978	0.753409	7.048674	7.802083	7.802083	55	2	BEDFORD
5	3009	180	2056	0.389394	7.802083	8.191477	8.191477	55	2	BEDFORD

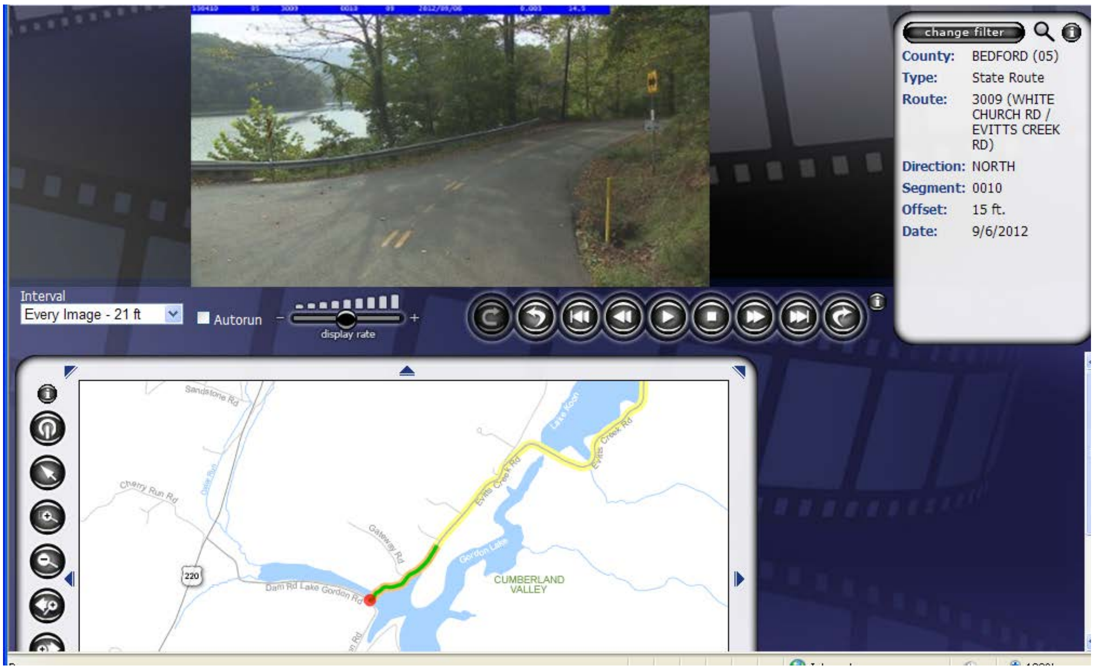

Figure B3. Screenshot for "*Show-up Map*" to locate beginning point for SR 3009

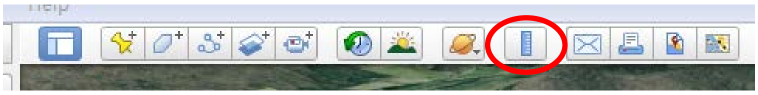

Figure B4. The "Show Ruler" Icon

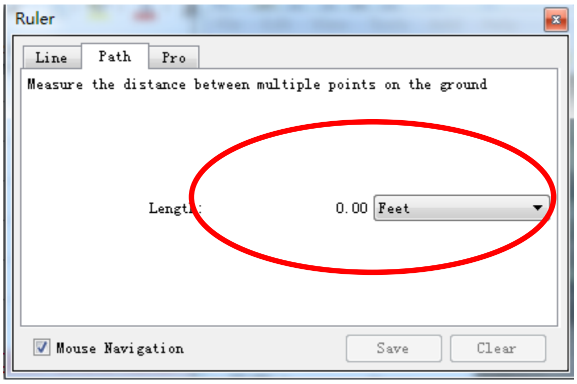

Figure B5. Screenshot for *"Show Ruler"* in The Starting Location

As shown in Table B1, the end of the first segment (0010) is 2472 ft from the start of the route in Bedford County. Using the ruler, measure a distance 2472 ft from the first point on the path. This location represents the end point of segment 0010 and the beginning point (offset 0000) of segment 0020. Save this location on the map. To do this, click ***"Save"*** and then click ***"Add Placemark"***  (see Figures B6 and B7). This will create a placemark that denotes the starting/ending point (see Figures B8 and B9).

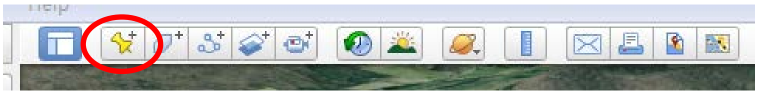

Figure B6. The *"Add Placemark"* Icon

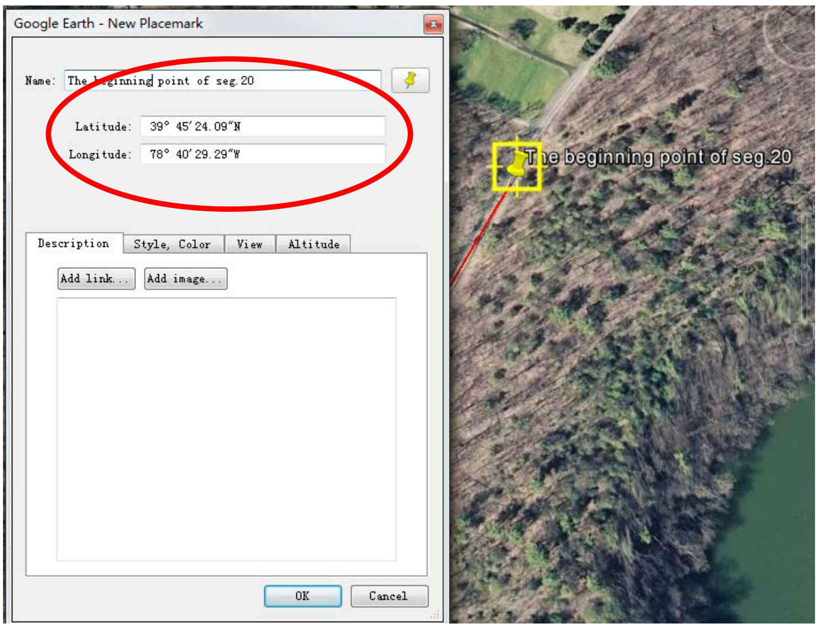

Figure B7. Screenshot for *"Add Placemark"*

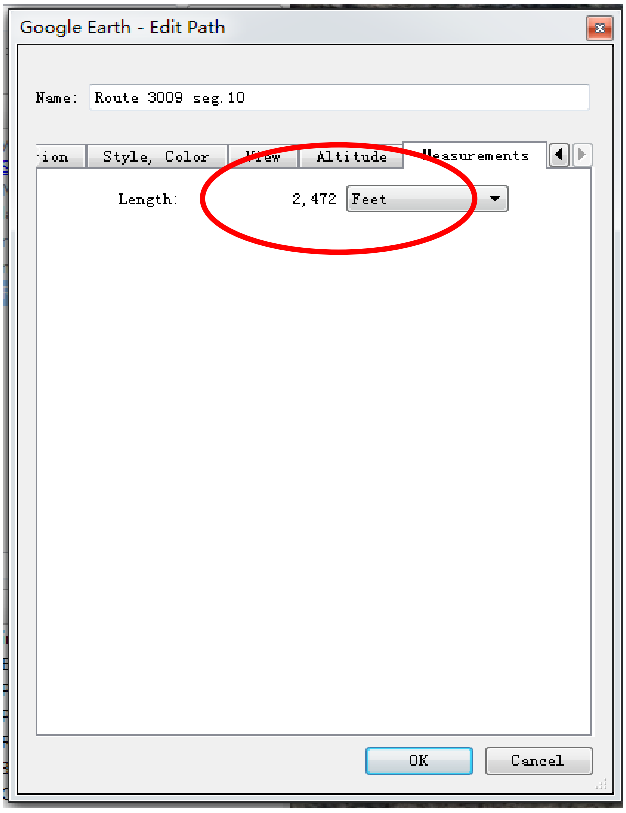

Figure B8. Locating the ending points of seg.10

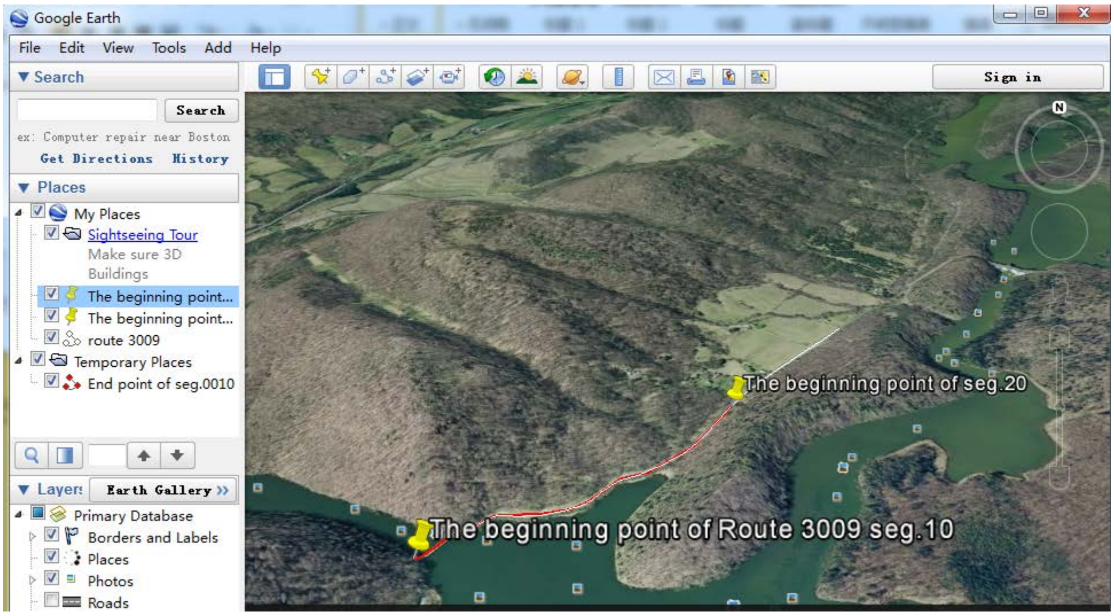

Figure B9. The Starting and Ending Points for Segments

Repeat this process for all segment starting/ending points along the route.

Step 3: Measuring Curves in Google Earth

Visually inspect each segment to identify any horizontal curves that exist based on your review of the video log. Once a curve has been identified from a driver's perspective, check the map below the video log to find the location and then go to Google Earth to confirm it. If this horizontal curve cannot be detected, scroll with the mouse to enlarge the picture. In order to keep consistently across individuals, we set up 1:1592.5cm (4cm: 209ft) as scale legend because the segment almost covers the whole screen in this zooming level (See Figure B10). This level helps when a big horizontal curve exists and stretches itself to another segment. Now, we will start to measure this curve's properties. Figure B11 shows the various components of a simple horizontal curve (AASHTO, 2011). Figure B12 shows how to apply each component on the Google Earth images. The radius of curve is "R" and the length of curve (arc) is denoted "L."

Figure B10. "Zooming Resolution" level

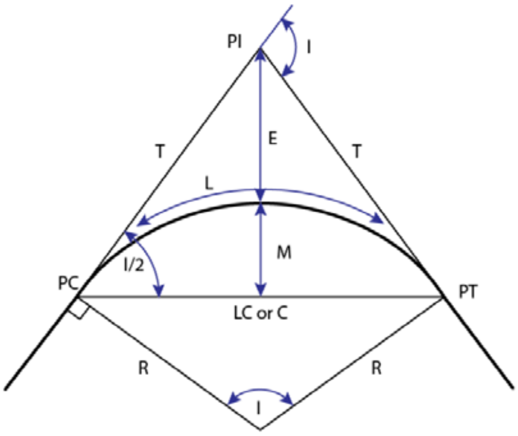

Figure B11. Measuring the length of arc and radius of the curve.

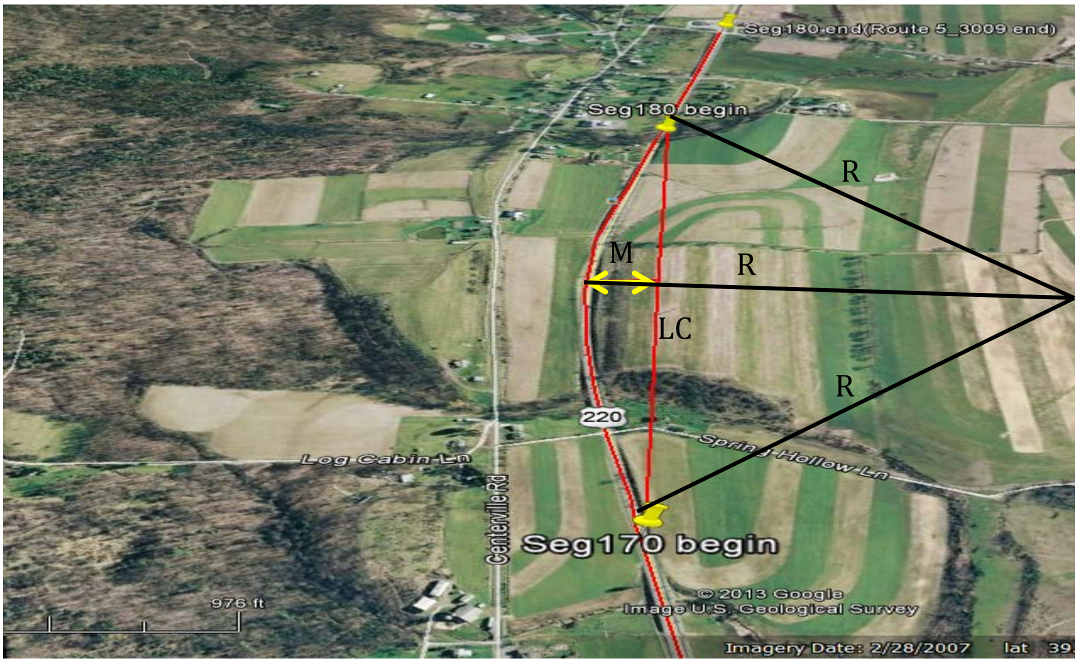

Figure B12. The Relationship between LC, M, and R

Based on the geometry of Figure B11 and Figure B12, the relationship between LC*,* M*,* and radius *R* is as follows:

$$(LC/2)^2 + (R-M)^2 = R^2 \qquad \text{(B1)}$$
$$R = LC^2/8M + M/2 \qquad \text{(B2)}$$

Consider a horizontal curve in segment 0010 of State Route 3009 in Bedford County, as an example. After identifying the curve using Google Earth, mark the two locations where the arc (length of curve) is adjacent to the intersecting tangents (labeled PC and PT in Figure B11), and record the coordinates of the PC (point of curve or beginning of curve in direction of increasing segment) and PT (point of tangent or end of curve in direction of increasing segment). This is done by clicking ***"Add Placemark"*** so you can move the yellow pin to gain the latitude and longitude information of the two points (an example is shown in Figure B13). Record the coordinates of these two points as shown in Table 31. The second procedure to measure the curve is to draw a chord (line LC or C in Figure B11) to connect the PC and PT. Then, draw a perpendicular line from the chord to the mid-point of the arc (line M in Figure B11), which is illustrated in Figures B14 and B15, respectively. Tables B2 and B3 illustrate how the data collector will populate the length of chord and mid-line length data into the respective cells.

Note that LC is the length of chord and M is the length of mid-point line, which can be calculated from the “***Show Ruler***” tool in Google Earth. The process used to access to the “***Show Ruler***” tool were noted above.

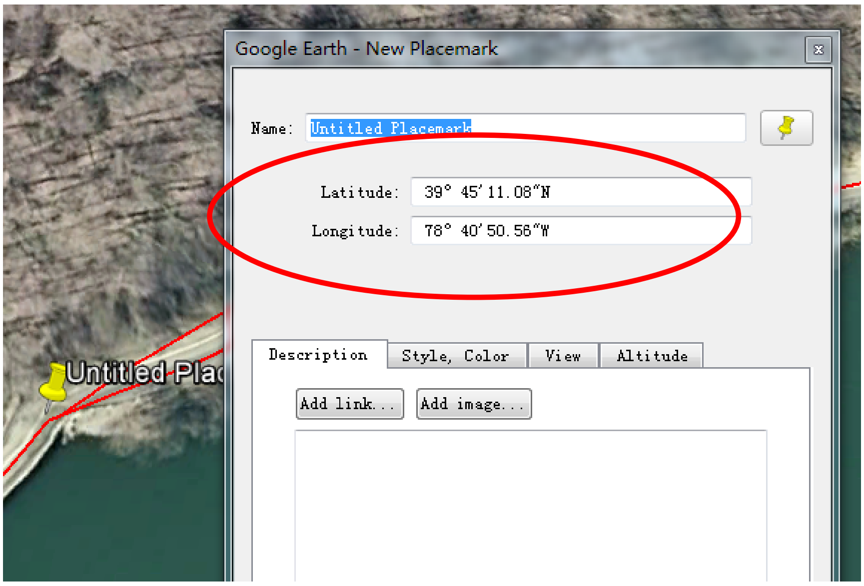

Figure B13. Example of Displaying Coordinates

Table B2. Filling in the Coordinates Data

CNTY	SR	SEG	LENGTH (ft)	Point of Tangents (PT) (1)	Length of chord(1) (LC,ft)	Mid-line length(1) (M,ft)	Radius in map(1) (ft)
5	3009	10	2472	(39°45'11.08"N, 78°40'50.56"W) (39°45'12.67"N, 78°40'47.93"W)	266.10	27.09	340.28

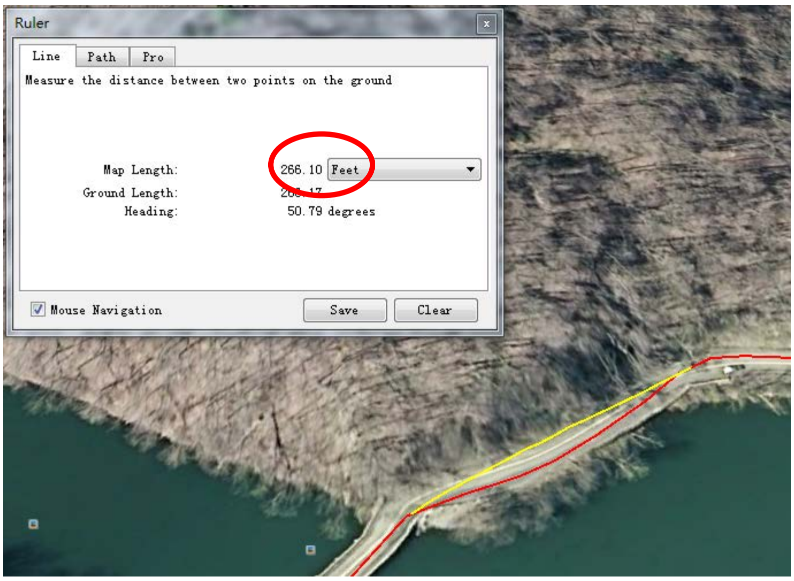

Figure B14. Example of Drawing the Chord

Table B3. Filling in Length of Chord Data

CNTY	SR	SEG	LENGTH (ft)	Point of Tangents (PT) (1)	Length of chord(1) (LC,ft)	Mid-line length(1) (M,ft)	Radius in map(1) (ft)
5	3009	10	2472	(39°45'11.08"N, 78°40'50.56"W) (39°45'12.67"N, 78°40'47.93"W)	266.10	27.09	340.28

