Regionalized Urban-suburban Collector Road Safety Performance Functions

FINAL REPORT

March 14, 2019

By Eric T. Donnell, Vikash Gayah,
Lingyu Li and Houjun Tang

The Pennsylvania State University

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF TRANSPORTATION

CONTRACT # 4400015622
WORK ORDER # PSU 007

Technical Report Documentation Page

1. Report No. PA-2019-001-511601 WO 007	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Regionalized Urban-suburban Collector Road Safety Performance Functions		**5. Report Date** March 14, 2019 **6. Performing Organization Code**
7. Author(s) Eric T. Donnell, Vikash V. Gayah, Lingyu Li and Houjun Tang		**8. Performing Organization Report No.** LTI 2019-03
9. Performing Organization Name and Address Thomas D. Larson Pennsylvania Transportation Institute Pennsylvania State University 201 Transportation Research Building University Park, PA 16802		**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.** 4400015622, PSU WO 007
12. Sponsoring Agency Name and Address The Pennsylvania Department of Transportation Bureau of Planning and Research Commonwealth Keystone Building 400 North Street, 6th Floor Harrisburg, PA 17120-0064		**13. Type of Report and Period Covered** June 14, 2018 - March 14, 2019 **14. Sponsoring Agency Code**

15. Supplementary Notes

Jason Hershock, Manager, Safety Engineering and Risk Management, served as the project technical advisor. Robert Ranieri, Crash Information Systems and Analysis Manager, supplied the data used for the project. Heather Heslop (hheslop@pa.gov) was the research project manager.

16. Abstract

The purpose of this project was to estimate regionalized safety performance functions (SPFs) for urban and suburban collector roads and at-grade intersections using roadway inventory and crash data from state-owned roadways in Pennsylvania. Five years of crash data (2013-2017) were appended to traffic volume and roadway and roadside features in order to estimate statistical models of total and fatal + injury crash frequency. SPFs were developed for two-lane undivided roadway segments and the following at-grade intersections types: three-leg intersections with stop-control on the minor approach; three-leg intersections with all-way stop control; four-leg intersections with stop-control on the minor approach, four-leg intersections with all-way stop control; and four-leg signalized intersections. Based on the regionalization process, engineering district-level SPFs with county-level adjustments were recommended for two-lane undivided roadway segments. Statewide SPFs were recommended for three-leg all-way stop controlled, four-leg minor-street stop-controlled, four-leg all-way stop-controlled and four-leg signalized intersections. Statewide SPFs with district-level adjustments were recommended for three-leg minor-street stop-controlled intersections.

17. Key Words Urban and suburban collectors; safety performance functions; negative binomial regression; roadway segments; intersections; regionalized SPFs	**18. Distribution Statement** No restrictions. This document is available from the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	**20. Security Classif. (of this page)**	**21. No. of Pages**	**22. Price**
Unclassified	Unclassified	96	

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

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CHAPTER 1

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 roadway and roadside features. In addition to the national SPFs included in the HSM, SPFs can also be developed using local data to provide crash frequency estimates that are more reliable for Pennsylvania roadways than applying the calibration procedure.

The objective of this project was to develop regionalized SPFs for urban-suburban collector roadways in Pennsylvania that are consistent with those in the HSM for other facility types but reflect local conditions. Through this project, SPFs were developed to predict the total crash frequency and frequency of fatal + injury crashes on both roadway segments and intersections, while considering the differences in safety performance that might occur within individual counties and Pennsylvania Department of Transportation (PennDOT) engineering districts.

This project builds upon two previous projects that developed safety performance functions for PennDOT:

- Work Order #1 (*Safety Performance Functions)* developed SPFs for rural two-lane roadways in Pennsylvania (Donnell et al., 2014); and,
- Work Order #17 (*Regionalized Safety Performance Functions)* developed regionalized SPFs for rural two-lane roadways, rural multi-lane roadways, and urban-suburban arterial roadways in Pennsylvania (Donnell et al., 2016).

The remainder of this report is organized into five subsequent sections. The first section describes the data that were obtained or collected for use in this project. The second describes the methodological approach used to develop the regionalized urban-suburban collector road segment and intersection SPFs. The third provides the final recommended roadway segment SPFs, and the fourth provides the final recommended intersection SPFs. The final section provides some concluding remarks and recommendations for implementation.

CHAPTER 2

Data and Data Structures

This section describes the data that were assembled and/or collected as a part of this project. The first part of this section describes the PennDOT Roadway Management System (RMS) datafiles that were acquired to develop the SPFs and how these files were organized for statistical modeling purposes. The next part describes the supplemental data elements that were collected by the research team. The last part provides information on the electronic crash data that were used to develop the roadway and intersection SPFs.

ROADWAY MANAGEMENT SYSTEM (RMS) DATA

PennDOT's RMS data files were used to identify the roadway segments and intersections that were included in this study. These data files were also used to obtain pertinent information about the infrastructure elements, including roadway cross-section, traffic volume, access control, functional classification, posted speed limit and intersection locations, and traffic control devices. The data are codified based on PennDOT's linear referencing system, which is defined by the county, state route, and segment number.

The research team obtained RMS and RMS ADMIN data files for the years 2013 through 2017 for use in this project. These data files were compared to identify if segments or intersections were added or deleted due to new roadway construction or major reconstruction, or due to changes in the functional classification of the segment. Since a comparison of the segment data revealed few differences, the 2017 file was used as the base file for the analysis database in this project, as it was the most recent.

The only variables that were expected to change significantly across the files were traffic volumes, expressed as the average annual daily traffic (AADT), which reflect changing travel demand patterns over the 5-year analysis period. To account for changing traffic volumes for the interim years between 2013 and 2017, the research team interpolated between known volumes, which assumes a constant rate of traffic growth (or decline) over the 5-year period.

Intersection location information was acquired from the RMS Intersection data files. The RMS Intersection data files included 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, two separate data files were created and used for SPF development—one for roadway segments only and the other for intersections only.

The roadway segment analysis file contained the following data elements:

- Linear reference information (county, route, and segment)
- Segment length (mi)
- 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 (ft)
- Left- and right-shoulder total width (ft)

The intersection data file included the same segment-level data listed above for each intersecting roadway in the intersection data files.

SUPPLEMENTAL DATA ELEMENTS

Additional data sources were used to supplement the information available in the RMS data files. This section describes these data sources and the available data elements that were obtained from each. The first describes the data elements that were obtained from other PennDOT databases. The second describes the data elements that were collected and codified using PennDOT's online VideoLog system. The third describes the data elements that were collected using the Google Earth web-based tool. The instructional guides that were used to train the staff that performed this data collection are provided in Appendices A and B of this report.

PennDOT Data Files

Two additional data files were obtained from PennDOT to supplement the existing RMS data files. The first was the inventory of all horizontal curves on state-owned roadways. The horizontal curves were identified using the same linear referencing system as in the RMS data files, allowing roadway segments with curves to be readily identified. Information available for each curve includes the beginning location, ending location, curve length, radius, and central angle. This information enabled the research team to consider various alignment indices to assess the association between horizontal curvature and crash frequency and severity when estimating the safety performance functions. The horizontal alignment indices that were considered by the research team included the following (Fitzpatrick et al., 1999):

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

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

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

where:
DC_i = degree of curve for curve i ($i = 1, 2, \ldots, n$) (degrees)
L = length of segment (mi)
CL_i = length of curve for curve i ($i = 1, 2, \ldots, n$) (mi)
R_i = Radius of curve i ($i = 1, 2, \ldots, n$) (ft)
n = number of horizontal curves per segment

Equation (1) provides the curve intensity of a segment in units of degree of curvature per mile. Equation (2) provides the fraction of a segment that is a horizontal curve. Finally, Equation (3) provides the average radius of all curves on a particular segment.

The second data file was a subset of the PennDOT sign inventory, which included the location of all roadway signs on state-owned roadways using PennDOT's linear referencing system. The research team requested the location of the following signs for use in this project:

- "STOP Except Right Turn" signs: used to identify stop-controlled intersections in which right turns do not have to stop.
- "Signal Ahead" signs: used to identify the presence of a traffic signal at an intersection.