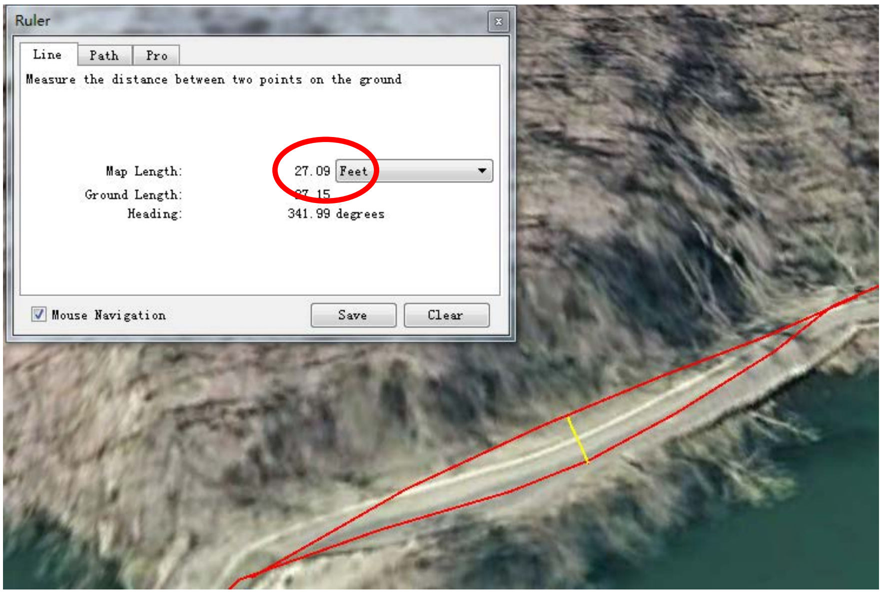

Figure B15. Example of Drawing the Mid-line

Table B4. Filling in Mid-line Data

CNTY	SR	SEG	LENGTH (ft)	Point of Tangents (PT) (1)	Length of chord(1) (LC,ft)	Mid-line length(1) (M,ft)	Radius in map(1) (ft)
5	3009	10	2472	(39°45'11.08"N, 78°40'50.56"W) (39°45'12.67"N, 78°40'47.93"W)	266.10	27.09	340.28

From equation (B2), the radius (R) is derived from the LC and M terms. The results are displayed in Table B5. When a segment does not have any curves, put an **"X"** in the curve cells for that particular segment to designate that you have checked the segment and no curves exist. Similarly, if there are more than three curves in a current segment, insert more curve columns to the database, to the right of the existing curve data columns. Note that if a single horizontal curve crosses two adjacent segments, this curve should be "split" into two parts and recorded in the corresponding segment data cells. For example, if a horizontal curve begins in segment 0040 and continues into segment 0050, the horizontal curve component that exists in segment 0040 will be recorded in segment 0040, and the other component of the curve that exists in segment 0050 will be identified as another horizontal curve in segment 0050. The end point of the curve (PT) in segment 0040 should be equal to the beginning point of the curve (PC) in segment 0050.

Table B5. PT Coordinates, Length of chord, Mid-line Length and Radius of Curve

CNTY	SR	SEG	LENGTH (ft)	Point of Tangents (1) (PT)	Length of chord (1) (LC,ft)	Middle line length (1) (M,ft)	Radius on map (1) (ft)	Point of Tangents (2) (PT)	Length of chord (2) (LC,ft)	Middle line length (2) (M,ft)	Radius in map (2) (ft)	Point of Tangents (3) (PT)	Length of chord (3) (LC,ft)	Middle line length (3) (M,ft)	Radius io map (3) (ft)
5	3009	10	2472	(39°45'11.08"N, 78°40'50.56"W) (39°45'12.67"N, 78°40'47.93"W)	266.1	27.09	340.28	(39°45'12.61"N, 78°40'47.99"W) (39°45'16.01"N, 78°40'38.94"W)	780.00	138.74	617.52	(39°45'16.01"N, 78°40'38.94"W) (39°45'19.69"N, 78°40'32.92"W)	1119.32	113.50	1436.57
5	3009	20	2769	(39°45'40.62"N, 78°40'12.15"W) (39°45'45.77"N, 78°40'6.14"W)	705.97	144.85	502.52	X	X	X	X	X	X	X	X
5	3009	40	3918	(39°46'1.78"N, 78°39'19.77"W) (39°46'3.60"N, 78°39'18.04"W)	222.88	13.06	481.98	X	X	X	X	X	X	X	X
5	3009	50	2929	(39°46'3.60"N, 78°39'18.04"W) (39°46'5.27"N, 78°39'17.78"W)	172.65	8.62	436.56	X	X	X	X	X	X	X	X

Intersection Data Collection

When it comes to the intersection skew angle data collection, we can zoom in the Google Map to enlarge the intersection, and place the protractor on the computer screen to measure the skew angle of the intersection. The skew angle is the smallest angle between the two intersection roads, and should also be less than or equal to 90 degrees.

Figure B16. Intersection skew angle of SR 3009 and SR3012

APPENDIX C

ENGINEERING DISTRICT SPFs FOR TOTAL AND FATAL+INJURY CRASHES ON TWO-LANE RURAL ROAD SEGMENTS

District 1 Total Crash SPF

```
Negative binomial regression                      Number of obs   =      19482
                                                  LR chi2(9)      =    2229.65
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -18569.866                       Pseudo R2       =     0.0566

------------------------------------------------------------------------------
  total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+---------------------------------------------------------------
       lnaadt |   .5872055   .0174332    33.68   0.000     .5530371     .621374
        rhr34 |   .3334148   .1326828     2.51   0.012     .0733613    .5934683
       rhr567 |   .4347278    .132578     3.28   0.001     .1748798    .6945759
    pass_zone |  -.1725044   .0235907    -7.31   0.000    -.2187413   -.1262675
        sh_rs |  -.0859003    .036089    -2.38   0.017    -.1566333   -.0151672
accessdensity |   .0094778   .0006693    14.16   0.000      .008166    .0107897
curve_density |   .0560092    .008402     6.67   0.000     .0395416    .0724769
     d_seg_mi |   .0016775   .0006214     2.70   0.007     .0004594    .0028955
 county276061 |   -.244946   .0270929    -9.04   0.000    -.2980471   -.1918449
        _cons |  -4.946174   .1881139   -26.29   0.000     -5.31487   -4.577477
     lnlength |          1  (offset)
--------------+---------------------------------------------------------------
     /lnalpha |  -.7978025   .0565348                     -.9086086   -.6869964
--------------+---------------------------------------------------------------
        alpha |   .4503175   .0254586                      .4030847    .5030849
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  554.35 Prob>=chibar2 = 0.000
```

District 1 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs   =      19482
                                                  LR chi2(9)      =    1355.66
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -13334.985                       Pseudo R2       =     0.0484

------------------------------------------------------------------------------
    fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+---------------------------------------------------------------
       lnaadt |   .5680252   .0225159    25.23   0.000     .5238948    .6121555
        rhr34 |   .5509551   .1895302     2.91   0.004     .1794827    .9224275
       rhr567 |   .6317566   .1894391     3.33   0.001     .2604627     1.00305
    pass_zone |  -.1833368   .0304208    -6.03   0.000    -.2429605   -.1237131
        sh_rs |  -.1230081   .0472679    -2.60   0.009    -.2156516   -.0303647
accessdensity |   .0096964   .0008562    11.32   0.000     .0080182    .0113745
curve_density |   .0548795   .0107799     5.09   0.000     .0337513    .0760078
     d_seg_mi |   .0015832    .000786     2.01   0.044     .0000426    .0031237
 county276061 |  -.2751542   .0352277    -7.81   0.000    -.3441992   -.2061093
        _cons |  -5.554013   .2563434   -21.67   0.000    -6.056437   -5.051589
     lnlength |          1  (offset)
--------------+---------------------------------------------------------------
     /lnalpha |  -.5249502   .0746327                     -.6712275   -.3786728
--------------+---------------------------------------------------------------
        alpha |   .5915849   .0441516                      .5110808    .6847696
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  309.80 Prob>=chibar2 = 0.000
```

District 2 Total Crash SPF

```
Negative binomial regression                      Number of obs   =      25952
                                                  LR chi2(9)      =    3931.68
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -20171.521                       Pseudo R2       =     0.0888

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .6485827    .013193    49.16   0.000     .6227249    .6744405
       rhr_4 |   .0912307   .0539113     1.69   0.091    -.0144336     .196895
      rhr567 |   .1005593   .0505175     1.99   0.047     .0015468    .1995719
   pass_zone |  -.2743023   .0246308   -11.14   0.000    -.3225779   -.2260268
accessdensity |   .0099464   .0007545    13.18   0.000     .0084676    .0114251
curve_density |    .017419   .0060849     2.86   0.004     .0054928    .0293451
    d_seg_mi |    .001463   .0002526     5.79   0.000     .0009679    .0019582
    county17 |   .0843682   .0287604     2.93   0.003     .0279988    .1407376
  county4452 |  -.3632593   .0343848   -10.56   0.000    -.4306522   -.2958664
       _cons |  -5.245193   .1147752   -45.70   0.000    -5.470148   -5.020238
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.8696119   .0624747                     -.9920601   -.7471637
-------------+----------------------------------------------------------------
       alpha |   .4191142    .026184                       .370812    .4737082
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  436.13 Prob>=chibar2 = 0.000
```

District 2 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs   =      25952
                                                  LR chi2(8)      =    2142.74
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -14253.653                       Pseudo R2       =     0.0699

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .6000208   .0170754    35.14   0.000     .5665536    .6334879
     rhr4567 |   .1043321   .0662754     1.57   0.115    -.0255652    .2342295
   pass_zone |  -.2417615   .0323427    -7.47   0.000     -.305152   -.1783709
accessdensity |   .0109456   .0009838    11.13   0.000     .0090175    .0128738
curve_density |   .0212681   .0079627     2.67   0.008     .0056614    .0368748
    d_seg_mi |   .0013198    .000331     3.99   0.000     .0006709    .0019686
    county17 |   .1459858   .0369513     3.95   0.000     .0735626    .2184089
  county4452 |  -.3605743    .044889    -8.03   0.000    -.4485552   -.2725934
       _cons |   -5.50125   .1489782   -36.93   0.000    -5.793242   -5.209258
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.4829217   .0797686                     -.6392653   -.3265781
-------------+----------------------------------------------------------------
       alpha |   .6169781   .0492155                        .52768     .721388
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  265.67 Prob>=chibar2 = 0.000
```

District 3 Total Crash SPF

```
Negative binomial regression                      Number of obs   =      22488
                                                  LR chi2(9)      =    2903.91
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -19555.191                       Pseudo R2       =     0.0691

------------------------------------------------------------------------------
  total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+----------------------------------------------------------------
       lnaadt |   .6643926   .0156295    42.51   0.000     .6337595    .6950258
    pass_zone |  -.1364248   .0243238    -5.61   0.000    -.1840984   -.0887511
        sh_rs |  -.1447669   .0537026    -2.70   0.007    -.2500219   -.0395118
accessdensity |   .0112307   .0008586    13.08   0.000     .0095478    .0129135
curve_density |   .0413751   .0059549     6.95   0.000     .0297037    .0530466
     d_seg_mi |   .0014288   .0002856     5.00   0.000     .0008691    .0019885
      county8 |   .0988094   .0287497     3.44   0.001      .042461    .1551578
   county4147 |    .089789   .0312559     2.87   0.004     .0285286    .1510495
   county5659 |  -.1479932   .0381314    -3.88   0.000    -.2227293    -.073257
        _cons |  -5.345157   .1271168   -42.05   0.000    -5.594301   -5.096012
     lnlength |          1  (offset)
--------------+----------------------------------------------------------------
     /lnalpha |  -.7349491   .0549179                     -.8425862   -.6273121
--------------+----------------------------------------------------------------
        alpha |   .4795298   .0263348                      .4305955    .5340253
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  611.41 Prob>=chibar2 = 0.000
```

District 3 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs   =      22488
                                                  LR chi2(7)      =    1687.28
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -13337.289                       Pseudo R2       =     0.0595

------------------------------------------------------------------------------
    fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+----------------------------------------------------------------
       lnaadt |   .6582399   .0205189    32.08   0.000     .6180235    .6984562
    pass_zone |  -.1320909   .0323489    -4.08   0.000    -.1954935   -.0686883
        sh_rs |  -.1815605   .0716464    -2.53   0.011    -.3219848   -.0411362
accessdensity |   .0121938   .0011241    10.85   0.000     .0099906    .0143969
curve_density |   .0538105   .0079156     6.80   0.000     .0382962    .0693249
     d_seg_mi |    .000967   .0003906     2.48   0.013     .0002014    .0017326
   county5659 |  -.1877215   .0486016    -3.86   0.000    -.2829789   -.0924641
        _cons |  -5.935613   .1649104   -35.99   0.000    -6.258831   -5.612394
     lnlength |          1  (offset)
--------------+----------------------------------------------------------------
     /lnalpha |   -.439871   .0759896                     -.5888078   -.2909341
--------------+----------------------------------------------------------------
        alpha |   .6441195   .0489464                      .5549886    .7475649
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  310.70 Prob>=chibar2 = 0.000
```

District 4 Total Crash SPF

```
Negative binomial regression                      Number of obs   =      15310
                                                  LR chi2(6)      =    2897.00
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -15261.096                       Pseudo R2       =     0.0867

------------------------------------------------------------------------------
  total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+----------------------------------------------------------------
       lnaadt |   .7183075   .0165554    43.39   0.000     .6858596    .7507554
    pass_zone |  -.2078609   .0453214    -4.59   0.000    -.2966892   -.1190326
accessdensity |   .0097949    .000885    11.07   0.000     .0080604    .0115294
curve_density |   .0184265   .0070385     2.62   0.009     .0046312    .0322218
     d_seg_mi |   .0023282    .000507     4.59   0.000     .0013344    .0033219
 county405165 |    .185188   .0254595     7.27   0.000     .1352882    .2350877
        _cons |  -5.678622   .1276956   -44.47   0.000      -5.9289   -5.428343
     lnlength |          1  (offset)
--------------+----------------------------------------------------------------
     /lnalpha |  -.8851435   .0586697                     -1.000134   -.7701531
--------------+----------------------------------------------------------------
        alpha |   .4126549   .0242103                      .3678301    .4629422
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  553.98 Prob>=chibar2 = 0.000
```

District 4 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs   =      15310
                                                  LR chi2(6)      =    1764.45
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -10784.79                        Pseudo R2       =     0.0756

------------------------------------------------------------------------------
    fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+----------------------------------------------------------------
       lnaadt |    .725164   .0218038    33.26   0.000     .6824292    .7678987
    pass_zone |  -.1337534   .0580565    -2.30   0.021    -.2475421   -.0199647
accessdensity |   .0109469   .0011457     9.55   0.000     .0087013    .0131925
curve_density |   .0178027   .0091932     1.94   0.053    -.0002157    .0358211
     d_seg_mi |   .0022683   .0006528     3.47   0.001     .0009888    .0035478
 county405165 |   .1473166   .0335038     4.40   0.000     .0816503    .2129829
        _cons |  -6.358134    .168606   -37.71   0.000    -6.688595   -6.027672
     lnlength |          1  (offset)
--------------+----------------------------------------------------------------
     /lnalpha |  -.5734437   .0778516                       -.72603   -.4208574
--------------+----------------------------------------------------------------
        alpha |   .5635813   .0438757                       .483826    .6564837
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  302.16 Prob>=chibar2 = 0.000
```

District 5 Total Crash SPF

```
Negative binomial regression                      Number of obs   =      10768
                                                  LR chi2(10)     =    3090.36
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -15907.217                       Pseudo R2       =     0.0885

------------------------------------------------------------------------------
  total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+---------------------------------------------------------------
       lnaadt |   .6545731   .0167845    39.00   0.000     .6216761    .6874702
       rhr567 |   .1145532   .0300741     3.81   0.000      .055609    .1734974
    pass_zone |  -.1395914   .0350573    -3.98   0.000    -.2083025   -.0708804
accessdensity |   .0111298   .0008977    12.40   0.000     .0093703    .0128892
curve_density |   .0163954   .0064391     2.55   0.011     .0037751    .0290158
     d_seg_mi |   .0028667    .000349     8.21   0.000     .0021827    .0035507
   county0645 |   .6602748   .0318506    20.73   0.000     .5978488    .7227008
     county13 |   .1456293   .0457782     3.18   0.001     .0559056     .235353
     county39 |   .2962797   .0608457     4.87   0.000     .1770242    .4155351
     county48 |   .3952719   .0509038     7.77   0.000     .2955023    .4950415
        _cons |  -5.243783   .1507448   -34.79   0.000    -5.539238   -4.948329
     lnlength |          1  (offset)
--------------+---------------------------------------------------------------
     /lnalpha |  -.6314484   .0380441                     -.7060135   -.5568833
--------------+---------------------------------------------------------------
        alpha |    .531821   .0202327                      .4936081    .5729921
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) = 1905.21 Prob>=chibar2 = 0.000
```

District 5 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs   =      10768
                                                  LR chi2(10)     =    1930.72
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -11535.574                       Pseudo R2       =     0.0772