These sign types were requested to identify intersections where the stop-except-right movement was permitted, and to more efficiently identify signalized intersections for SPF development. The presence of these signs was verified during the online VideoLog system review, which is detailed in the subsequent section.

PennDOT Online VideoLog System

PennDOT's VideoLog system[1] was used to collect both roadway segment and intersection details. The segment data included:

- Presence of bicycle lanes
- Presence of on-street parking
- Presence of curb/sidewalk combinations
- Driveway density
- Presence of auxiliary lanes (e.g., turn lanes, bus lanes, etc.)

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

Each of these data elements was coded into the RMS data files described above for roadway segments.

The intersection data elements that were collected using the online VideoLog system included:

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

Each of these data elements was coded into the RMS Intersection data files that were described above.

Google Earth

The satellite imagery in Google Earth was used to collect intersection skew angle data and confirm horizontal curve data for roadway segments. Intersection skew angle was estimated using a protractor to measure the angle of the intersecting roadways from Google Earth images. However, during the initial data collection it became clear that most intersections in the analysis database were perpendicular (i.e., did not have any skew), which is generally reasonable because most urban-suburban street networks are constructed in the form of a grid. Due to the lack of variability in the skew angle, this variable was removed from the database. The radius of curvature and length of horizontal curve were verified for individual segments using the Google Earth imagery. The data collection confirmed that the horizontal curve data provided by PennDOT were fairly accurate and no significant changes were necessary.

ELECTRONIC CRASH DATA

The research team obtained the most recent five years of crash data (2013 through 2017, inclusive) to estimate SPFs for this project. The crash data files available from PennDOT contained 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, suspected serious injury, suspected minor injury, possible injury, injury (unknown severity), unknown if injured, property damage only

Crash data were merged with the RMS and supplemental data files based on the location of the crash (county, route, and segment). For segments, the matching is direct based on the segment identified in the crash data file. For intersections, only crashes within 250 ft of the intersection location (on any of the intersection approaches) were associated with that intersection. Crash counts (total, total for each severity level, and total for each crash type) for each roadway segment and intersection were then generated for each analysis year. Locations that did not experience a crash during any one or more years were retained in the analysis database with an observed frequency of zero crashes.

CHAPTER 3

Methodology

This section of the report describes the statistical modeling methodology and regionalization process used to estimate the regionalized SPF for roadway segments and intersections.

STATISTICAL MODELING METHODS

Negative binomial regression was used to develop the roadway segment and intersection SPFs in this study to be consistent with the models developed in the first edition of the HSM. The negative binomial model estimates relationships between the expected number of crashes per year as a function of one or more explanatory variables. This is a very common approach to model roadway segment and intersection crash frequencies (e.g., Miaou, 1994; Shankar et al., 1995; Poch and Mannering, 1996; El-Basyouny and Sayed, 2006) because it accounts for the overdispersion that is often observed 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:

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

where:

λ_i	= expected number of crashes 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:

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

where:

$Var\ (y_i)$	= variance of observed crashes y occurring on roadway segment or intersection i;
$E(y_i)$	= expected crash frequency on roadway segment or intersection 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):

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

where:

N = total number of roadway segments or intersections 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:

$$\lambda_i = e^{\beta_0} \times L^{\beta_1} \times AADT^{\beta_2} \times e^{(\beta_3 X_3 + \cdots + \beta_n X_n)} \quad (7)$$

where:

λ_i = expected number of crashes 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 segment length;
β_2 = regression coefficient for AADT;
$\beta_3, \ldots, \beta_n$ = regression coefficients for explanatory variables, $i = 3, \ldots, n$; and
$X_3, \ldots, X_n$ = vector of geometric design, traffic volume, and other site-specific data.

The following functional forms were considered for the intersection SPFs:

$$\lambda_i = e^{\beta_0} \times \left(AADT_{major}\right)^{\beta_1} \times \left(AADT_{minor}\right)^{\beta_2} \times e^{(\beta_3 X_3 + \cdots + \beta_n X_n)}, \text{ or} \tag{8a}$$

$$\lambda_i = e^{\beta_0} \times \left(AADT_{major} + AADT_{minor}\right)^{\beta_T} \times e^{(\beta_3 X_3 + \cdots + \beta_n X_n)} \tag{8b}$$

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;
β_T	= regression coefficient for total intersection entering volume;
$\beta_3, \dots, \beta_n$	= regression coefficients for explanatory variables, $i = 3, \dots, n$; and
$X_3, \dots, X_n$	= vector of geometric design and other site-specific data.

The elasticity of each independent variable included in the model is also computed to help interpret the results of the roadway segment and intersection 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 or intersection 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:

$$E_{X_{ijk}}^{\lambda_{ij}} = \frac{\partial \lambda_{ij} / \lambda_{ij}}{\partial X_{ijk} / X_{ijk}} = \frac{\partial \lambda_{ij}}{\partial X_{ijk}} \times \frac{X_{ijk}}{\lambda_{ij}} \tag{9}$$

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

$$E_{X_{ijk}}^{\lambda_{ij}} = \beta_k \tag{10}$$

$$E_{X_{ijk}}^{\lambda_{ij}} = \beta_k X_{ijk} \tag{11}$$

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:

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

REGIONALIZATION PROCESS

This section of the report presents the regionalization process that was used to develop SPFs for urban-suburban collector roadway segments and intersections. Because there is considerable overlap between engineering districts and MPOs and RPOs, the regionalization process focused on statewide, engineering district, and county-level SPFs.

Step 1 – Develop statewide SPF: these were estimated for all roadway segments and the following intersection types:

- 3-leg minor-street stop-controlled intersections (3L MS)
- 3-leg all-way stop-controlled intersections (3L AWS)
- 4-leg minor-street stop-controlled intersections (4L MS)
- 4-leg all-way stop-controlled intersections (4L AWS)
- 4-leg signalized intersections (4L SIG)

Because counties are the smallest area among the regionalization options, and likely have the most consistency with regard 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 because a county-specific SPF cannot be estimated. If a sufficient number of counties remain that meet these criteria, 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

- Confirm that there is variability in AADT to estimate an SPF.
- For categorical variables (e.g., roadside hazard rating (RHR), presence of shoulder rumble strips, etc.), there should generally be at least 5% of the sample in all categories. If not, categorical variables should be grouped such that each category included in the SPF has approximately 5% or more of the observations in the data file.
- For counties that do not meet these criteria, a statewide or district-level SPF should be considered, as a county-specific SPF cannot be estimated. If a sufficient number of counties remain that meet these criteria, 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

- Confirm that there is sufficient variability in AADT to estimate an SPF.
- For categorical variables (e.g., RHR, presence of shoulder rumble strips, etc.), there should generally be at least 5% of the sample in all categories. If not, categorical variables should

be grouped such that each category included in the SPF has approximately 5% 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-wide SPFs and determine if county-specific adjustments are needed within each district SPF

- Include county-specific dummy variables within each district-wide SPF.
- The county with the highest number of observations in a district was chosen as the baseline category against which the safety performance of all other counties was compared.
- Districts with similar coefficients were grouped when possible, especially if individual districts had fewer than 5% of the observations for that district.
- The presence of regression coefficients that are not statistically significant suggests that county-specific adjustment is not necessary for that county.
- The presence of a statistically significant regression coefficient suggests county-specific adjustment is necessary for that county.

Because there is considerable overlap among the counties that are included in engineering districts and Pennsylvania MPOs/RPOs, SPFs for MPOs and RPOs were not estimated. The following series of steps consider district-specific adjustments within statewide SPFs.

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

- Include district-specific dummy variables within the statewide SPF.
- The district with the highest number of observations was chosen as the baseline category against which the safety performance of all other districts was compared.
- Counties with similar coefficients were grouped when possible, especially if individual districts had fewer than 5% of the observations in the sample.
- The presence of regression coefficients that are not statistically significant suggests that district-specific adjustment is not necessary for that district.
- The presence of 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.
- Calculate the root-mean-square error (RMSE) between the reported crash frequency and the estimated crash frequency for each of the SPF types developed.
- Calculate the average RMSE for all observations within each county for each of the SPF types developed.

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

- Select the SPF type that provides the RMSE nearest 0.0 for the majority of counties in the dataset.