------------------------------------------------------------------------------
    fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+---------------------------------------------------------------
       lnaadt |   .6582027   .0212071    31.04   0.000     .6166375    .6997679
       rhr567 |    .129262   .0375278     3.44   0.001     .0557088    .2028152
    pass_zone |  -.1444908   .0444736    -3.25   0.001    -.2316574   -.0573243
accessdensity |   .0115012   .0010986    10.47   0.000     .0093479    .0136544
curve_density |   .0160965    .008064     2.00   0.046     .0002914    .0319016
     d_seg_mi |   .0026983   .0004348     6.21   0.000     .0018461    .0035506
   county0645 |   .5347131   .0400668    13.35   0.000     .4561835    .6132426
     county13 |   .1063286   .0579985     1.83   0.067    -.0073463    .2200035
     county39 |   .3106493   .0749888     4.14   0.000      .163674    .4576247
     county48 |   .3702681   .0634639     5.83   0.000     .2458812    .4946551
        _cons |  -5.873316   .1902577   -30.87   0.000    -6.246214   -5.500418
     lnlength |          1  (offset)
--------------+---------------------------------------------------------------
     /lnalpha |  -.5138261   .0545064                     -.6206566   -.4069955
--------------+---------------------------------------------------------------
        alpha |   .5982024   .0326059                      .5375913    .6656472
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  753.98 Prob>=chibar2 = 0.000
```

District 6 Total Crash SPF

```
Negative binomial regression                      Number of obs   =       4272
                                                  LR chi2(7)      =     705.18
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -6224.4953                       Pseudo R2       =     0.0536

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .6125753   .0270829    22.62   0.000     .5594939    .6656567
       rhr45 |   .1830455   .0734254     2.49   0.013     .0391343    .3269567
       rhr67 |   .2882832   .0886163     3.25   0.001     .1145985    .4619679
accessdensity |  .0095593    .001246     7.67   0.000     .0071171    .0120015
curve_density |  .0478631   .0095391     5.02   0.000     .0291668    .0665594
    d_seg_mi |   .0014711   .0007208     2.04   0.041     .0000583    .0028839
    county46 |   .1941046   .0728214     2.67   0.008     .0513773    .3368318
       _cons |  -4.825541   .2437863   -19.79   0.000    -5.303353   -4.347728
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.6288651   .0610857                     -.7485909   -.5091393
-------------+----------------------------------------------------------------
       alpha |   .5331966   .0325707                      .4730326    .6010126
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  708.32 Prob>=chibar2 = 0.000
```

District 6 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs   =       4272
                                                  LR chi2(4)      =     427.55
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -4422.3964                       Pseudo R2       =     0.0461

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .5891907   .0337347    17.47   0.000     .5230719    .6553095
accessdensity |  .0098488   .0015315     6.43   0.000     .0068472    .0128504
curve_density |   .061557   .0089638     6.87   0.000     .0439883    .0791256
    county46 |   .2650477   .0904302     2.93   0.003     .0878078    .4422876
       _cons |  -5.144041   .2924995   -17.59   0.000    -5.717329   -4.570752
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.4172964   .0855382                     -.5849482   -.2496447
-------------+----------------------------------------------------------------
       alpha |   .6588256   .0563547                      .5571347    .7790776
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  311.83 Prob>=chibar2 = 0.000
```

District 8 Total Crash SPF

```
Negative binomial regression                      Number of obs   =      22896
                                                  LR chi2(8)      =    4987.95
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -28359.414                       Pseudo R2       =     0.0808

------------------------------------------------------------------------------
  total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+----------------------------------------------------------------
       lnaadt |   .7108351   .0117292    60.60   0.000     .6878462    .7338239
    pass_zone |  -.2270131   .0234847    -9.67   0.000    -.2730421   -.180984
accessdensity |   .0052941   .0007089     7.47   0.000     .0039047    .0066836
curve_density |   .0343204   .0053633     6.40   0.000     .0238086    .0448322
     d_seg_mi |   .0024064   .0003501     6.87   0.000     .0017202    .0030927
   county0136 |   .2244159    .022224    10.10   0.000     .1808577    .2679741
   county2250 |  -.0836708   .0255397    -3.28   0.001    -.1337277   -.0336139
     county66 |   .0904898   .0271462     3.33   0.001     .0372842    .1436955
        _cons |  -5.422361    .099506   -54.49   0.000    -5.617389   -5.227333
     lnlength |          1  (offset)
--------------+----------------------------------------------------------------
     /lnalpha |   -.636323   .0318551                     -.6987577   -.5738882
--------------+----------------------------------------------------------------
        alpha |   .5292349   .0168588                      .4972026    .5633308
```

District 8 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs   =      22896
                                                  LR chi2(8)      =    3310.50
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -20309.285                       Pseudo R2       =     0.0754

------------------------------------------------------------------------------
    fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+----------------------------------------------------------------
       lnaadt |    .717571       .015    47.84   0.000     .6881715    .7469705
    pass_zone |  -.2470604   .0298904    -8.27   0.000    -.3056445   -.1884764
accessdensity |   .0054641   .0008836     6.18   0.000     .0037323    .0071959
curve_density |    .034726   .0067587     5.14   0.000     .0214791    .0479729
     d_seg_mi |   .0020881   .0004377     4.77   0.000     .0012303     .002946
   county0136 |    .243897   .0278094     8.77   0.000     .1893916    .2984023
   county2250 |  -.0926619   .0327494    -2.83   0.005    -.1568496   -.0284743
     county66 |   .0977064   .0343405     2.85   0.004     .0304002    .1650125
        _cons |  -6.112312   .1278742   -47.80   0.000    -6.362941   -5.861683
     lnlength |          1  (offset)
--------------+----------------------------------------------------------------
     /lnalpha |  -.5383551   .0463995                     -.6292964   -.4474138
--------------+----------------------------------------------------------------
        alpha |   .5837076   .0270837                      .5329667    .6392793
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  947.79 Prob>=chibar2 = 0.000
```

District 9 Total Crash SPF

```
Negative binomial regression                      Number of obs   =      17792
                                                  LR chi2(9)      =    2530.20
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -16113.54                        Pseudo R2       =     0.0728
```

total_crash	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnaadt	.7343079	.0168633	43.54	0.000	.7012564	.7673595
rhr567	.2061116	.0274069	7.52	0.000	.1523951	.2598281
pass_zone	-.1667527	.0323153	-5.16	0.000	-.2300895	-.1034159
sh_rs	-.11763	.0295999	-3.97	0.000	-.1756448	-.0596152
accessdensity	.0067323	.0008277	8.13	0.000	.0051101	.0083545
curve_density	.0375363	.0064118	5.85	0.000	.0249694	.0501032
d_seg_mi	.0015457	.0002696	5.73	0.000	.0010173	.002074
county050711	.1029852	.0260663	3.95	0.000	.0518961	.1540743
county29	.3129736	.0424624	7.37	0.000	.2297488	.3961985
_cons	-6.038617	.1342157	-44.99	0.000	-6.301675	-5.775559
lnlength	1	(offset)				
/lnalpha	-.8535287	.0625435			-.9761118	-.7309457
alpha	.4259094	.0266379			.3767732	.4814535

Likelihood-ratio test of alpha=0: chibar2(01) = 448.48 Prob>=chibar2 = 0.000

District 9 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs   =      17792
                                                  LR chi2(9)      =    1494.18
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -11484.904                       Pseudo R2       =     0.0611
```

fatal_inj	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnaadt	.7282982	.0216206	33.69	0.000	.6859226	.7706739
rhr567	.1632931	.0351318	4.65	0.000	.094436	.2321502
pass_zone	-.2124138	.0420315	-5.05	0.000	-.294794	-.1300335
sh_rs	-.182055	.0384755	-4.73	0.000	-.2574655	-.1066445
accessdensity	.0056305	.0010641	5.29	0.000	.0035448	.0077162
curve_density	.0407421	.0081973	4.97	0.000	.0246756	.0568085
d_seg_mi	.0014293	.0003383	4.23	0.000	.0007664	.0020923
county050711	.0978001	.0335934	2.91	0.004	.0319583	.163642
county29	.3215966	.0543312	5.92	0.000	.2151093	.4280839
_cons	-6.510372	.1724749	-37.75	0.000	-6.848417	-6.172327
lnlength	1	(offset)				
/lnalpha	-.7029944	.0924955			-.8842823	-.5217065
alpha	.4951006	.0457946			.4130105	.5935069

Likelihood-ratio test of alpha=0: chibar2(01) = 185.62 Prob>=chibar2 = 0.000

District 10 Total Crash SPF

```
Negative binomial regression                      Number of obs   =      15672
                                                  LR chi2(10)     =    2489.93
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -15632.024                       Pseudo R2       =     0.0738

------------------------------------------------------------------------------
  total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+----------------------------------------------------------------
       lnaadt |   .7019259   .0165603    42.39   0.000     .6694683    .7343835
        rhr_4 |   .1317801   .0424525     3.10   0.002     .0485748    .2149854
       rhr567 |   .2255163   .0403951     5.58   0.000     .1463433    .3046893
    pass_zone |  -.1469089   .0265061    -5.54   0.000    -.1988599   -.0949579
        sh_rs |  -.1228636   .0483457    -2.54   0.011    -.2176193   -.0281078
accessdensity |   .0066485   .0007539     8.82   0.000     .0051709    .0081261
curve_density |   .0262822   .0063301     4.15   0.000     .0138755     .038689
     d_seg_mi |    .000913   .0003012     3.03   0.002     .0003226    .0015035
   county0316 |   .0938071   .0270789     3.46   0.001     .0407335    .1468808
     county10 |   .1730156   .0300247     5.76   0.000     .1141682     .231863
        _cons |  -5.776607    .139076   -41.54   0.000    -6.049191   -5.504023
     lnlength |          1  (offset)
--------------+----------------------------------------------------------------
     /lnalpha |  -1.225649    .077448                     -1.377444   -1.073854
--------------+----------------------------------------------------------------
        alpha |   .2935671   .0227362                      .2522223    .3416892
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  258.45 Prob>=chibar2 = 0.000
```

District 10 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs   =      15672
                                                  LR chi2(10)     =    1444.17
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -11395.377                       Pseudo R2       =     0.0596

------------------------------------------------------------------------------
    fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+----------------------------------------------------------------
       lnaadt |   .6813696   .0215496    31.62   0.000     .6391332     .723606
        rhr_4 |   .1062179   .0547243     1.94   0.052    -.0010397    .2134756
       rhr567 |   .1782215   .0520821     3.42   0.001     .0761425    .2803005
    pass_zone |  -.1425726   .0344999    -4.13   0.000    -.2101913    -.074954
        sh_rs |  -.1247308   .0631279    -1.98   0.048    -.2484591   -.0010024
accessdensity |   .0070833   .0009749     7.27   0.000     .0051725    .0089941
curve_density |   .0231383   .0082658     2.80   0.005     .0069377    .0393389
     d_seg_mi |   .0008901   .0003922     2.27   0.023     .0001215    .0016588
   county0316 |   .1057425     .03522     3.00   0.003     .0367126    .1747724
     county10 |   .1518161   .0391352     3.88   0.000     .0751124    .2285197
        _cons |  -6.141224   .1808346   -33.96   0.000    -6.495653   -5.786794
     lnlength |          1  (offset)
--------------+----------------------------------------------------------------
     /lnalpha |  -.8939888   .0982041                     -1.086465   -.7015123
--------------+----------------------------------------------------------------
        alpha |    .409021   .0401675                       .337407    .4958349
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  159.01 Prob>=chibar2 = 0.000
```

District 11 Total Crash SPF

```
Negative binomial regression                      Number of obs   =       4080
                                                  LR chi2(8)      =     491.61
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -4497.3552                       Pseudo R2       =     0.0518

------------------------------------------------------------------------------
  total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       lnaadt |   .5708137   .0342393    16.67   0.000      .503706    .6379214
        rhr_5 |   .2933594   .0601101     4.88   0.000     .1755458    .4111731
        rhr67 |    .327187   .0758546     4.31   0.000     .1785148    .4758592
accessdensity |   .0085258   .0015565     5.48   0.000     .0054751    .0115764
curve_density |   .0290099   .0130824     2.22   0.027     .0033689     .054651
     d_seg_mi |   .0012727   .0004956     2.57   0.010     .0003013    .0022442
      county2 |   .3792507   .1220958     3.11   0.002     .1399473    .6185541
      county4 |   .3909686   .0579359     6.75   0.000     .2774163     .504521
        _cons |   -4.94486    .279951   -17.66   0.000    -5.493554   -4.396166
     lnlength |          1  (offset)
-------------+----------------------------------------------------------------
     /lnalpha |  -.7020661   .0971984                     -.8925715   -.5115607
-------------+----------------------------------------------------------------
        alpha |   .4955604   .0481677                      .4096011    .5995591
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  208.71 Prob>=chibar2 = 0.000
```

District 11 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs   =       4080
                                                  LR chi2(8)      =     263.77
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -3190.528                        Pseudo R2       =     0.0397

------------------------------------------------------------------------------
    fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       lnaadt |   .5524361   .0443536    12.46   0.000     .4655046    .6393675
        rhr_5 |   .2646961   .0781052     3.39   0.001     .1116126    .4177795
        rhr67 |   .3166667   .0984609     3.22   0.001     .1236868    .5096465
accessdensity |   .0064015   .0020572     3.11   0.002     .0023696    .0104335
curve_density |   .0434331   .0169554     2.56   0.010     .0102011    .0766652
     d_seg_mi |   .0006614   .0006602     1.00   0.316    -.0006327    .0019554
      county2 |    .284272   .1572523     1.81   0.071    -.023937     .5924809
      county4 |   .3381879    .075473     4.48   0.000     .1902635    .4861123
        _cons |  -5.351274   .3629734   -14.74   0.000    -6.062689   -4.639859
     lnlength |          1  (offset)
-------------+----------------------------------------------------------------
     /lnalpha |  -.4868889   .1367027                     -.7548213   -.2189564
-------------+----------------------------------------------------------------
        alpha |   .6145353   .0840087                      .4700946    .8033567
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   97.35 Prob>=chibar2 = 0.000
```

District 12 Total Crash SPF

```
Negative binomial regression                      Number of obs   =      11756
                                                  LR chi2(6)      =    2042.98
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -12485.824                       Pseudo R2       =     0.0756

------------------------------------------------------------------------------
  total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+----------------------------------------------------------------
       lnaadt |   .6296277     .01756    35.86   0.000     .5952108    .6640447
    pass_zone |  -.1525146   .0358959    -4.25   0.000    -.2228692    -.08216
accessdensity |   .0149771    .001064    14.08   0.000     .0128917    .0170624
     d_seg_mi |   .0017972    .000286     6.28   0.000     .0012366    .0023578
     county26 |   .1383483   .0333514     4.15   0.000     .0729808    .2037158
     county30 |  -.2410938   .0379693    -6.35   0.000    -.3155122   -.1666753
        _cons |  -4.947995    .142315   -34.77   0.000    -5.226927   -4.669063
     lnlength |          1  (offset)
--------------+----------------------------------------------------------------
     /lnalpha |  -1.071503   .0716825                     -1.211999   -.9310083
--------------+----------------------------------------------------------------
        alpha |   .3424932   .0245508                      .2976019    .3941561
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  331.09 Prob>=chibar2 = 0.000
```

District 12 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs   =      11756
                                                  LR chi2(6)      =    1236.79
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -9202.3282                       Pseudo R2       =     0.0630

------------------------------------------------------------------------------
    fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
--------------+----------------------------------------------------------------
       lnaadt |   .6151826   .0228167    26.96   0.000     .5704626    .6599026
    pass_zone |  -.2162583   .0477208    -4.53   0.000    -.3097895   -.1227272
accessdensity |   .0164794   .0013697    12.03   0.000     .0137949    .0191639
     d_seg_mi |   .0018147   .0003684     4.93   0.000     .0010928    .0025367
     county26 |   .2006097   .0431319     4.65   0.000     .1160728    .2851466
     county30 |  -.2124702    .049212    -4.32   0.000     -.308924   -.1160165
        _cons |   -5.42705   .1848752   -29.36   0.000    -5.789398   -5.064701
     lnlength |          1  (offset)
--------------+----------------------------------------------------------------
     /lnalpha |  -.6638172   .0866811                      -.833709   -.4939253
--------------+----------------------------------------------------------------
        alpha |   .5148822   .0446306                       .434435    .6102264
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  226.45 Prob>=chibar2 = 0.000
```

APPENDIX D

TOTAL AND FATAL+INJURY SPFs FOR INTERSECTIONS ON TWO-LANE RURAL HIGHWAYS

4-leg Signalized Statewide Total Crash SPF

```
Negative binomial regression                      Number of obs     =        840
                                                  LR chi2(5)        =     174.82
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -1832.3353                       Pseudo R2         =     0.0455

------------------------------------------------------------------------------
  TotalCrash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   lnAADTMaj |   .3130848   .0730359     4.29   0.000      .169937    .4562325
 lnAADTMinor |   .2503745   .0708532     3.53   0.000     .1115047    .3892442
    SpeedMaj |   .0252611   .0042305     5.97   0.000     .0169696    .0335527
    SpeedMin |   .0144646   .0043317     3.34   0.001     .0059747    .0229545
    ERTMajor |   .2155217   .0915857     2.35   0.019     .0360171    .3950264
       _cons |  -5.353049   .5518726    -9.70   0.000      -6.4347   -4.271399
-------------+----------------------------------------------------------------
    /lnalpha |  -.5472675   .0906781                     -.7249933   -.3695416
-------------+----------------------------------------------------------------
       alpha |   .5785285   .0524599                      .4843278     .691051
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  481.24 Prob>=chibar2 = 0.000
```

4-leg Signalized Statewide Fatal + Injury SPF

```
Negative binomial regression                      Number of obs     =        840
                                                  LR chi2(5)        =     109.79
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -1428.9306                       Pseudo R2         =     0.0370

------------------------------------------------------------------------------
 TotalFatInj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   lnAADTMaj |   .2023028   .0939608     2.15   0.031      .018143    .3864626
 lnAADTMinor |   .2093656   .0908324     2.30   0.021     .0313373    .3873938
    SpeedMaj |   .0283435   .0054363     5.21   0.000     .0176886    .0389984
    SpeedMin |   .0177271   .0055282     3.21   0.001     .0068919    .0285622
    ERTMajor |   .3880421   .1166886     3.33   0.001     .1593366    .6167476
       _cons |  -4.960176   .7148187    -6.94   0.000    -6.361194   -3.559157
-------------+----------------------------------------------------------------
    /lnalpha |  -.1142026   .1042722                     -.3185724    .0901672
-------------+----------------------------------------------------------------
       alpha |   .8920772   .0930189                      .7271864    1.094357
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  336.84 Prob>=chibar2 = 0.000
```

3-leg Signalized Statewide Total Crash SPF

```
Negative binomial regression                      Number of obs     =        360
                                                  LR chi2(5)        =      65.68
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -637.61203                       Pseudo R2         =     0.0490