CHAPTER 4

Findings

ROADWAY SEGMENT RESULTS

This section of the report describes the development of SPFs for urban-suburban collector roadway segments. The remainder of this section summarizes the data available for SPF development, assesses the level of regionalization that can be provided for roadway segment SPFs, and then provides the final SPF recommendations.

Statewide Data Summary

State-owned urban-suburban collector roadway segments were identified using the following codes in the RMS database:

- FUNC_CLS = 5 (major collector) or 6 (minor collector)
- FED_AID_URBAN_AREA = 2 (small urban, pop. 5,000 – 49,999), 3 (urbanized, pop. 50,000 – 199,999) or 4 (urbanized, pop. 200,000 and above)
- URBAN_RURAL = 2 (small urban, pop. 5,000 – 49,999), 3 (urbanized, pop. 50,000 – 199,999) or 4 (urbanized, pop. 200,000 and above)

These codes provided approximately 5,700 miles of urban-suburban collector roadways in the PennDOT RMS database. However, the resulting roadway segments contained many roadways with state route numbers that had an alphabetical prefix or suffix. Discussions with the technical project manager revealed that the state routes with an alphabetical prefix or suffix were locally owned roadways that received federal funding and are not part of the state-owned roadway network. To determine if the roadway segments with alphabetical prefixes or suffixes could be included as a part of this study, the research team matched the crash data to these roadway segments to see if there were sufficient crashes on these non-state-owned roadways to be included in the SPF development. A summary of the total mileage of urban-suburban collectors identified without and with alphabetical prefix/suffixes and the crash frequency estimates associated with these roadway segments is provided in Table 1.

Table 1. Summary of urban-suburban collector roadways with and without alphabetical prefix/suffix indicators

Year	Miles without alphabetical prefix/suffix indicators	Crashes on routes without alphabetical prefix/suffix indicators	Miles with alphabetical prefix/suffix indicators	Crashes on routes with alphabetical prefix/suffix indicators
2013	3951.46	6437	1654.32	0
2014	3954.69	6408	1668.51	0
2015	3956.15	6524	1688.34	0
2016	3762.43	6718	1761.89	0
2017	3824.85	6637	1895.1	40

Of the 5,700 miles of roadways identified as urban-suburban collectors, between 1,600 and nearly 1,900 miles (depending on the year) contained an alphabetical prefix or suffix in the state route name, indicating that this was a locally owned road. Additionally, while the number of crashes on the approximately 3,800 miles of state-owned, urban-suburban collector roadways was relatively consistent across the 5-year analysis period (approximately 6,500 crashes observed annually), zero crashes were recorded for the roadways with alphabetical prefixes or suffixes for the first four years of the analysis period (2013-2016) and only 40 crashes were recorded in 2017 across more than 1,900 miles of roadway. For these reasons, roadway segments with an alphabetical prefix or suffix were excluded from the analysis database and were not considered for SPF development.

Furthermore, during the data collection process, the research team determined that over 400 miles of urban-suburban collector roadways identified in the 2017 RMS datafile without alphabetical prefixes or suffixes were designated as local roads receiving federal aid in the PennDOT VideoLog system. Again, the research team matched the crash data to these roadway segments to determine if there were sufficient crash frequencies for SPF development. Of the 400 miles of local roadways receiving federal aid, only 40-70 crashes were reported annually compared to about 6,500 crashes on the 3,400 miles of state-owned, urban-suburban collector roadways. This suggests that there might be issues with underreporting crashes on these local roadways, so this sample of roadways was also excluded from SPF development.

The final roadway segment analysis database consisted of 7,805 segments representing 3,414.23 miles of urban-suburban collector roadways. These roadway segments were then grouped into the following roadway segment types for potential SPF development:

- Two-lane undivided roadway segments;
- Four-lane undivided roadways;
- One-way, multi-lane roadways; and
- One-way, single-lane roadways.

Table 2 provides the specific codes used to identify these roadway segment types in the RMS data files. Table 3 provides the total mileage for each of these roadway types using the data codes and 5-year crash counts on each roadway type for the entire state-owned roadway network.

Table 2. Codes to identify urban-suburban roadway types

Roadway type	Lane variable	Divisor variable	Facility type variable
Two-lane undivided roadways	2	0 = None 1 = Paint Divided 4 = 4-ft Greater Painted Center	2 = two-way road
Four-lane undivided roadways	4	0 = None 1 = Paint Divided 4 = 4-ft Greater Painted Center	2 = two-way road
One-way, multi-lane roadways	2, 3, or 4	Not used	1 = one-way road
One-way, single-lane roadways	1	Not used	1 = one-way road

Table 3. State segment mileage and 5-year crash counts for urban-suburban collectors

Roadway type	Miles	5-year crash counts	Miles incorrectly coded in RMS database
All roads	3,414.23	32,469	---
Two-lane undivided	3,316.29	30,760	---
Four-lane undivided	0.81	22	---
One-way single-lane	24.22	301	14.51
One-way multi-lane	60.76	1,222	57.53
Other	12.15	164	---

As shown in Table 3, the majority of urban-suburban collector roadways are two-lane undivided roadway segments and, therefore, both statewide and regionalized SPFs were possible to estimate for this roadway type. The sample size (0.81 miles) of four-lane undivided roadways was not sufficient for the development of statewide or regionalized SPFs. Finally, the mileage of one-way single-lane and one-way multi-lane roadway segments appears sufficient for the development of statewide SPFs. However, the research team noted during the data collection process that a significant fraction of the one-way single-lane and one-way multi-lane roadway types identified using the codes in the RMS database are actually two-way roadways that were incorrectly coded. Specifically, just 9.71 miles of the 24.22 miles identified as one-way single-lane roadways were actually one-way roads, while the rest were two-way roadways. Similarly, just 3.23 miles of 60.76 miles identified as one-way multi-lane roadways were actually one-way roads, while the rest were two-way roadways. Thus, the sample size of one-way single-lane and one-way multi-lane roadway was not sufficient for the development of statewide or regionalized SPFs. Reliable adjustment factors that could be applied to other SPFs are also not possible due to the small sample size.

A total of 7,492 unique roadway segments were available in the two-lane undivided urban-suburban collector segment analysis file. Because five years of crash data were available for each segment (2013 to 2017), the analysis database consisted of 37,460 total observations. Table 4 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 4, there are more injury and PDO crashes per segment than fatal crashes per segment. The categorical variables are shown in the lower panel of Table 4. The majority of roadway segments have no curb, sidewalk, or on-street parking. Fewer than 2 percent of roadway segments have exclusive or shared bike lane or two-way left-turn lanes.

Table 4. Summary statistics for two-lane undivided roadway segments

Continuous variable	Mean	Standard deviation	Minimum	Maximum
Total crashes per year	0.821	1.269	0	16
Total fatal + injury crashes per year	0.370	0.753	0	14
Total fatal crashes per year	0.007	0.086	0	2
Total injury crashes per year	0.363	0.744	0	14
Total property-damage only (PDO) crashes per year	0.432	0.803	0	10
Average annual daily traffic (veh/day)	3,710.708	2,700.236	50	23,253
Segment length (miles)	0.443	0.166	0.001	0.820
Total paved width (feet)	23.411	5.404	6	68.000
Left paved shoulder width (feet)	1.733	2.054	0	15
Right paved shoulder width (feet)	1.784	2.138	0	22
Access density (access points and intersections per mile)	33.173	22.326	0	377.143
Horizontal curve density (curves per mile)	1.995	3.563	0	28.541
Degree of curve per mile	20.512	52.587	0	1,379.865
Length of curve per mile (feet/mile)	519.830	950.112	0	5,280
Categorical variable	**Category**		**Proportion (%)**	
Presence of exclusive bike lane	Yes		0.37	
	No		99.63	
Presence of shared bike lane	Yes		0.07	
	No		99.93	
Presence of on-street parking	Yes		9.08	
	No		90.92	
Presence of curb	Yes		19.45	
	No		80.55	
Presence of paved sidewalk	Yes		17.35	
	No		82.65	
Presence of two-way left-turn lane	Yes		1.09	
	No		98.91	
Posted speed limit (mph)	15		0.08	
	20		0.08	
	25		9.95	
	30		3.48	
	35		36.53	
	40		27.47	
	45		17.37	
	50		0.46	
	55		4.58	

Table 5 provides a summary of all crashes identified on two-lane undivided roadway segments by collision type and severity using the KABCO scale (the police-reported injury coding system).