------------------------------------------------------------------------------
  TotalCrash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   lnAADTMaj |    .450666   .1849495     2.44   0.015     .0881717    .8131603
 lnAADTMinor |   .3491701   .1582086     2.21   0.027     .0390869    .6592532
    SpeedMaj |   .0199681   .0064731     3.08   0.002     .0072811    .0326551
  CrossMajor |  -.4328133   .1877024    -2.31   0.021    -.8007033   -.0649233
  CrossMinor |  -.3454868   .1996357    -1.73   0.084    -.7367656     .045792
       _cons |  -6.812914   1.050433    -6.49   0.000    -8.871725   -4.754102
-------------+----------------------------------------------------------------
    /lnalpha |  -.0177451   .1521439                     -.3159416    .2804514
-------------+----------------------------------------------------------------
       alpha |   .9824114   .1494679                       .729102    1.323727
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  173.68 Prob>=chibar2 = 0.000
```

3-leg Signalized Statewide Fatal + Injury SPF

```
Negative binomial regression                      Number of obs     =        360
                                                  LR chi2(5)        =      55.84
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -511.26259                       Pseudo R2         =     0.0518

------------------------------------------------------------------------------
 TotalFatInj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   lnAADTMaj |   .4521355    .208237     2.17   0.030     .0439985    .8602725
 lnAADTMinor |   .2866595   .1803992     1.59   0.112    -.0669165    .6402355
    SpeedMaj |   .0259061   .0074753     3.47   0.001     .0112549    .0405574
  CrossMajor |  -.6045717    .218325    -2.77   0.006    -1.032481   -.1766626
  CrossMinor |   -.413081   .2352275    -1.76   0.079    -.8741185    .0479565
       _cons |  -6.980613    1.18219    -5.90   0.000    -9.297663   -4.663563
-------------+----------------------------------------------------------------
    /lnalpha |   .1078768   .1841103                     -.2529727    .4687263
-------------+----------------------------------------------------------------
       alpha |   1.113911   .2050824                      .7764891    1.597958
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  102.06 Prob>=chibar2 = 0.000
```

4-leg All-way Stop control Statewide Total Crash SPF

```
Negative binomial regression                      Number of obs   =        264
                                                  LR chi2(3)      =      35.51
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -476.70836                       Pseudo R2       =     0.0359

------------------------------------------------------------------------------
  TotalCrash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   lnAADTMaj |    .680308   .1458876     4.66   0.000     .3943734    .9662425
   lnAADTMin |   .0640196   .1699082     0.38   0.706    -.2689942    .3970335
    SpeedMaj |   .0267323   .0097372     2.75   0.006     .0076477    .0458169
       _cons |  -6.581233    1.32337    -4.97   0.000     -9.17499   -3.987475
-------------+----------------------------------------------------------------
    /lnalpha |   .2495881   .1612056                      -.066369    .5655452
-------------+----------------------------------------------------------------
       alpha |   1.283497   .2069068                      .9357855    1.760407
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  195.14 Prob>=chibar2 = 0.000
```

4-leg All-way Stop control Statewide Fatal + Injury SPF

```
Negative binomial regression                      Number of obs   =        264
                                                  LR chi2(3)      =      26.68
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -350.20464                       Pseudo R2       =     0.0367

------------------------------------------------------------------------------
 TotalFatInj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   lnAADTMaj |   .6392018   .1815574     3.52   0.000     .2833559    .9950477
   lnAADTMin |   .1341598   .1967135     0.68   0.495    -.2513916    .5197113
    SpeedMaj |   .0290747   .0111641     2.60   0.009     .0071935    .0509559
       _cons |  -7.540503   1.533069    -4.92   0.000    -10.54526   -4.535743
-------------+----------------------------------------------------------------
    /lnalpha |    .420041   .2042173                      .0197825    .8202995
-------------+----------------------------------------------------------------
       alpha |   1.522024   .3108236                      1.019979     2.27118
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   97.61 Prob>=chibar2 = 0.000
```

4-leg Minor Stop control Statewide Total Crash SPF

```
Negative binomial regression                      Number of obs     =        688
                                                  LR chi2(3)        =      76.60
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood =  -1150.677                       Pseudo R2         =     0.0322

------------------------------------------------------------------------------
  TotalCrash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   lnAADTMaj |   .5280603   .0904453     5.84   0.000     .3507907      .70533
 lnAADTMinor |   .2752452   .0784126     3.51   0.000     .1215593     .428931
        Skew |   .0072075   .0030781     2.34   0.019     .0011746    .0132404
       _cons |  -6.358953    .773571    -8.22   0.000    -7.875125   -4.842782
-------------+----------------------------------------------------------------
    /lnalpha |   .2982594   .1024226                      .0975148    .4990041
-------------+----------------------------------------------------------------
       alpha |   1.347511   .1380157                      1.102428     1.64708
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  472.68 Prob>=chibar2 = 0.000
```

4-leg Minor Stop control Statewide Fatal + Injury SPF

```
Negative binomial regression                      Number of obs     =        688
                                                  LR chi2(3)        =      34.70
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -854.78385                       Pseudo R2         =     0.0199

------------------------------------------------------------------------------
 TotalFatInj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
   lnAADTMaj |   .5121033   .1232493     4.16   0.000     .2705392    .7536675
 lnAADTMinor |   .1763578   .1036102     1.70   0.089    -.0267145    .3794301
        Skew |   .0082982   .0041916     1.98   0.048     .0000829    .0165135
       _cons |  -6.156151   1.026843    -6.00   0.000    -8.168726   -4.143575
-------------+----------------------------------------------------------------
    /lnalpha |   .9540047   .1158705                      .7269026    1.181107
-------------+----------------------------------------------------------------
       alpha |   2.596085   .3008098                      2.068663    3.257978
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  421.06 Prob>=chibar2 = 0.000
```

3-leg Minor Stop control Statewide Total Crash SPF

```
Negative binomial regression                      Number of obs     =      3,312
                                                  LR chi2(4)        =     515.15
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -5055.1112                       Pseudo R2         =     0.0485

------------------------------------------------------------------------------
  TotalCrash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    lnAADTMaj |   .4789912   .0426245    11.24   0.000     .3954487    .5625338
 lnAADTMinor |   .3620124   .0346351    10.45   0.000     .2941288     .429896
    ELTMajor |  -.3299338   .1127844    -2.93   0.003    -.5509873   -.1088804
    ERTMajor |   .5070817   .1281221     3.96   0.000     .2559669    .7581965
       _cons |  -6.337367   .3113063   -20.36   0.000    -6.947516   -5.727218
-------------+----------------------------------------------------------------
    /lnalpha |   .1108604   .0539016                      .0052151    .2165056
-------------+----------------------------------------------------------------
       alpha |   1.117239    .060221                      1.005229     1.24173
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) = 1393.94 Prob>=chibar2 = 0.000
```

3-leg Minor Stop control Statewide Fatal + Injury SPF

```
Negative binomial regression                      Number of obs     =      3,312
                                                  LR chi2(4)        =     285.78
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -3756.4061                       Pseudo R2         =     0.0366

------------------------------------------------------------------------------
 TotalFatInj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
    lnAADTMaj |   .4393691   .0558766     7.86   0.000      .329853    .5488853
 lnAADTMinor |   .3429157   .0453142     7.57   0.000     .2541016    .4317298
    ELTMajor |  -.2666087   .1443481    -1.85   0.065    -.5495258    .0163084
    ERTMajor |   .5598856   .1626274     3.44   0.001     .2411418    .8786294
       _cons |  -6.457272   .4018051   -16.07   0.000    -7.244796   -5.669748
-------------+----------------------------------------------------------------
    /lnalpha |   .5942051   .0634987                        .46975    .7186602
-------------+----------------------------------------------------------------
       alpha |    1.81159   .1150336                      1.599594    2.051683
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  975.32 Prob>=chibar2 = 0.000
```

APPENDIX E

TOTAL AND FATAL+INJURY SPFs FOR TOTAL AND FATAL + INJURY CRASHES ON RURAL MULTILANE HIGHWAY SEGMENTS

Statewide Total Crash SPF

```
Negative binomial regression                    Number of obs     =      6,810
                                                LR chi2(14)       =     691.59
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -8017.6557                     Pseudo R2         =     0.0413

------------------------------------------------------------------------------
  total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       lnaadt |   .5873804   .0386376    15.20   0.000     .5116522    .6631086
      barrier |    .096759   .0401079     2.41   0.016      .018149    .1753691
     d_seg_mi |   .0022864    .000666     3.43   0.001     .0009809    .0035918
       RRHR_4 |   .1878767   .0412771     4.55   0.000     .1069751    .2687783
      RRHR567 |   .3860411   .0548421     7.04   0.000     .2785526    .4935297
accessdensity |   .0226639   .0031567     7.18   0.000     .0164769    .0288508
      PSL4550 |  -.1429339    .064985    -2.20   0.028    -.2703022   -.0155657
       PSL55p |  -.3848332   .0680886    -5.65   0.000    -.5182844    -.251382
          crs |  -.1839657   .0555011    -3.31   0.001    -.2927459   -.0751855
          srs |  -.1878233   .0495028    -3.79   0.000     -.284847   -.0907997
  district2_5 |   .2269488   .0586129     3.87   0.000     .1120696    .3418281
    district3 |  -.1952663   .0805748    -2.42   0.015      -.35319   -.0373426
  district6_8 |   .0001227   .0583267     0.00   0.998    -.1141955    .1144408
district11_12 |   .1946548     .05569     3.50   0.000     .0855043    .3038052
        _cons |   -4.57068   .3290009   -13.89   0.000     -5.21551    -3.92585
     lnlength |          1  (offset)
-------------+----------------------------------------------------------------
     /lnalpha |  -.2356822   .0536084                     -.3407528   -.1306117
-------------+----------------------------------------------------------------
        alpha |   .7900317   .0423523                      .7112347    .8775585
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  928.92 Prob>=chibar2 = 0.000
```

Statewide Fatal + Injury SPF

```
Negative binomial regression                    Number of obs     =      6,810
                                                LR chi2(10)       =     386.73
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood =  -5394.132                     Pseudo R2         =     0.0346

------------------------------------------------------------------------------
    fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       lnaadt |    .424293   .0479087     8.86   0.000     .3303936    .5181923
     d_seg_mi |    .002156   .0008421     2.56   0.010     .0005056    .0038064
       RRHR_4 |   .1856487   .0533922     3.48   0.001     .0810019    .2902955
      RRHR567 |   .4306205   .0680898     6.32   0.000     .2971669     .564074
accessdensity |   .0286987     .00398     7.21   0.000      .020898    .0364994
       PSL55p |  -.2807602   .0516693    -5.43   0.000    -.3820301   -.1794902
          crs |  -.2589282   .0716286    -3.61   0.000    -.3993177   -.1185386
          srs |  -.1312274   .0638748    -2.05   0.040    -.2564196   -.0060352
  district2_5 |   .3051732   .0676244     4.51   0.000     .1726317    .4377147
district11_12 |   .2978614   .0620804     4.80   0.000      .176186    .4195368
        _cons |  -4.047669    .413542    -9.79   0.000    -4.858196   -3.237141
     lnlength |          1  (offset)
-------------+----------------------------------------------------------------
     /lnalpha |  -.0739413   .0815935                     -.2338617     .085979
-------------+----------------------------------------------------------------
        alpha |   .9287262    .075778                      .7914713    1.089783
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  331.89 Prob>=chibar2 = 0.000
```

APPENDIX F

TOTAL AND FATAL+INJURY SPFs FOR INTERSECTIONS ON RURAL MULTILANE HIGHWAYS

3-leg Minor Stop control Statewide Total Crash SPF

```
Negative binomial regression                      Number of obs     =        395
                                                  LR chi2(1)        =      98.53
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -490.57647                       Pseudo R2         =     0.0913

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 lnaadt_prod |   .5089178   .0494184    10.30   0.000     .4120595    .6057762
       _cons |  -8.071517    .795699   -10.14   0.000    -9.631058   -6.511975
-------------+----------------------------------------------------------------
    /lnalpha |  -1.676622   .4638753                     -2.585801   -.7674427
-------------+----------------------------------------------------------------
       alpha |   .1870047   .0867469                      .0753357    .4641986
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =    7.75 Prob>=chibar2 = 0.003
```

3-leg Minor Stop control Statewide Fatal + Injury SPF

```
Negative binomial regression                      Number of obs     =        395
                                                  LR chi2(1)        =      48.82
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -374.54925                       Pseudo R2         =     0.0612

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
 lnaadt_prod |   .4585784    .065493     7.00   0.000     .3302144    .5869423
       _cons |  -7.830064   1.049624    -7.46   0.000     -9.88729   -5.772839
-------------+----------------------------------------------------------------
    /lnalpha |  -.8181529   .4036692                      -1.60933   -.0269757
-------------+----------------------------------------------------------------
       alpha |   .4412459   .1781174                      .2000216    .9733849
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   11.22 Prob>=chibar2 = 0.000
```

4-leg Minor Stop control Statewide Total Crash SPF

```
Negative binomial regression                      Number of obs     =        220
                                                  LR chi2(2)        =      15.29
Dispersion     = mean                             Prob > chi2       =     0.0005
Log likelihood = -322.12548                       Pseudo R2         =     0.0232

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .3342203   .1407495     2.37   0.018     .0583563    .6100843
  lnaadt_min |   .2640263   .0824175     3.20   0.001      .102491    .4255616
       _cons |  -4.432429   1.326133    -3.34   0.001    -7.031602   -1.833256
-------------+----------------------------------------------------------------
    /lnalpha |  -.9660783   .3322343                     -1.617246    -.314911
-------------+----------------------------------------------------------------
       alpha |   .3805726   .1264393                      .1984445    .7298538
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   17.55 Prob>=chibar2 = 0.000
```

4-leg Minor Stop control Statewide Fatal + Injury SPF

```
Negative binomial regression                      Number of obs     =        220
                                                  LR chi2(2)        =       3.63
Dispersion     = mean                             Prob > chi2       =     0.1631
Log likelihood = -243.77862                       Pseudo R2         =     0.0074

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .2166937   .1717755     1.26   0.207    -.1199801    .5533674
  lnaadt_min |    .151693   .1012951     1.50   0.134    -.0468418    .3502277
       _cons |  -3.248409   1.628743    -1.99   0.046    -6.440686    -.056132
-------------+----------------------------------------------------------------
    /lnalpha |  -.8848101   .4794161                     -1.824448    .0548282
-------------+----------------------------------------------------------------
       alpha |   .4127926   .1978994                      .1613066    1.056359
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =    7.29 Prob>=chibar2 = 0.003
```

4-leg Signalized Statewide Total Crash SPF

```
Negative binomial regression                      Number of obs     =        225
                                                  LR chi2(2)        =      17.93
Dispersion     = mean                             Prob > chi2       =     0.0001
Log likelihood = -439.66723                       Pseudo R2         =     0.0200

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .3887254   .1303678     2.98   0.003     .1332092    .6442416
  lnaadt_min |   .1344107   .0589851     2.28   0.023     .0188019    .2500194
       _cons |   -3.56312     1.1298    -3.15   0.002    -5.777488   -1.348752
-------------+----------------------------------------------------------------
    /lnalpha |  -1.596965   .3016079                     -2.188106   -1.005825
-------------+----------------------------------------------------------------
       alpha |   .2025101   .0610787                      .1121289    .3657429
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   20.44 Prob>=chibar2 = 0.000
```

4-leg Signalized Statewide Fatal + Injury SPF

```
Negative binomial regression                      Number of obs     =        225
                                                  LR chi2(2)        =       8.06
Dispersion     = mean                             Prob > chi2       =     0.0178
Log likelihood = -345.28474                       Pseudo R2         =     0.0115

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .2905048   .1645557     1.77   0.077    -.0320184    .6130279
  lnaadt_min |   .1333887   .0757987     1.76   0.078     -.015174    .2819514
       _cons |  -3.301449   1.433255    -2.30   0.021    -6.110578   -.4923206
-------------+----------------------------------------------------------------
    /lnalpha |  -1.483348   .4455988                     -2.356706   -.6099906
-------------+----------------------------------------------------------------
       alpha |   .2268768    .101096                      .0947318     .543356
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =    7.88 Prob>=chibar2 = 0.002
```

APPENDIX G

TOTAL AND FATAL+INJURY SPFs FOR TOTAL AND FATAL + INJURY CRASHES ON URBAN-SUBURAN ARTERIAL SEGMENTS

2-lane Undivided District 1 Total Crash SPF

```
Negative binomial regression                    Number of obs     =      2,725
                                                LR chi2(7)        =     666.21
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -4432.4073                     Pseudo R2         =     0.0699

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .8536646   .0450556    18.95   0.000     .7653572     .941972
      PSL_35 |  -.2297857   .0591084    -3.89   0.000     -.345636   -.1139354
      PSL_40 |  -.4783343   .0807319    -5.92   0.000    -.6365659   -.3201026
   PSL_45_65 |  -.6339027   .0632834   -10.02   0.000    -.7579359   -.5098695
    county25 |   .2365827   .0580407     4.08   0.000      .122825    .3503404
    county43 |   .2628302    .063208     4.16   0.000     .1389448    .3867156
    county60 |   .1249183   .0813551     1.54   0.125    -.0345348    .2843714
       _cons |   -6.00001   .4043218   -14.84   0.000    -6.792466   -5.207553
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.8682267   .0737515                     -1.012777   -.7236765
-------------+----------------------------------------------------------------
       alpha |   .4196951   .0309531                       .363209     .484966
------------------------------------------------------------------------------
```

2-lane Undivided District 1 Fatal + Injury Crash SPF

```
Negative binomial regression                    Number of obs     =      2,725
                                                LR chi2(6)        =     458.96
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -3270.6105                     Pseudo R2         =     0.0656

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .8827251   .0570969    15.46   0.000     .7708171     .994633
      PSL_35 |  -.3321205   .0711541    -4.67   0.000    -.4715799    -.192661
      PSL_40 |  -.5446625    .098918    -5.51   0.000    -.7385382   -.3507867
   PSL_45_65 |   -.660399   .0767538    -8.60   0.000    -.8108337   -.5099643
    county25 |   .2024823   .0637741     3.17   0.001     .0774875    .3274772
    county43 |   .2595376   .0714481     3.63   0.000     .1195019    .3995733
       _cons |  -6.825303   .5141273   -13.28   0.000    -7.832974   -5.817632
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.8247491   .1089555                     -1.038298   -.6112002
-------------+----------------------------------------------------------------
       alpha |   .4383449   .0477601                      .3540568    .5426991
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  178.42 Prob>=chibar2 = 0.000
```

2-lane Undivided District 2 Total Crash SPF

```
Negative binomial regression                    Number of obs     =      1,420
                                                LR chi2(4)        =     357.58
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -2186.3411                     Pseudo R2         =     0.0756