Table 5. Distribution of collision type and severity for crashes on two-lane undivided roadway segments

Collision Type	Crash severity level							
	Fatal (K)	Suspected serious injury (A)	Suspected minor injury (B)	Possible injury (C)	Injury/ unknown severity	Unknown (U)	Not injured (O)	Sum
Non-collision	0.05%	0.19%	0.54%	0.51%	0.35%	0.05%	1.48%	**3.17%**
Rear-end	0.04%	0.15%	1.49%	3.51%	2.72%	0.27%	8.60%	**16.78%**
Head-on	0.10%	0.32%	0.92%	0.87%	0.84%	0.11%	1.65%	**4.81%**
Rear-to-rear (backing)	0.00%	0.00%	0.01%	0.02%	0.04%	0.00%	0.09%	**0.16%**
Angle	0.16%	0.50%	2.96%	4.88%	4.09%	0.40%	13.11%	**26.09%**
Sideswipe (same direction)	0.03%	0.04%	0.18%	0.33%	0.26%	0.12%	1.48%	**2.44%**
Sideswipe (opposite direction)	0.01%	0.06%	0.28%	0.48%	0.35%	0.08%	1.36%	**2.62%**
Hit fixed object	0.38%	0.99%	4.21%	5.78%	4.11%	1.20%	23.21%	**39.88%**
Hit pedestrian	0.11%	0.19%	0.43%	0.52%	0.55%	0.00%	0.00%	**1.80%**
Other or unknown	0.02%	0.05%	0.11%	0.24%	0.13%	0.02%	1.68%	**2.25%**
Total	**0.88%**	**2.48%**	**11.13%**	**17.15%**	**13.44%**	**2.26%**	**52.65%**	**100%**

Regionalization Assessment

The statewide data assessment reveals that SPFs are only possible for two-lane undivided urban-suburban collector roadway segments. Table 6 provides a summary of two-lane undivided roadway segment mileage and 5-year crash counts by county (ordered by segment mileage in each county from largest to smallest). As shown, more than half of the counties (shaded in the table) contain less than 30 miles of two-lane undivided urban-suburban collector roadway segments, which is the minimum deemed sufficient for the consideration of a county-level SPF. Therefore, county-level SPFs were not feasible for two-lane undivided roadway segments and Step 4 of the regionalized procedure was not valid. However, county-specific indicators were still considered in the district-level SPFs, as described in Step 7.

Table 7 provides a similar summary by PennDOT engineering district. As shown, there is sufficient roadway mileage and crash frequency for the consideration of district-level SPFs or the consideration of district-specific indicators in the statewide SPF (Steps 7 and 8 in the regionalization process).

Table 6. Two-lane undivided roadway segment mileage and crash frequencies by county