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .8071739   .0639558    12.62   0.000     .6818228     .932525
   PSL_40_65 |  -.6064702    .059045   -10.27   0.000    -.7221963   -.4907441
         CTL |    .230464   .0632177     3.65   0.000     .1065596    .3543683
    county17 |  -.3097284    .066241    -4.68   0.000    -.4395583   -.1798985
       _cons |  -5.620534   .5678871    -9.90   0.000    -6.733572   -4.507495
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |   -1.02384   .1242319                      -1.26733   -.7803503
-------------+----------------------------------------------------------------
       alpha |   .3592128   .0446257                      .2815824    .4582455
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  147.67 Prob>=chibar2 = 0.000
```

2-lane Undivided District 2 Fatal + Injury Crash SPF

```
Negative binomial regression                    Number of obs     =      1,420
                                                LR chi2(4)        =     262.67
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -1534.5091                     Pseudo R2         =     0.0788

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .9426093   .0840228    11.22   0.000     .7779277    1.107291
   PSL_40_65 |  -.6097185   .0741732    -8.22   0.000    -.7550952   -.4643418
         CTL |   .1145742   .0782019     1.47   0.143    -.0386986    .2678471
    county17 |  -.2413444   .0815942    -2.96   0.003    -.4012661   -.0814227
       _cons |   -7.51977   .7505488   -10.02   0.000    -8.990819   -6.048722
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -1.264287    .228392                     -1.711927   -.8166466
-------------+----------------------------------------------------------------
       alpha |   .2824407   .0645072                      .1805176    .4419111
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   31.75 Prob>=chibar2 = 0.000
```

2-lane Undivided District 3 Total Crash SPF

```
Negative binomial regression                    Number of obs     =      2,165
                                                LR chi2(5)        =     411.42
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -3349.3685                     Pseudo R2         =     0.0579

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .8839819   .0551132    16.04   0.000     .7759619    .9920018
   PSL_40_65 |  -.5286305     .05189   -10.19   0.000    -.6303331    -.426928
    county19 |   .1179476   .0782558     1.51   0.132    -.0354311    .2713262
    county41 |   .2033334   .0685513     2.97   0.003     .0689754    .3376914
    county49 |  -.1405179   .0757098    -1.86   0.063    -.2889065    .0078707
       _cons |  -6.321401   .5020502   -12.59   0.000    -7.305401   -5.337401
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.6666316   .0808991                      -.825191   -.5080723
-------------+----------------------------------------------------------------
       alpha |   .5134351   .0415365                      .4381513    .6016543
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  419.10 Prob>=chibar2 = 0.000
```

2-lane Undivided District 3 Fatal + Injury Crash SPF

```
Negative binomial regression                    Number of obs     =      2,165
                                                LR chi2(4)        =     270.99
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -2391.6717                     Pseudo R2         =     0.0536

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .9198727   .0689173    13.35   0.000     .7847973    1.054948
   PSL_40_65 |  -.4758434   .0637662    -7.46   0.000    -.6008229    -.350864
    county41 |   .1432274   .0713363     2.01   0.045     .0034108    .2830439
    county49 |    -.17667   .0826312    -2.14   0.033    -.3386242   -.0147158
       _cons |  -7.321175   .6331355   -11.56   0.000    -8.562098   -6.080253
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.6662411   .1240681                     -.9094102   -.4230721
-------------+----------------------------------------------------------------
       alpha |   .5136356   .0637258                      .4027617    .6550314
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  137.16 Prob>=chibar2 = 0.000
```

2-lane Undivided District 4 Total Crash SPF

```
Negative binomial regression                      Number of obs     =      2,735
                                                  LR chi2(3)        =    1139.70
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -4929.3673                       Pseudo R2         =     0.1036

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |    1.01483   .0341117    29.75   0.000     .9479725    1.081688
      PSL_35 |  -.4934167   .0407457   -12.11   0.000    -.5732767   -.4135566
   PSL_40_65 |  -.8011622   .0571783   -14.01   0.000    -.9132295   -.6890948
       _cons |  -7.088555    .309795   -22.88   0.000    -7.695742   -6.481368
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.9120328   .0652519                     -1.039924   -.7841415
-------------+----------------------------------------------------------------
       alpha |   .4017068   .0262121                      .3534815    .4565114
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  745.21 Prob>=chibar2 = 0.000
```

2-lane Undivided District 4 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs     =      2,735
                                                  LR chi2(3)        =     895.91
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -3701.0468                       Pseudo R2         =     0.1080

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   1.123866   .0438249    25.64   0.000     1.037971    1.209761
      PSL_35 |  -.5001636   .0497197   -10.06   0.000    -.5976125   -.4027148
   PSL_40_65 |  -.8231227   .0717542   -11.47   0.000    -.9637583   -.6824871
       _cons |  -8.713356   .3997659   -21.80   0.000    -9.496882   -7.929829
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.8213584   .0886622                     -.9951332   -.6475837
-------------+----------------------------------------------------------------
       alpha |   .4398338   .0389966                      .3696742    .5233087
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  321.12 Prob>=chibar2 = 0.000
```

2-lane Undivided District 5 Total Crash SPF

```
Negative binomial regression                    Number of obs     =      4,575
                                                LR chi2(8)        =    1704.47
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -9503.8806                     Pseudo R2         =     0.0823

------------------------------------------------------------------------------
   total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------+--------------------------------------------------------------
        lnaadt |   .8999223   .0275636    32.65   0.000     .8458987    .9539459
        PSL_35 |  -.4066035   .0415592    -9.78   0.000    -.4880579    -.325149
        PSL_40 |  -.5152789   .0455984   -11.30   0.000    -.6046502   -.4259076
     PSL_45_65 |  -.8767987   .0427087   -20.53   0.000    -.9605062   -.7930912
parking_lane_2 |   .1561689   .0424218     3.68   0.000     .0730237     .239314
     county648 |   .3609497   .0402541     8.97   0.000     .2820531    .4398463
      county39 |   .4647215   .0442889    10.49   0.000      .377917    .5515261
      county45 |   .2832864   .0521808     5.43   0.000     .1810139     .385559
         _cons |    -6.1621   .2502131   -24.63   0.000    -6.652509   -5.671692
      lnlength |          1  (offset)
---------------+--------------------------------------------------------------
      /lnalpha |  -1.079948   .0450774                     -1.168298   -.9915979
---------------+--------------------------------------------------------------
         alpha |   .3396132   .0153089                      .3108957    .3709834
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) = 1647.50 Prob>=chibar2 = 0.000
```

2-lane Undivided District 5 Fatal + Injury Crash SPF

```
Negative binomial regression                    Number of obs     =      4,575
                                                LR chi2(8)        =    1171.01
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood =   -7335.45                     Pseudo R2         =     0.0739

------------------------------------------------------------------------------
     fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------+--------------------------------------------------------------
        lnaadt |   .9427623   .0352689    26.73   0.000     .8736366    1.011888
        PSL_35 |  -.4030476   .0509856    -7.91   0.000    -.5029775   -.3031177
        PSL_40 |  -.4913905   .0557911    -8.81   0.000    -.6007391   -.3820419
     PSL_45_65 |  -.8633035   .0526076   -16.41   0.000    -.9664125   -.7601944
parking_lane_2 |    .081781   .0518246     1.58   0.115    -.0197933    .1833553
     county648 |   .2906858    .050435     5.76   0.000     .1918351    .3895366
      county39 |    .404721   .0550673     7.35   0.000     .2967911    .5126509
      county45 |   .2611807   .0645926     4.04   0.000     .1345815    .3877798
         _cons |   -7.17035    .320776   -22.35   0.000    -7.799059    -6.54164
      lnlength |          1  (offset)
---------------+--------------------------------------------------------------
      /lnalpha |  -.9342369   .0597981                     -1.051439   -.8170348
---------------+--------------------------------------------------------------
         alpha |   .3928856   .0234938                      .3494346    .4417396
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  713.49 Prob>=chibar2 = 0.000
```

2-lane Undivided District 6 Total Crash SPF

Negative binomial regression

Dispersion = mean

Log likelihood = -25779.571

Number of obs	=	12,310
LR chi2(10)	=	3033.53
Prob > chi2	=	0.0000
Pseudo R2	=	0.0556

total_crash	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnaadt	.7736757	.0184241	41.99	0.000	.7375652	.8097862
PSL_35	-.2472834	.0291924	-8.47	0.000	-.3044995	-.1900673
PSL_40	-.3764593	.0334472	-11.26	0.000	-.4420145	-.3109041
PSL_45_65	-.4737916	.0316988	-14.95	0.000	-.53592	-.4116632
CTL	.1798792	.0243668	7.38	0.000	.1321212	.2276372
parking_lane_2	.183433	.034373	5.34	0.000	.1160631	.2508029
county9	-.1020757	.0215827	-4.73	0.000	-.1443771	-.0597743
county15	-.1718642	.0238006	-7.22	0.000	-.2185125	-.1252158
county23	.0557307	.025439	2.19	0.028	.0058713	.1055901
county67	.3075896	.0401473	7.66	0.000	.2289023	.386277
_cons	-5.004017	.1716028	-29.16	0.000	-5.340352	-4.667682
lnlength	1	(offset)				
/lnalpha	-1.00977	.0271862			-1.063054	-.956486
alpha	.3643028	.009904			.3453994	.3842407

Likelihood-ratio test of alpha=0: chibar2(01) = 4205.00 Prob>=chibar2 = 0.000

2-lane Undivided District 6 Fatal + Injury Crash SPF

Negative binomial regression

Dispersion = mean

Log likelihood = -19790.188

Number of obs	=	12,310
LR chi2(10)	=	3637.11
Prob > chi2	=	0.0000
Pseudo R2	=	0.0842

fatal_inj	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnaadt	.7868615	.022901	34.36	0.000	.7419763	.8317467
PSL_35	-.2613426	.0336753	-7.76	0.000	-.3273451	-.1953402
PSL_40	-.4449378	.0398227	-11.17	0.000	-.5229888	-.3668867
PSL_45_65	-.5496643	.0375859	-14.62	0.000	-.6233313	-.4759972
CTL	.2421526	.0288649	8.39	0.000	.1855784	.2987268
parking_lane_2	.2573368	.0392677	6.55	0.000	.1803734	.3343001
county9	-.1466907	.0267942	-5.47	0.000	-.1992063	-.094175
county15	-.3137889	.0303423	-10.34	0.000	-.3732587	-.254319
county23	.1195919	.0304624	3.93	0.000	.0598866	.1792972
county67	.6901003	.0454043	15.20	0.000	.6011096	.779091
_cons	-5.772602	.2131025	-27.09	0.000	-6.190275	-5.354929
lnlength	1	(offset)				
/lnalpha	-.9345024	.0364497			-1.005942	-.8630624
alpha	.3927813	.0143167			.3656998	.4218682

Likelihood-ratio test of alpha=0: chibar2(01) = 1984.46 Prob>=chibar2 = 0.000

2-lane Undivided District 8 Total Crash SPF

```
Negative binomial regression                    Number of obs     =      7,235
                                                LR chi2(10)       =    1963.19
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood =  -14582.24                     Pseudo R2         =     0.0631

------------------------------------------------------------------------------
   total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------+----------------------------------------------------------------
        lnaadt |   .8461738   .0240682    35.16   0.000      .799001    .8933466
        PSL_35 |  -.1401328   .0356228    -3.93   0.000    -.2099523   -.0703133
        PSL_40 |   -.294752   .0415825    -7.09   0.000    -.3762522   -.2132519
     PSL_45_65 |   -.572172   .0404468   -14.15   0.000    -.6514462   -.4928978
           CTL |   .1632359   .0273489     5.97   0.000     .1096331    .2168387
parking_lane_2 |    .326261   .0327095     9.97   0.000     .2621514    .3903705
       county1 |  -.1731706   .0516148    -3.36   0.001    -.2743338   -.0720074
      county21 |   .1184623    .035699     3.32   0.001     .0484935    .1884311
      county36 |   .0832594   .0282223     2.95   0.003     .0279448    .1385741
      county66 |   .1514275   .0304616     4.97   0.000     .0917239    .2111311
         _cons |  -5.872389   .2237871   -26.24   0.000    -6.311004   -5.433774
      lnlength |          1  (offset)
---------------+----------------------------------------------------------------
      /lnalpha |   -.997773   .0367358                     -1.069774   -.9257722
---------------+----------------------------------------------------------------
         alpha |   .3686996   .0135445                      .3430861    .3962254
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) = 2306.17 Prob>=chibar2 = 0.000
```

2-lane Undivided District 8 Fatal + Injury Crash SPF

```
Negative binomial regression                    Number of obs     =      7,235
                                                LR chi2(9)        =    1408.65
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -10997.517                     Pseudo R2         =     0.0602

------------------------------------------------------------------------------
     fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------+----------------------------------------------------------------
        lnaadt |    .885324    .031255    28.33   0.000     .8240654    .9465826
        PSL_35 |  -.1692357   .0446042    -3.79   0.000    -.2566582   -.0818131
        PSL_40 |   -.298639   .0522257    -5.72   0.000    -.4009995   -.1962785
     PSL_45_65 |  -.5884409   .0509747   -11.54   0.000    -.6883494   -.4885324
           CTL |   .2427507   .0333569     7.28   0.000     .1773723     .308129
parking_lane_2 |   .3258074   .0410165     7.94   0.000     .2454165    .4061982
       county1 |  -.2507024   .0653301    -3.84   0.000    -.3787471   -.1226577
      county36 |   .0660388   .0319907     2.06   0.039     .0033382    .1287394
      county66 |   .1379921   .0348494     3.96   0.000     .0696886    .2062956
         _cons |   -6.90209   .2907709   -23.74   0.000    -7.471991    -6.33219
      lnlength |          1  (offset)
---------------+----------------------------------------------------------------
      /lnalpha |  -.8324599   .0496658                     -.9298032   -.7351167
---------------+----------------------------------------------------------------
         alpha |   .4349779   .0216035                      .3946314    .4794495
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) = 1004.37 Prob>=chibar2 = 0.000
```

2-lane Undivided District 9 Total Crash SPF

```
Negative binomial regression                      Number of obs     =      1,740
                                                  LR chi2(4)        =     352.93
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -2624.3888                       Pseudo R2         =     0.0630

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .7912601   .0533193    14.84   0.000     .6867561    .8957641
      PSL_35 |  -.3319719   .0606125    -5.48   0.000    -.4507701   -.2131736
   PSL_40_65 |  -.7414776   .0671668   -11.04   0.000    -.8731221   -.6098332
     county7 |   .1165266   .0567343     2.05   0.040     .0053294    .2277238
       _cons |  -5.289596   .4679254   -11.30   0.000    -6.206713   -4.372479
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -1.322604   .1286308                     -1.574716   -1.070492
-------------+----------------------------------------------------------------
       alpha |   .2664406   .0342725                      .2070665    .3428397
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  115.85 Prob>=chibar2 = 0.000
```

2-lane Undivided District 9 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs     =      1,740
                                                  LR chi2(3)        =     202.09
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -1881.2937                       Pseudo R2         =     0.0510

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |    .875857   .0686402    12.76   0.000     .7413246    1.010389
      PSL_35 |  -.1878997   .0822887    -2.28   0.022    -.3491826   -.0266168
   PSL_40_65 |  -.5703963   .0884377    -6.45   0.000     -.743731   -.3970616
       _cons |  -6.828408   .6087913   -11.22   0.000    -8.021617   -5.635199
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |   -1.05356   .1827503                     -1.411744   -.6953756
-------------+----------------------------------------------------------------
       alpha |   .3486943    .063724                      .2437179    .4988871
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   50.95 Prob>=chibar2 = 0.000
```

2-lane Undivided District 10 Total Crash SPF

```
Negative binomial regression                    Number of obs     =      1,835
                                                LR chi2(3)        =     509.97
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -2992.2473                     Pseudo R2         =     0.0785

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .9364766   .0484697    19.32   0.000     .8414777    1.031476
   PSL_40_65 |  -.3278864   .0518725    -6.32   0.000    -.4295547   -.2262181
     county3 |  -.3625317   .0689082    -5.26   0.000    -.4975893    -.227474
       _cons |  -6.679403   .4418201   -15.12   0.000    -7.545354   -5.813451
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.6875335   .0831493                     -.8505032   -.5245639
-------------+----------------------------------------------------------------
       alpha |   .5028147   .0418087                      .4271999    .5918134
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  429.36 Prob>=chibar2 = 0.000
```

2-lane Undivided District 10 Fatal + Injury Crash SPF

```
Negative binomial regression                    Number of obs     =      1,835
                                                LR chi2(3)        =     329.87
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -2166.9237                     Pseudo R2         =     0.0707

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .8886067   .0617045    14.40   0.000     .7676682    1.009545
   PSL_40_65 |  -.3433649   .0652184    -5.26   0.000    -.4711907   -.2155391
     county3 |  -.4538891   .0907798    -5.00   0.000    -.6318142   -.2759639
       _cons |  -6.914795   .5634039   -12.27   0.000    -8.019046   -5.810543
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.5428534   .1154168                     -.7690662   -.3166406
-------------+----------------------------------------------------------------
       alpha |   .5810878   .0670673                      .4634457    .7285925
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  178.41 Prob>=chibar2 = 0.000
```

2-lane Undivided District 11 Total Crash SPF

```
Negative binomial regression                    Number of obs     =      6,070
                                                LR chi2(6)        =    1434.62
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -10865.834                     Pseudo R2         =     0.0619

--------------------------------------------------------------------------------
   total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------+----------------------------------------------------------------
        lnaadt |   .8915243   .0264044    33.76   0.000     .8397727    .9432759
        PSL_35 |  -.2291025   .0351917    -6.51   0.000     -.298077    -.160128
        PSL_40 |  -.4078866   .0526583    -7.75   0.000    -.5110949   -.3046783
     PSL_45_65 |  -.5643849   .0468557   -12.05   0.000    -.6562203   -.4725495
parking_lane_2 |   .3068974   .0506391     6.06   0.000     .2076466    .4061482
       county4 |  -.1801839    .039111    -4.61   0.000    -.2568401   -.1035277
         _cons |  -6.289231    .241963   -25.99   0.000     -6.76347   -5.814992
      lnlength |          1  (offset)
---------------+----------------------------------------------------------------
      /lnalpha |  -.5764102     .04054                     -.6558671   -.4969533
---------------+----------------------------------------------------------------
         alpha |   .5619119   .0227799                      .5189919    .6083814
--------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) = 2083.66 Prob>=chibar2 = 0.000
```

2-lane Undivided District 11 Fatal + Injury Crash SPF

```
Negative binomial regression                    Number of obs     =      6,070
                                                LR chi2(6)        =    1080.72
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -7818.5339                     Pseudo R2         =     0.0646

--------------------------------------------------------------------------------
     fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
---------------+----------------------------------------------------------------
        lnaadt |   .9303475   .0328755    28.30   0.000     .8659127    .9947823
        PSL_35 |  -.2489306   .0419065    -5.94   0.000    -.3310658   -.1667955
        PSL_40 |   -.415075   .0638595    -6.50   0.000    -.5402372   -.2899127
     PSL_45_65 |  -.5566575   .0564789    -9.86   0.000    -.6673541   -.4459609
parking_lane_2 |   .2706941   .0598363     4.52   0.000      .153417    .3879711
       county4 |  -.2248388   .0488266    -4.60   0.000    -.3205371   -.1291405
         _cons |   -7.34259   .3026923   -24.26   0.000    -7.935856   -6.749324
      lnlength |          1  (offset)
---------------+----------------------------------------------------------------
      /lnalpha |  -.5965769   .0597656                     -.7137154   -.4794385
---------------+----------------------------------------------------------------
         alpha |   .5506935   .0329125                       .489821    .6191309
--------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  696.31 Prob>=chibar2 = 0.000
```

2-lane Undivided District 12 Total Crash SPF

```
Negative binomial regression                    Number of obs     =      3,670
                                                LR chi2(5)        =     732.11
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -5642.0672                     Pseudo R2         =     0.0609

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .8864392   .0347014    25.54   0.000     .8184257    .9544527
      PSL_35 |  -.2057831   .0549355    -3.75   0.000    -.3134547   -.0981116
   PSL_40_65 |  -.3280949   .0552324    -5.94   0.000    -.4363484   -.2198414
    county62 |  -.1747787   .0557898    -3.13   0.002    -.2841247   -.0654327
    county64 |  -.1090534   .0543384    -2.01   0.045    -.2155547   -.0025522
       _cons |   -6.21231   .3089698   -20.11   0.000    -6.817879    -5.60674
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.8589724   .0681404                     -.9925253   -.7254196
-------------+----------------------------------------------------------------
       alpha |   .4235971   .0288641                      .3706395    .4841214
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  549.97 Prob>=chibar2 = 0.000
```

2-lane Undivided District 12 Fatal + Injury Crash SPF

```
Negative binomial regression                    Number of obs     =      3,670
                                                LR chi2(5)        =     440.23
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -4096.0885                     Pseudo R2         =     0.0510

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .8274103   .0437036    18.93   0.000     .7417529    .9130678
      PSL_35 |  -.1732342   .0681756    -2.54   0.011    -.3068559   -.0396126
   PSL_40_65 |  -.3541538   .0691215    -5.12   0.000    -.4896294   -.2186781
    county62 |  -.2699544   .0687362    -3.93   0.000    -.4046749    -.135234
    county64 |  -.1926218   .0666373    -2.89   0.004    -.3232284   -.0620151
       _cons |  -6.293274   .3893029   -16.17   0.000    -7.056294   -5.530255
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.8108969   .1046743                     -1.016055   -.6057389
-------------+----------------------------------------------------------------
       alpha |   .4444593   .0465235                      .3620204    .5456711
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  176.75 Prob>=chibar2 = 0.000
```

4-lane Undivided Statewide Total Crash SPF

Negative binomial regression — Number of obs = 13,520
LR chi2(11) = 1808.17
Dispersion = mean — Prob > chi2 = 0.0000
Log likelihood = -28817.459 — Pseudo R2 = 0.0304

total_crash	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnaadt	.6446859	.0243472	26.48	0.000	.5969663	.6924055
PSL_35	-.2623955	.0326505	-8.04	0.000	-.3263894	-.1984016
PSL_40	-.554551	.0358003	-15.49	0.000	-.6247183	-.4843838
PSL_45_65	-.8037262	.0347562	-23.12	0.000	-.8718471	-.7356053
CTL	.3877392	.0286217	13.55	0.000	.3316416	.4438367
dist1	-.150935	.0396013	-3.81	0.000	-.2285521	-.073318
dist29	-.3137037	.0546686	-5.74	0.000	-.4208523	-.2065552
dist3	-.2260356	.0572571	-3.95	0.000	-.3382575	-.1138137
dist5	.3531571	.0421972	8.37	0.000	.2704521	.4358621
dist8	.1063932	.0371367	2.86	0.004	.0336066	.1791798
dist10	-.5644031	.0774783	-7.28	0.000	-.7162578	-.4125485
_cons	-3.486563	.2213612	-15.75	0.000	-3.920423	-3.052703
lnlength	1	(offset)				
/lnalpha	-.0934299	.0193467			-.1313488	-.0555109
alpha	.9108019	.0176211			.8769119	.9460017

Likelihood-ratio test of alpha=0: chibar2(01) = 1.6e+04 Prob>=chibar2 = 0.000

4-lane Undivided Statewide Fatal + Injury Crash SPF

Negative binomial regression — Number of obs = 13,520
LR chi2(11) = 1820.55
Dispersion = mean — Prob > chi2 = 0.0000
Log likelihood = -22641.217 — Pseudo R2 = 0.0387

fatal_inj	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnaadt	.6514459	.0280859	23.19	0.000	.5963986	.7064932
PSL_35	-.4819106	.0355947	-13.54	0.000	-.551675	-.4121462
PSL_40	-.8260875	.0395645	-20.88	0.000	-.9036324	-.7485426
PSL_45_65	-1.094924	.0385949	-28.37	0.000	-1.170568	-1.019279
CTL	.4403234	.0317772	13.86	0.000	.3780413	.5026056
dist1	-.1024932	.045321	-2.26	0.024	-.1913208	-.0136657
dist29	-.4520101	.0649591	-6.96	0.000	-.5793276	-.3246927
dist3	-.2687899	.0687636	-3.91	0.000	-.4035641	-.1340156
dist5	.32937	.0479353	6.87	0.000	.2354185	.4233216
dist8	.0719479	.0423696	1.70	0.089	-.0110951	.1549908
dist10	-.6022128	.0929663	-6.48	0.000	-.7844233	-.4200023
_cons	-3.908609	.2555025	-15.30	0.000	-4.409384	-3.407833
lnlength	1	(offset)				
/lnalpha	-.0092971	.0238356			-.0560139	.0374198
alpha	.990746	.023615			.945526	1.038129

Likelihood-ratio test of alpha=0: chibar2(01) = 8164.72 Prob>=chibar2 = 0.000

4-lane Divided Statewide Total Crash SPF

Negative binomial regression — Number of obs = 15,105

LR chi2(13) = 2640.59

Dispersion = mean — Prob > chi2 = 0.0000

Log likelihood = -28488.128 — Pseudo R2 = 0.0443

total_crash	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnaadt	.746822	.023707	31.50	0.000	.7003571	.7932868
PSL_35	-.1263566	.0500546	-2.52	0.012	-.2244619	-.0282514
PSL_40	-.2827562	.0488973	-5.78	0.000	-.3785931	-.1869193
PSL_45	-.4794799	.0473223	-10.13	0.000	-.57223	-.3867298
PSL_50_65	-.9117333	.0498363	-18.29	0.000	-1.009411	-.814056
barrier3	.1552714	.0283438	5.48	0.000	.0997186	.2108241
CTL	.5009315	.0420822	11.90	0.000	.4184519	.5834112
dist3	-.1348596	.0643889	-2.09	0.036	-.2610596	-.0086596
dist4	.2533468	.0523945	4.84	0.000	.1506554	.3560382
dist5	.4986989	.0371038	13.44	0.000	.4259768	.571421
dist6	.1586932	.0314657	5.04	0.000	.0970216	.2203648
dist8	.2881363	.0408567	7.05	0.000	.2080586	.3682141
dist11	.049194	.0334283	1.47	0.141	-.0163243	.1147123
_cons	-5.043922	.2141789	-23.55	0.000	-5.463705	-4.624139
lnlength	1	(offset)				
/lnalpha	-.0056515	.0199801			-.0448117	.0335087
alpha	.9943644	.0198675			.9561775	1.034076

Likelihood-ratio test of alpha=0: chibar2(01) = 1.3e+04 Prob>=chibar2 = 0.000

4-lane Divided Statewide Fatal + Injury Crash SPF

Negative binomial regression — Number of obs = 15,105

LR chi2(12) = 2242.86

Dispersion = mean — Prob > chi2 = 0.0000

Log likelihood = -21440.869 — Pseudo R2 = 0.0497

fatal_inj	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnaadt	.7324696	.0281714	26.00	0.000	.6772546	.7876845
PSL_35	-.2747451	.0561973	-4.89	0.000	-.3848899	-.1646004
PSL_40	-.4457067	.0551527	-8.08	0.000	-.5538041	-.3376093
PSL_45	-.7216632	.0531239	-13.58	0.000	-.8257841	-.6175423
PSL_50_65	-1.172479	.0564526	-20.77	0.000	-1.283124	-1.061834
barrier3	.1285348	.0335086	3.84	0.000	.0628591	.1942105
CTL	.5443104	.0472046	11.53	0.000	.4517911	.6368297
dist3	-.2074052	.0787414	-2.63	0.008	-.3617355	-.0530749
dist4	.2418714	.0590858	4.09	0.000	.1260654	.3576774
dist5	.553216	.0400974	13.80	0.000	.4746265	.6318054
dist6	.2255678	.0320653	7.03	0.000	.162721	.2884146
dist8	.223515	.0451508	4.95	0.000	.135021	.312009
_cons	-5.343623	.2556651	-20.90	0.000	-5.844718	-4.842529
lnlength	1	(offset)				
/lnalpha	.1135209	.0255594			.0634253	.1636165
alpha	1.120215	.0286321			1.06548	1.177763

Likelihood-ratio test of alpha=0: chibar2(01) = 6250.76 Prob>=chibar2 = 0.000

2-lane Undivided Statewide Total Crash SPF (500 miles)

```
Negative binomial regression                      Number of obs   =       2650
                                                  LR chi2(7)      =     427.88
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -5170.9895                       Pseudo R2       =     0.0397

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .7513335   .0407882    18.42   0.000     .6713902    .8312768
      PSL_35 |  -.3748019   .0713399    -5.25   0.000    -.5146254   -.2349783
      PSL_40 |  -.5982741   .0754137    -7.93   0.000    -.7460822    -.450466
   PSL_45_65 |  -.6123054   .0684267    -8.95   0.000    -.7464193   -.4781915
         CTL |   .0469278   .0623791     0.75   0.452     -.075333    .1691887
parking_lane |   .0584349   .1076133     0.54   0.587    -.1524833    .2693531
    d_seg_mi |    .000523   .0002259     2.31   0.021     .0000801    .0009658
       _cons |  -4.830798   .3855525   -12.53   0.000    -5.586467   -4.075129
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |   -1.01731   .0650056                     -1.144719   -.8899012
-------------+----------------------------------------------------------------
       alpha |   .3615663   .0235038                      .3183135    .4106963
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  616.14 Prob>=chibar2 = 0.000
```

2-lane Undivided Statewide Fatal + Injury Crash SPF (500 miles)

```
Negative binomial regression                      Number of obs   =       2650
                                                  LR chi2(7)      =     286.38
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -3643.6609                       Pseudo R2       =     0.0378

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .7201654    .054013    13.33   0.000     .6143019     .826029
      PSL_35 |  -.4604212   .0889094    -5.18   0.000    -.6346804    -.286162
      PSL_40 |  -.6952448   .0946771    -7.34   0.000    -.8808085    -.509681
   PSL_45_65 |  -.7467783   .0852684    -8.76   0.000    -.9139014   -.5796553
         CTL |    .213194   .0772067     2.76   0.006     .0618717    .3645163
parking_lane |   .1200389    .133999     0.90   0.370    -.1425943    .3826722
    d_seg_mi |   .0003867   .0002933     1.32   0.187    -.0001881    .0009615
       _cons |  -5.254386   .5106812   -10.29   0.000    -6.255303   -4.253469
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.9295402   .1022136                     -1.129875   -.7292052
-------------+----------------------------------------------------------------
       alpha |   .3947352   .0403473                      .3230736    .4822921
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  184.64 Prob>=chibar2 = 0.000
```

4-lane Undivided Statewide Total Crash SPF (500 miles)

```
Negative binomial regression                      Number of obs   =        895
                                                  LR chi2(4)      =      27.69
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -2069.4368                       Pseudo R2       =     0.0066

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |    .206027   .0917973     2.24   0.025     .0261076    .3859464
   PSL_50_65 |  -1.135399   .3792479    -2.99   0.003    -1.878711   -.3920872
         CTL |   .4548024   .1281317     3.55   0.000     .2036689     .705936
    d_seg_mi |   .0007678   .0009181     0.84   0.403    -.0010317    .0025673
       _cons |   .1357876      .8469     0.16   0.873    -1.524106    1.795681
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |   .1172346   .0652034                     -.0105617     .245031
-------------+----------------------------------------------------------------
       alpha |   1.124383   .0733136                      .9894939    1.277661
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) = 1862.31 Prob>=chibar2 = 0.000
```

4-lane Undivided Statewide Fatal + Injury Crash SPF (500 miles)

```
Negative binomial regression                      Number of obs   =        895
                                                  LR chi2(4)      =      17.18
Dispersion     = mean                             Prob > chi2     =     0.0018
Log likelihood = -1511.9778                       Pseudo R2       =     0.0056

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .1532626   .1088637     1.41   0.159    -.0601063    .3666316
   PSL_50_65 |  -1.391051   .5097288    -2.73   0.006    -2.390101   -.3920011
         CTL |   .3673754   .1460942     2.51   0.012     .0810361    .6537147
    d_seg_mi |   .0006592   .0010519     0.63   0.531    -.0014024    .0027208
       _cons |  -.1278602    1.00436    -0.13   0.899    -2.096369    1.840648
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |   .2203907   .0853827                      .0530436    .3877377
-------------+----------------------------------------------------------------
       alpha |   1.246564    .106435                      1.054476    1.473643
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  699.73 Prob>=chibar2 = 0.000
```

4-lane Divided Statewide Total Crash SPF (500 miles)

```
Negative binomial regression                      Number of obs   =       1530
                                                  LR chi2(6)      =     155.00
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -3016.4291                       Pseudo R2       =     0.0250

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .6968195   .0681361    10.23   0.000     .5632751    .8303638
      PSL_45 |  -.2808522   .0630656    -4.45   0.000    -.4044586   -.1572458
   PSL_50_65 |  -.5261541   .0759899    -6.92   0.000    -.6750915   -.3772167
     barrier |   .2247305   .0696326     3.23   0.001     .0882532    .3612078
         CTL |   .1865092   .2378366     0.78   0.433     -.279642    .6526603
    d_seg_mi |  -.0003928   .0005395    -0.73   0.467    -.0014503    .0006646
       _cons |   -4.79639   .6399855    -7.49   0.000    -6.050739   -3.542041
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.3744858    .068078                     -.5079163   -.2410553
-------------+----------------------------------------------------------------
       alpha |   .6876428   .0468134                      .6017481    .7857982
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  841.55 Prob>=chibar2 = 0.000
```

4-lane Divided Statewide Fatal + Injury Crash SPF (500 miles)

```
Negative binomial regression                      Number of obs   =       1530
                                                  LR chi2(6)      =     120.18
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -2131.6471                       Pseudo R2       =     0.0274

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .6477753   .0876768     7.39   0.000     .4759319    .8196187
      PSL_45 |  -.4495723   .0758938    -5.92   0.000    -.5983213   -.3008232
   PSL_50_65 |  -.7050068   .0926729    -7.61   0.000    -.8866424   -.5233712
     barrier |   .1872639   .0836228     2.24   0.025     .0233663    .3511616
         CTL |   .0945833   .2849554     0.33   0.740    -.4639189    .6530856
    d_seg_mi |  -.0009832   .0008786    -1.12   0.263    -.0027052    .0007388
       _cons |  -4.977839   .8235817    -6.04   0.000     -6.59203   -3.363649
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.3734195    .099484                     -.5684044   -.1784345
-------------+----------------------------------------------------------------
       alpha |   .6883764   .0684824                      .5664285    .8365789
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  272.58 Prob>=chibar2 = 0.000
```

APPENDIX H

TOTAL AND FATAL+INJURY SPFs FOR INTERSECTIONS ON URBAN-SUBURBAN ARTERIALS

3-leg Minor Stop Control District 1 & 2 Total Crash SPF

```
Negative binomial regression                      Number of obs     =        485
                                                  LR chi2(4)        =      32.94
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -514.08727                       Pseudo R2         =     0.0310

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .5380258   .1421927     3.78   0.000     .2593332    .8167184
  lnaadt_min |   .1879987   .0728194     2.58   0.010     .0452753     .330722
    MajPSL40p |    .210031   .1398885     1.50   0.133    -.0641455    .4842075
    MinPSL40p |   .3562512   .1359221     2.62   0.009     .0898487    .6226537
       _cons |  -6.758381   1.253796    -5.39   0.000    -9.215776   -4.300985
-------------+----------------------------------------------------------------
    /lnalpha |  -1.250782   .4500491                     -2.132862   -.3687021
-------------+----------------------------------------------------------------
       alpha |   .2862808   .1288404                      .1184977    .6916314
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =    7.16 Prob>=chibar2 = 0.004
```

3-leg Minor Stop Control District 1 & 2 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs     =        485
                                                  LR chi2(3)        =      18.68
Dispersion     = mean                             Prob > chi2       =     0.0003
Log likelihood = -330.94533                       Pseudo R2         =     0.0275

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .5571355   .1886804     2.95   0.003     .1873288    .9269422
  lnaadt_min |   .1501354   .0961584     1.56   0.118    -.0383316    .3386023
   MajPSL40p |   .5507209   .1834775     3.00   0.003     .1911116    .9103302
       _cons |  -7.447398   1.648259    -4.52   0.000    -10.67793   -4.216871
-------------+----------------------------------------------------------------
    /lnalpha |  -12.07516   707.3974                     -1398.549    1374.398
-------------+----------------------------------------------------------------
       alpha |   5.70e-06   .0040317                             0           .
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) = 0.0e+00 Prob>=chibar2 = 0.500
```

3-leg Minor Stop Control District 3 Total Crash SPF

```
Negative binomial regression                      Number of obs     =        295
                                                  LR chi2(4)        =      41.88
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood =  -329.4061                       Pseudo R2         =     0.0598

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .5319791   .1511264     3.52   0.000     .2357768    .8281813
  lnaadt_min |   .3913633   .0783691     4.99   0.000     .2377626     .544964
    MajPSL40p |   .3437408   .1615618     2.13   0.033     .0270855    .6603962
    MinPSL40p |   .3268845   .1770793     1.85   0.065    -.0201845    .6739535
       _cons |  -8.382106   1.411701    -5.94   0.000    -11.14899   -5.615223
-------------+----------------------------------------------------------------
    /lnalpha |  -1.645874   .6950419                     -3.008131   -.2836168
-------------+----------------------------------------------------------------
       alpha |    .192844   .1340346                      .0493839    .7530551
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =    2.90 Prob>=chibar2 = 0.044
```

3-leg Minor Stop Control District 3 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs     =        295
                                                  LR chi2(4)        =      36.71
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -227.04322                       Pseudo R2         =     0.0748

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .6379045   .1987661     3.21   0.001     .2483302    1.027479
  lnaadt_min |   .4510142     .10215     4.42   0.000     .2508038    .6512245
    MajPSL40p |   .5223482   .2193669     2.38   0.017     .0923968    .9522995
    MinPSL40p |    .485592   .2389786     2.03   0.042     .0172025    .9539816
       _cons |  -10.65987   1.859627    -5.73   0.000    -14.30467   -7.015067
-------------+----------------------------------------------------------------
    /lnalpha |  -2.129787   1.664227                     -5.391612    1.132038
-------------+----------------------------------------------------------------
       alpha |   .1188626   .1978143                      .0045546    3.101971
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =    0.44 Prob>=chibar2 = 0.254
```

3-leg Minor Stop Control District 4 Total Crash SPF

```
Negative binomial regression                      Number of obs     =        510
                                                  LR chi2(2)        =     110.66
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -641.76707                       Pseudo R2         =     0.0794

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .6619079   .1036667     6.38   0.000     .4587249    .8650908
  lnaadt_min |   .3618271   .0613889     5.89   0.000     .2415071    .4821471
       _cons |  -8.654829   .9175842    -9.43   0.000    -10.45326   -6.856397
-------------+----------------------------------------------------------------
    /lnalpha |  -1.798477   .4721182                     -2.723812   -.8731423
-------------+----------------------------------------------------------------
       alpha |   .1655508   .0781596                      .0656242    .4176371
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =    6.12 Prob>=chibar2 = 0.007
```

3-leg Minor Stop Control District 4 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs     =        510
                                                  LR chi2(2)        =      86.67
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -455.49563                       Pseudo R2         =     0.0869

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .8836029   .1357063     6.51   0.000     .6176234    1.149582
  lnaadt_min |   .3232814   .0771466     4.19   0.000     .1720768     .474486
       _cons |  -10.97969   1.231929    -8.91   0.000    -13.39422   -8.565149
-------------+----------------------------------------------------------------
    /lnalpha |  -3.017999    2.21077                     -7.351029     1.31503
-------------+----------------------------------------------------------------
       alpha |    .048899   .1081043                      .0006419    3.724864
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =    0.22 Prob>=chibar2 = 0.319
```

3-leg Minor Stop Control District 5 Total Crash SPF

```
Negative binomial regression                      Number of obs     =        745
                                                  LR chi2(3)        =     124.98
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -1137.6649                       Pseudo R2         =     0.0521

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .4026869   .0783149     5.14   0.000     .2491925    .5561814
  lnaadt_min |   .3500566   .0381702     9.17   0.000     .2752443    .4248688
   MajPSL40p |    .293257   .0866278     3.39   0.001     .1234696    .4630444
       _cons |  -6.255299   .7606567    -8.22   0.000    -7.746159   -4.764439
-------------+----------------------------------------------------------------
    /lnalpha |  -1.072535   .1657115                     -1.397324   -.7477464
-------------+----------------------------------------------------------------
       alpha |   .3421401   .0566965                      .2472579    .4734323
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   77.11 Prob>=chibar2 = 0.000
```

3-leg Minor Stop Control District 5 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs     =        745
                                                  LR chi2(3)        =      88.09
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -840.31901                       Pseudo R2         =     0.0498

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .5493162   .1033513     5.32   0.000     .3467514    .7518809
  lnaadt_min |   .3206308   .0487894     6.57   0.000     .2250053    .4162563
   MajPSL40p |   .3923358   .1140138     3.44   0.001     .1688729    .6157987
       _cons |  -8.088272     1.0055    -8.04   0.000    -10.05902   -6.117527
-------------+----------------------------------------------------------------
    /lnalpha |   -.900872   .2392254                     -1.369745   -.4319989
-------------+----------------------------------------------------------------
       alpha |   .4062153    .097177                      .2541718    .6492101
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   31.99 Prob>=chibar2 = 0.000
```

3-leg Minor Stop Control District 6 Total Crash SPF

```
Negative binomial regression                    Number of obs     =      1,135
                                                LR chi2(3)        =     164.74
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -1696.2037                     Pseudo R2         =     0.0463

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .4227776   .0721907     5.86   0.000     .2812864    .5642687
  lnaadt_min |   .3725749   .0398526     9.35   0.000     .2944652    .4506846
   MajPSL40p |     .13087   .0684545     1.91   0.056    -.0032984    .2650385
       _cons |  -6.728728   .6575872   -10.23   0.000    -8.017575   -5.439881
-------------+----------------------------------------------------------------
    /lnalpha |  -.9238619   .1344219                     -1.187324   -.6603998
-------------+----------------------------------------------------------------
       alpha |    .396983   .0533632                      .3050364    .5166447
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  118.67 Prob>=chibar2 = 0.000
```

3-leg Minor Stop Control District 6 Fatal + Injury Crash SPF

```
Negative binomial regression                    Number of obs     =      1,135
                                                LR chi2(2)        =     146.29
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -1230.0503                     Pseudo R2         =     0.0561

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .5746789   .0942514     6.10   0.000     .3899496    .7594083
  lnaadt_min |   .4319699   .0515054     8.39   0.000     .3310211    .5329187
       _cons |   -9.18575   .8679861   -10.58   0.000    -10.88697   -7.484528
-------------+----------------------------------------------------------------
    /lnalpha |   -.800745   .1964312                     -1.185743   -.4157469
-------------+----------------------------------------------------------------
       alpha |   .4489943   .0881965                      .3055191    .6598473
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   49.94 Prob>=chibar2 = 0.000
```

3-leg Minor Stop Control District 8 Total Crash SPF

```
Negative binomial regression                      Number of obs     =        730
                                                  LR chi2(3)        =     112.50
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -948.29442                       Pseudo R2         =     0.0560

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .6230992    .095845     6.50   0.000     .4352464    .8109521
  lnaadt_min |   .3344989   .0541092     6.18   0.000     .2284469     .440551
   MinPSL40p |   .2363103   .0879075     2.69   0.007     .0640148    .4086057
       _cons |  -8.416923   .8742567    -9.63   0.000    -10.13043   -6.703411
-------------+----------------------------------------------------------------
    /lnalpha |  -1.301101   .2556933                      -1.80225   -.7999511
-------------+----------------------------------------------------------------
       alpha |    .272232   .0696079                      .1649273    .4493509
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   25.59 Prob>=chibar2 = 0.000
```

3-leg Minor Stop Control District 8 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs     =        730
                                                  LR chi2(3)        =      79.31
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -656.72868                       Pseudo R2         =     0.0569

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |    .722262   .1313406     5.50   0.000     .4648392    .9796848
  lnaadt_min |   .3567581   .0732597     4.87   0.000     .2131718    .5003444
   MinPSL40p |   .2666763   .1168201     2.28   0.022     .0377132    .4956394
       _cons |  -10.21711   1.193822    -8.56   0.000    -12.55695   -7.877257
-------------+----------------------------------------------------------------
    /lnalpha |  -1.334586   .4446611                     -2.206106   -.4630666
-------------+----------------------------------------------------------------
       alpha |   .2632671   .1170646                      .1101287    .6293507
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =    7.44 Prob>=chibar2 = 0.003
```

3-leg Minor Stop Control District 9 & 10 Total Crash SPF

```
Negative binomial regression                      Number of obs     =        510
                                                  LR chi2(2)        =      42.21
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -537.80951                       Pseudo R2         =     0.0378

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .5496594   .1325669     4.15   0.000      .289833    .8094858
  lnaadt_min |   .2440187   .0653995     3.73   0.000     .1158381    .3721994
       _cons |  -7.089701   1.152307    -6.15   0.000    -9.348182   -4.831219
-------------+----------------------------------------------------------------
    /lnalpha |  -.7300681    .301756                     -1.321499   -.1386372
-------------+----------------------------------------------------------------
       alpha |   .4818762    .145409                      .2667351    .8705438
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   20.06 Prob>=chibar2 = 0.000
```

3-leg Minor Stop Control District 9 & 10 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs     =        510
                                                  LR chi2(2)        =      22.19
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -353.68938                       Pseudo R2         =     0.0304

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .6418736   .1757105     3.65   0.000     .2974874    .9862598
  lnaadt_min |   .1615609   .0859594     1.88   0.060    -.0069164    .3300382
       _cons |  -8.010688    1.54027    -5.20   0.000    -11.02956   -4.991814
-------------+----------------------------------------------------------------
    /lnalpha |  -.7846488   .5485979                     -1.859881    .2905833
-------------+----------------------------------------------------------------
       alpha |   .4562799   .2503142                      .1556912    1.337207
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =    5.11 Prob>=chibar2 = 0.012
```

3-leg Minor Stop Control District 11 Total Crash SPF

```
Negative binomial regression                    Number of obs     =      1,035
                                                LR chi2(5)        =     209.09
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -1369.0485                     Pseudo R2         =     0.0709

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .7869918   .0849959     9.26   0.000     .6204028    .9535807
  lnaadt_min |   .2883716   .0439709     6.56   0.000     .2021902    .3745529
   MajPSL40p |   .1525756    .081681     1.87   0.062    -.0075161    .3126674
   MinPSL40p |   .1394641   .0832517     1.68   0.094    -.0237062    .3026344
     county4 |   .3771091   .0834345     4.52   0.000     .2135806    .5406377
       _cons |  -9.484532   .7470881   -12.70   0.000     -10.9488   -8.020266
-------------+----------------------------------------------------------------
    /lnalpha |  -.8981809   .1584815                     -1.208799    -.587563
-------------+----------------------------------------------------------------
       alpha |   .4073099   .0645511                      .2985557    .5556798
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   82.18 Prob>=chibar2 = 0.000
```

3-leg Minor Stop Control District 11 Fatal + Injury Crash SPF

```
Negative binomial regression                    Number of obs     =      1,035
                                                LR chi2(4)        =     144.18
Dispersion     = mean                           Prob > chi2       =     0.0000
Log likelihood = -950.04782                     Pseudo R2         =     0.0705

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .9128666   .1124675     8.12   0.000     .6924343    1.133299
  lnaadt_min |    .229177   .0563588     4.07   0.000     .1187158    .3396383
   MajPSL40p |   .3088351   .1031225     2.99   0.003     .1067186    .5109515
     county4 |   .4472734    .107201     4.17   0.000     .2371633    .6573836
       _cons |  -10.89859    .978295   -11.14   0.000    -12.81601   -8.981169
-------------+----------------------------------------------------------------
    /lnalpha |  -.7933313   .2529104                     -1.289027    -.297636
-------------+----------------------------------------------------------------
       alpha |   .4523354   .1144003                      .2755389    .7425716
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   26.90 Prob>=chibar2 = 0.000
```

3-leg Minor Stop Control District 12 Total Crash SPF

```
Negative binomial regression                      Number of obs     =        865
                                                  LR chi2(3)        =     102.72
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -973.06328                       Pseudo R2         =     0.0501

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .8260415   .0984633     8.39   0.000      .633057    1.019026
  lnaadt_min |   .1685276   .0568028     2.97   0.003     .0571961     .279859
   MajPSL40p |    .245274   .0963565     2.55   0.011     .0564187    .4341293
       _cons |  -9.022445   .8898752   -10.14   0.000    -10.76657   -7.278322
-------------+----------------------------------------------------------------
    /lnalpha |  -.8215701   .2231161                      -1.25887   -.3842706
-------------+----------------------------------------------------------------
       alpha |   .4397407   .0981132                      .2839749    .6809471
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   35.59 Prob>=chibar2 = 0.000
```

3-leg Minor Stop Control District 12 Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs     =        865
                                                  LR chi2(3)        =      79.29
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -678.88277                       Pseudo R2         =     0.0552

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .8704518   .1241495     7.01   0.000     .6271232     1.11378
  lnaadt_min |   .1934677     .07136     2.71   0.007     .0536048    .3333307
   MajPSL40p |   .3507147   .1225885     2.86   0.004     .1104457    .5909837
       _cons |  -10.30511   1.116736    -9.23   0.000    -12.49388   -8.116351
-------------+----------------------------------------------------------------
    /lnalpha |  -1.011911   .3974852                     -1.790968   -.2328546
-------------+----------------------------------------------------------------
       alpha |   .3635235   .1444952                      .1667987    .7922687
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =    9.48 Prob>=chibar2 = 0.001
```

3-leg Signalized Statewide Total Crash SPF

Negative binomial regression — Number of obs = 3,255; LR chi2(8) = 362.62; Prob > chi2 = 0.0000; Pseudo R2 = 0.0287

Dispersion = mean

Log likelihood = -6131.5179

total_crash	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnaadt_maj	.3927964	.0468461	8.38	0.000	.3009797	.484613
lnaadt_min	.2188556	.0280995	7.79	0.000	.1637816	.2739296
ELTMaj	.0971054	.034596	2.81	0.005	.0292985	.1649122
ELTMin	.1098072	.036805	2.98	0.003	.0376707	.1819437
MajPSL30_35	.1306669	.0508355	2.57	0.010	.0310312	.2303026
MajPSL40p	.3455295	.0513992	6.72	0.000	.244789	.4462701
dist030809	-.1421631	.0453828	-3.13	0.002	-.2311117	-.0532145
dist0511	.1689851	.0374564	4.51	0.000	.0955719	.2423983
_cons	-5.112788	.4172636	-12.25	0.000	-5.930609	-4.294966
/lnalpha	-.9540839	.0593263			-1.070361	-.8378065
alpha	.3851648	.0228504			.3428846	.4326585

Likelihood-ratio test of alpha=0: chibar2(01) = 729.05 Prob>=chibar2 = 0.000

3-leg Signalized Statewide Fatal + Injury Crash SPF

Negative binomial regression — Number of obs = 3,255; LR chi2(6) = 213.10; Prob > chi2 = 0.0000; Pseudo R2 = 0.0221

Dispersion = mean

Log likelihood = -4723.692

fatal_inj	Coef.	Std. Err.	z	P>|z|	[95% Conf.	Interval]
lnaadt_maj	.3812779	.0588386	6.48	0.000	.2659563	.4965994
lnaadt_min	.2466613	.0355774	6.93	0.000	.1769309	.3163918
ELTMaj	.1150882	.0419401	2.74	0.006	.0328872	.1972892
MajPSL40p	.181049	.0417151	4.34	0.000	.099289	.262809
dist030809	-.2141396	.0573144	-3.74	0.000	-.3264737	-.1018055
dist0511	.1137173	.0461228	2.47	0.014	.0233184	.2041163
_cons	-5.676701	.5247825	-10.82	0.000	-6.705256	-4.648146
/lnalpha	-.7809173	.080695			-.9390765	-.622758
alpha	.4579857	.0369571			.3909888	.5364628

Likelihood-ratio test of alpha=0: chibar2(01) = 322.14 Prob>=chibar2 = 0.000

4-leg Signalized Statewide Total Crash SPF

```
Negative binomial regression                      Number of obs     =     10,585
                                                  LR chi2(14)       =    2071.85
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -22897.438                       Pseudo R2         =     0.0433

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .4033219   .0249541    16.16   0.000     .3544127     .452231
  lnaadt_min |   .3155368   .0148085    21.31   0.000     .2865127    .3445609
      ELTMaj |   .0530066    .018557     2.86   0.004     .0166356    .0893776
      ERTMaj |   .1262414   .0214566     5.88   0.000     .0841873    .1682956
      ELTMin |   .0559682   .0190776     2.93   0.003     .0185768    .0933596
      ERTMin |   .0448331   .0228997     1.96   0.050    -.0000495    .0897158
 MajPSL40_45 |   .1005854   .0189067     5.32   0.000      .063529    .1376419
 MajPSL50_55 |   .2902061   .0347804     8.34   0.000     .2220377    .3583745
   MinPSL35p |   .0745955   .0200421     3.72   0.000     .0353138    .1138773
  dist010212 |  -.2493943    .027883    -8.94   0.000     -.304044   -.1947445
    dist0310 |  -.3459949   .0393469    -8.79   0.000    -.4231134   -.2688764
       dist4 |   .1050534   .0395118     2.66   0.008     .0276117     .182495
    dist0809 |  -.1236054   .0229701    -5.38   0.000     -.168626   -.0785847
      dist11 |  -.0453053   .0319029    -1.42   0.156    -.1078339    .0172232
       _cons |  -5.501372   .2267245   -24.26   0.000    -5.945744      -5.057
-------------+----------------------------------------------------------------
    /lnalpha |  -1.033212   .0278511                     -1.087799   -.9786244
-------------+----------------------------------------------------------------
       alpha |   .3558623   .0099111                      .3369574    .3758277
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) = 4004.54 Prob>=chibar2 = 0.000
```

4-leg Signalized Statewide Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs     =     10,585
                                                  LR chi2(10)       =    1562.64
Dispersion     = mean                             Prob > chi2       =     0.0000
Log likelihood = -18456.793                       Pseudo R2         =     0.0406

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .4107397   .0301667    13.62   0.000     .3516141    .4698653
  lnaadt_min |   .3625904   .0182105    19.91   0.000     .3268984    .3982824
      ERTMaj |   .1302163   .0255352     5.10   0.000     .0801682    .1802644
      ELTMin |   .0529656   .0213125     2.49   0.013     .0111939    .0947372
 MajPSL50_55 |   .2259616   .0409977     5.51   0.000     .1456076    .3063156
  dist010212 |  -.2998546   .0342098    -8.77   0.000    -.3669045   -.2328047
    dist0310 |  -.4420003   .0492727    -8.97   0.000     -.538573   -.3454276
       dist4 |   .0887795   .0466416     1.90   0.057    -.0026362    .1801953
    dist0809 |  -.2403234   .0281344    -8.54   0.000    -.2954658    -.185181
      dist11 |  -.1890422   .0394539    -4.79   0.000    -.2663704   -.1117141
       _cons |  -6.374333   .2759674   -23.10   0.000    -6.915219   -5.833447
-------------+----------------------------------------------------------------
    /lnalpha |  -.8389767   .0345198                     -.9066343    -.771319
-------------+----------------------------------------------------------------
       alpha |   .4321525   .0149178                      .4038813    .4624027
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) = 2186.55 Prob>=chibar2 = 0.000
```

4-leg Minor Stop Statewide Total Crash SPF

```
Negative binomial regression                      Number of obs   =       1980
                                                  LR chi2(7)      =     311.94
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -2951.1179                       Pseudo R2       =     0.0502

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .5296939   .0542078     9.77   0.000     .4234485    .6359392
  lnaadt_min |   .2785342   .0296708     9.39   0.000     .2203806    .3366879
 MajPSL40_45 |   .1825377   .0587374     3.11   0.002     .0674145    .2976608
 MajPSL50_55 |   .3559669    .081151     4.39   0.000     .1969138      .51502
   MinPSL40p |   .1308739   .0526513     2.49   0.013     .0276793    .2340684
 district5_8 |   .3618318   .0602139     6.01   0.000     .2438148    .4798489
   district6 |   .1462908   .0702833     2.08   0.037      .008538    .2840436
       _cons |  -6.908665   .5401184   -12.79   0.000    -7.967277   -5.850052
-------------+----------------------------------------------------------------
    /lnalpha |  -.9492806   .1046298                     -1.154351   -.7442099
-------------+----------------------------------------------------------------
       alpha |   .3870193   .0404938                       .315262    .4751095
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  188.71 Prob>=chibar2 = 0.000
```

4-leg Minor Stop Statewide Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs   =       1980
                                                  LR chi2(7)      =     221.02
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -2096.7275                       Pseudo R2       =     0.0501

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
  lnaadt_maj |   .5847251   .0701047     8.34   0.000     .4473225    .7221277
  lnaadt_min |   .2962268   .0379546     7.80   0.000      .221837    .3706165
 MajPSL40_45 |   .1318144   .0743838     1.77   0.076    -.0139753     .277604
 MajPSL50_55 |   .3956055   .1020366     3.88   0.000     .1956174    .5955936
   MinPSL40p |    .169334   .0668427     2.53   0.011     .0383247    .3003434
 district5_8 |   .3665587   .0764676     4.79   0.000      .216685    .5164324
   district6 |   .1332345   .0893828     1.49   0.136    -.0419526    .3084216
       _cons |  -8.225508   .6986409   -11.77   0.000    -9.594819   -6.856197
-------------+----------------------------------------------------------------
    /lnalpha |  -1.000786   .1749272                     -1.343637    -.657935
-------------+----------------------------------------------------------------
       alpha |   .3675904   .0643016                      .2608951    .5179198
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =   54.45 Prob>=chibar2 = 0.000
```

APPENDIX I

MODIFICATION FACTORS FOR OTHER COMMON INTERSECTION FORMS

Due to data limitations, reliable safety models were not possible for 3-leg minor stop-controlled intersections with "STOP Except Right Turns" signs on two-lane rural roadways and the following intersection types on urban-suburban arterials:

- 5-leg signalized intersections
- 4-leg all-way stop-controlled intersections
- 3-leg minor stop-controlled intersections with "STOP Except Right Turns" signs

In the two-lane rural roadway database, only 15 3-leg minor stop-controlled intersections had "STOP Except Right Turns" signs installed. Only 40 5-leg intersections of state-owned urban-suburban arterials were identified using PennDOT's RMS database. For 4-leg all-way stop-controlled intersections on urban-suburban arterials, 47 intersections were identified. For 3-leg minor stop-controlled intersections with "STOP Except Right Turns" signs on urban-suburban arterials, only 17 intersections were identified. Preliminary models found that any SPFs developed for these intersection types would be unreliable.

To help provide PennDOT with guidance on how to predict crash frequencies for these intersection forms, the research team has estimated calibration coefficients to modify the outputs of other intersection SPFs to predict crash frequencies on these intersection types. The calibration coefficients were determined as follows:

1. A "base" SPF was selected that most closely represented traffic conditions at the desired intersection type
2. For each available observation, the estimated crash frequency was computed using the base SPF
3. For the entire set of observations, the sum of total estimated crash frequency and the total reported crash frequency is computed
4. The ratio of total estimated crash frequency to total reported crash frequency provides the calibration factor that should be applied to each individual observation

The remainder of this appendix provides the calibration factors that should be applied for these intersection types to estimate crash frequencies at these locations.

3-leg minor stop-controlled intersections with "STOP Except Right Turns" signs on two-lane rural roads

For this intersection type, the SPF for 3-leg minor stop-controlled intersections is used as the "base" SPF. The calibration coefficient was provided for each of the 8 years that crash data were available as well as the total for the entire 8-year period. The results are shown in Table I1. As shown in Table I1, the calibration coefficient appears to have significant variation across the 8-year period. This suggests that the relationship between reported crash frequency on 3-leg minor stop-controlled intersections with "STOP Except Right Turns" signs and estimated crash frequency using the 3-leg minor stop-controlled intersection SPF is not consistent throughout this period. Therefore, actual crash frequencies might vary from the predictions using this method.

Table I1. Calibration factors for 3-leg minor stop-controlled intersections on two-lane rural roads

Total crash frequency			
Year	Reported crash frequency	Predicted crash frequency (3-leg minor stop-controlled SPF)	Calibration factor
2005	17	19.57	0.87
2006	17	19.53	0.87
2007	19	19.48	0.98
2008	23	19.41	1.19
2009	7	19.32	0.36
2010	15	19.22	0.78
2011	27	19.12	1.41
2012	29	18.99	1.53
TOTAL	154	154.64	1.00
Fatal + injury crash frequency			
2005	10	10.74	0.93
2006	11	10.73	1.03
2007	7	10.70	0.65
2008	21	10.67	1.97
2009	2	10.64	0.19
2010	13	10.59	1.23
2011	8	10.54	0.76
2012	9	10.47	0.86
TOTAL	81	85.08	0.95

If estimates of crash frequency on 3-leg minor stop-controlled intersections with "STOP Except Right Turns" signs are needed, we recommend first using the SPF for 3-leg minor stop-controlled intersections on two-lane rural roads. However, the estimates from the SPF should be adjusted by a multiplicative calibration factor to obtain the estimate of crash frequency at the 3-leg minor stop-controlled intersection with "STOP Except Right Turns" signs. The calibration factor for total crash frequency is 1.00 and the calibration factor for fatal + injury crash frequency is 0.95. Based on these results, we expect that the presence of a "STOP Except Right Turns" sign to not significantly impact the safety performance of 3-leg minor-stop controlled intersections on two-lane rural roads.

5-leg signalized intersections on urban-suburban arterials

For this intersection type, the SPF for 4-leg signalized intersections is used as the "base" SPF. The calibration coefficient was provided for each of the 5 years that crash data were available as well as the total for the entire 5-year period. The results are shown in Table I2. As shown in Table I2, the calibration coefficient appears to have very little variation across the 5-year period. This suggests that the relationship between reported crash frequency on 5-leg signalized intersections and estimated crash frequency using the 4-leg signalized intersection SPF is fairly consistent throughout this period.

Table I2. Calibration factors for 5-leg signalized intersections

Total crash frequency			
Year	Reported crash frequency	Predicted crash frequency (4-leg signalized SPF)	Calibration factor
2010	136	126.80	1.07
2011	125	125.92	0.99
2012	135	125.00	1.08
2013	134	124.04	1.08
2014	124	123.05	1.01
TOTAL	654	624.80	1.05
Fatal + injury crash frequency			
2010	63	72.12	0.87
2011	76	71.60	1.06
2012	79	71.06	1.11
2013	66	70.50	0.94
2014	63	69.91	0.90
TOTAL	347	355.19	0.98

Therefore, estimates of crash frequency on 5-leg signalized intersections can be performed using the SPF for 4-leg signalized intersections. However, the estimates from the SPF should be adjusted by a multiplicative calibration factor to obtain the estimate of crash frequency at the 5-leg signalized intersection. The calibration factor for total crash frequency is 1.05 and the calibration factor for fatal + injury crash frequency is 0.98. Based on these results, we expect that the 5-leg signalized intersections have about the same safety performance as the 4-leg signalized intersections on urban-suburban arterials.

4-leg all-way stop-controlled intersections on urban-suburban arterials

For this intersection type, the SPF for 4-leg minor stop-controlled intersections is used as the "base" SPF. The calibration coefficient was provided for each of the five years that crash data were available as well as the total for the entire 5-year period. The results are provided in Table I3. As shown in Table I3, the calibration coefficient appears to have some variation across the 5-year period. This suggests that the relationship between reported crash frequency on 4-leg all-way stop-controlled intersections and estimated crash frequency using the 4-leg minor stop-controlled intersection SPF may not be consistent during this period.

Table I3. Calibration factors for 4-leg all-way stop-controlled intersections

Total crash frequency			
Year	Reported crash frequency	Predicted crash frequency (4-leg signalized SPF)	Calibration factor
2010	54	58.98	0.92
2011	66	58.42	1.13
2012	59	57.82	1.02
2013	45	57.19	0.79
2014	53	56.51	0.94
TOTAL	277	288.92	0.96
Fatal + injury crash frequency			
2010	28	28.99	0.97
2011	31	28.69	1.08
2012	26	28.37	0.92
2013	19	28.03	0.68
2014	16	27.67	0.58
TOTAL	120	141.76	0.85

Overall, it appears that estimates of crash frequency on 4-leg all-way stop-controlled intersections can be performed using the SPF for 4-leg minor stop-controlled intersections. However, the estimates from the SPF should be adjusted by a multiplicative calibration factor to obtain the estimate of crash frequency at the 4-leg all-way stop-controlled intersection. The calibration factor for total crash frequency is 0.96 and the calibration factor for fatal + injury crash frequency is 0.85. In general, it appears that the crash frequency of 4-leg all-way stop-controlled intersections tends to be lower than equivalent 4-leg minor-stop-controlled intersections.

3-leg minor stop-controlled intersections with "STOP Except Right Turns" signs on urban-suburban arterials

For this intersection type, the SPF for 3-leg minor stop-controlled intersections is used as the "base" SPF. The calibration coefficient was provided for each of the 5 years that crash data were available as well as the total for the entire 5-year period. The results are shown in Table I4. As shown in Table I4, the calibration coefficient appears to have significant variation across the 5-year period. This suggests that the relationship between reported crash frequency on 3-leg minor stop-controlled intersections with "STOP Except Right Turns" signs and estimated crash frequency using the 3-leg minor stop-controlled intersection SPF is not consistent throughout this period. Therefore, actual crash frequencies might vary from the predictions using this method.

Table I4. Calibration factors for 3-leg minor stop-controlled intersections on urban-suburban arterials

Total crash frequency			
Year	Reported crash frequency	Predicted crash frequency (3-leg minor stop controlled SPF)	Calibration factor
2010	13	13.79	0.94
2011	12	13.70	0.88
2012	4	13.60	0.29
2013	9	13.50	0.67
2014	8	13.39	0.60
TOTAL	46	67.97	0.68
Fatal + injury crash frequency			
2010	4	6.77	0.59
2011	7	6.71	1.04
2012	2	6.65	0.30
2013	1	6.59	0.15
2014	4	6.53	0.61
TOTAL	18	33.26	0.54

If estimates of crash frequency on 3-leg minor stop-controlled intersections with "STOP Except Right Turns" signs are needed, we recommend first using the SPF for 3-leg minor stop-controlled intersections on urban-suburban arterials. However, the estimates from the SPF should be adjusted by a multiplicative calibration factor to obtain the estimate of crash frequency at the 3-leg minor stop-controlled intersection with "STOP Except Right Turns" signs. The calibration factor for total crash frequency is 0.68 and the calibration factor for fatal + injury crash frequency is 0.54. Based on these results, it appears that 3-leg minor stop-controlled intersections on urban-suburban arterials with the presence of a "STOP Except Right Turns" sign to have lower crash frequencies than equivalent 3-leg minor stop-controlled intersections without the sign.

APPENDIX J

TOTAL AND FATAL+INJURY SPFs FOR TOTAL AND FATAL + INJURY CRASHES ON URBAN-SUBURAN ARTERIAL SEGMENTS – 500-MILE DATABASE

2-Lane Undivided Roadway Total Crash SPF

```
Negative binomial regression                      Number of obs   =       2650
                                                  LR chi2(7)      =     427.88
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -5170.9895                       Pseudo R2       =     0.0397

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .7513335   .0407882    18.42   0.000     .6713902    .8312768
      PSL_35 |  -.3748019   .0713399    -5.25   0.000    -.5146254   -.2349783
      PSL_40 |  -.5982741   .0754137    -7.93   0.000    -.7460822    -.450466
   PSL_45_65 |  -.6123054   .0684267    -8.95   0.000    -.7464193   -.4781915
         CTL |   .0469278   .0623791     0.75   0.452     -.075333    .1691887
parking_lane |   .0584349   .1076133     0.54   0.587    -.1524833    .2693531
    d_seg_mi |    .000523   .0002259     2.31   0.021     .0000801    .0009658
       _cons |  -4.830798   .3855525   -12.53   0.000    -5.586467   -4.075129
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |   -1.01731   .0650056                     -1.144719   -.8899012
-------------+----------------------------------------------------------------
       alpha |   .3615663   .0235038                      .3183135    .4106963
------------------------------------------------------------------------------

Likelihood-ratio test of alpha=0:  chibar2(01) =  616.14 Prob>=chibar2 = 0.000
```

2-Lane Undivided Roadway Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs   =       2650
                                                  LR chi2(7)      =     286.38
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -3643.6609                       Pseudo R2       =     0.0378


------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .7201654    .054013    13.33   0.000     .6143019     .826029
      PSL_35 |  -.4604212   .0889094    -5.18   0.000    -.6346804    -.286162
      PSL_40 |  -.6952448   .0946771    -7.34   0.000    -.8808085    -.509681
   PSL_45_65 |  -.7467783   .0852684    -8.76   0.000    -.9139014   -.5796553
         CTL |    .213194   .0772067     2.76   0.006     .0618717    .3645163
parking_lane |   .1200389    .133999     0.90   0.370    -.1425943    .3826722
    d_seg_mi |   .0003867   .0002933     1.32   0.187    -.0001881    .0009615
       _cons |  -5.254386   .5106812   -10.29   0.000    -6.255303   -4.253469
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.9295402   .1022136                     -1.129875   -.7292052
-------------+----------------------------------------------------------------
       alpha |   .3947352   .0403473                      .3230736    .4822921
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  184.64 Prob>=chibar2 = 0.000
```

4-Lane Undivided Roadway Total Crash SPF

```
Negative binomial regression                      Number of obs   =        895
                                                  LR chi2(4)      =      27.69
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -2069.4368                       Pseudo R2       =     0.0066

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |    .206027   .0917973     2.24   0.025     .0261076    .3859464
   PSL_50_65 |  -1.135399   .3792479    -2.99   0.003    -1.878711   -.3920872
         CTL |   .4548024   .1281317     3.55   0.000     .2036689     .705936
    d_seg_mi |   .0007678   .0009181     0.84   0.403    -.0010317    .0025673
       _cons |   .1357876      .8469     0.16   0.873    -1.524106    1.795681
    lnlength |          1  (offset)
-------------+---------------------------------------------------------------
    /lnalpha |   .1172346   .0652034                     -.0105617     .245031
-------------+----------------------------------------------------------------
       alpha |   1.124383   .0733136                      .9894939    1.277661
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) = 1862.31 Prob>=chibar2 = 0.000
```

4-Lane Undivided Roadway Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs   =        895
                                                  LR chi2(4)      =      17.18
Dispersion     = mean                             Prob > chi2     =     0.0018
Log likelihood = -1511.9778                       Pseudo R2       =     0.0056
------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .1532626   .1088637     1.41   0.159    -.0601063    .3666316
   PSL_50_65 |  -1.391051   .5097288    -2.73   0.006    -2.390101   -.3920011
         CTL |   .3673754   .1460942     2.51   0.012     .0810361    .6537147
    d_seg_mi |   .0006592   .0010519     0.63   0.531    -.0014024    .0027208
       _cons |  -.1278602    1.00436    -0.13   0.899    -2.096369    1.840648
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |   .2203907   .0853827                      .0530436    .3877377
-------------+---------------------------------------------------------------
       alpha |   1.246564    .106435                      1.054476    1.473643
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  699.73 Prob>=chibar2 = 0.000
```

4-Lane Divided Roadway Total Crash SPF

```
Negative binomial regression                      Number of obs   =       1530
                                                  LR chi2(6)      =     155.00
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -3016.4291                       Pseudo R2       =     0.0250

------------------------------------------------------------------------------
 total_crash |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
      lnaadt |   .6968195   .0681361    10.23   0.000     .5632751    .8303638
      PSL_45 |  -.2808522   .0630656    -4.45   0.000    -.4044586   -.1572458
   PSL_50_65 |  -.5261541   .0759899    -6.92   0.000    -.6750915   -.3772167
     barrier |   .2247305   .0696326     3.23   0.001     .0882532    .3612078
         CTL |   .1865092   .2378366     0.78   0.433     -.279642    .6526603
    d_seg_mi |  -.0003928   .0005395    -0.73   0.467    -.0014503    .0006646
       _cons |   -4.79639   .6399855    -7.49   0.000    -6.050739   -3.542041
    lnlength |          1  (offset)
-------------+----------------------------------------------------------------
    /lnalpha |  -.3744858    .068078                     -.5079163   -.2410553
-------------+----------------------------------------------------------------
       alpha |   .6876428   .0468134                      .6017481    .7857982
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  841.55 Prob>=chibar2 = 0.000
```

4-Lane Divided Roadway Fatal + Injury Crash SPF

```
Negative binomial regression                      Number of obs   =       1530
                                                  LR chi2(6)      =     120.18
Dispersion     = mean                             Prob > chi2     =     0.0000
Log likelihood = -2131.6471                       Pseudo R2       =     0.0274

------------------------------------------------------------------------------
   fatal_inj |      Coef.   Std. Err.      z    P>|z|     [95% Conf. Interval]
------------+-----------------------------------------------------------------
      lnaadt |   .6477753   .0876768     7.39   0.000     .4759319    .8196187
      PSL_45 |  -.4495723   .0758938    -5.92   0.000    -.5983213   -.3008232
   PSL_50_65 |  -.7050068   .0926729    -7.61   0.000    -.8866424   -.5233712
     barrier |   .1872639   .0836228     2.24   0.025     .0233663    .3511616
         CTL |   .0945833   .2849554     0.33   0.740    -.4639189    .6530856
    d_seg_mi |  -.0009832   .0008786    -1.12   0.263    -.0027052    .0007388
       _cons |  -4.977839   .8235817    -6.04   0.000     -6.59203   -3.363649
    lnlength |          1  (offset)
------------+-----------------------------------------------------------------
    /lnalpha |  -.3734195    .099484                     -.5684044   -.1784345
-------------+----------------------------------------------------------------
       alpha |   .6883764   .0684824                      .5664285    .8365789
------------------------------------------------------------------------------
Likelihood-ratio test of alpha=0:  chibar2(01) =  272.58 Prob>=chibar2 = 0.000
```