County no.	Name	Miles	5-year crash freq.	County no. (cont.)	Name	Miles	5-year crash freq.
15	Chester	257.31	2,304	20	Crawford	21.45	123
64	Westmoreland	237.60	1,789	32	Indiana	19.87	149
9	Bucks	219.54	2,590	49	Northumberland	17.79	81
2	Allegheny	225.77	1,685	3	Armstrong	17.29	53
66	York	197.78	2,233	67	Philadelphia	17.27	531
46	Montgomery	180.97	2,153	55	Somerset	16.29	77
36	Lancaster	172.26	1,770	54	Snyder	15.70	89
23	Delaware	126.73	1,735	60	Venango	15.54	87
48	Northampton	103.33	1,175	17	Clearfield	13.69	58
28	Franklin	98.21	838	59	Union	12.75	64
40	Luzerne	93.74	897	44	Mifflin	10.75	77
39	Lehigh	87.51	861	24	Elk	8.43	48
62	Washington	84.75	459	51	Pike	7.07	76
26	Fayette	79.88	500	63	Wayne	6.75	47
4	Beaver	83.94	558	57	Susquehanna	6.23	42
21	Cumberland	76.34	786	47	Montour	5.89	36
6	Berks	79.08	902	42	Mckean	5.72	45
45	Monroe	64.80	1,019	61	Warren	5.49	37
10	Butler	60.75	477	8	Bradford	5.33	24
7	Blair	53.69	499	30	Greene	4.21	30
35	Lackawanna	54.17	511	33	Jefferson	3.69	15
11	Cambria	49.47	297	31	Huntingdon	2.91	15
22	Dauphin	49.13	540	65	Wyoming	2.17	7
38	Lebanon	50.00	465	50	Perry	2.07	12
53	Schuylkill	39.74	222	16	Clarion	2.01	16
25	Erie	33.72	250	5	Bedford	1.68	7
1	Adams	32.68	202	12	Cameron	0.00	0
14	Centre	30.65	206	27	Forest	0.00	0
19	Columbia	28.58	194	29	Fulton	0.00	0
13	Carbon	23.97	170	34	Juniata	0.00	0
18	Clinton	23.55	82	52	Potter	0.00	0
43	Mercer	23.91	240	56	Sullivan	0.00	0
37	Lawrence	22.55	175	58	Tioga	0.00	0
41	Lycoming	22.14	130	**Total**		**3,316.29**	**30,760**

Table 7. Two-lane undivided roadway segment mileage and crash frequencies by engineering district

District no.	Miles	5-year crash frequency
1	100.11	737
2	92.79	516
3	108.17	618
4	170.13	1,580
5	398.43	4,349
6	801.83	9,313
8	678.47	6,846
9	124.04	895
10	103.62	710
11	332.26	2,418
12	406.43	2,778
Total	**3,316.29**	**30,760**

District-level models with county indicators, statewide models with district indicators, and a statewide model were all estimated for this roadway segment type. The statewide models had the highest number of observations and thus contained the most independent variables in the model. Districts with the largest sample size (e.g., Districts 5, 6, and 8) also contained many independent variables, while districts with smaller sample sizes (e.g., Districts 2, 3, 9, and 10) contained relatively few variables; for example, the district-level models for Districts 3 and 10 contained only segment length, traffic volume, and county indicator variables.

The RMSE values for the district-level and statewide SPFs were calculated for each level of regionalization. Table 8 provides a summary of these RMSE values for total and fatal + injury crash frequency. For each county, the bolded value under the total crash frequency and fatal + injury crash frequencies columns represent the smallest RMSE value across the different regionalized SPFs estimated. The results in Table 8 reveal that, for total crash frequency, the statewide model performs best (i.e., produces the lowest RMSE values) in 5 out of 60 counties, the statewide model with district indicators performs best in 12 out of 60 counties, and the district-level models perform best in 43 out of 60 counties. For fatal + injury crash frequency, the statewide model performs best in 4 out of 60 counties, the statewide model with district indicators performs best in 15 out of 60 counties, and the district models perform best in 41 out of 60 counties. The last row of Table 8 also provides the average RMSE value measured across the entire commonwealth. As shown, the district-level SPFs provide the lowest RMSE values for both total and fatal + injury crash frequency of the three SPFs considered. Overall, the results suggest that district-level SPFs are generally preferred over other regionalization levels for two-lane undivided urban-suburban collector roadway segments.

Table 8. County RMSE summary for two-lane undivided urban-suburban collector segment SPFs

#	County	Seg # (5-yr)	Mileage	Total crash SPF prediction RMSE			Fatal + injury SPF prediction RMSE		
				Statewide	Statewide w/ district indicators	District	Statewide	Statewide w/ district indicators	District
1	ADAMS	400	32.7	0.8416	0.8326	**0.7875**	0.5073	0.4945	**0.4678**
2	ALLEGHENY	2,400	225.8	1.1441	**1.1194**	1.1216	0.6760	**0.6676**	0.6687
3	ARMSTRONG	205	17.3	0.5002	0.4819	**0.4782**	0.3272	**0.3255**	0.3257
4	BEAVER	880	83.9	1.0278	1.0088	**1.0077**	0.5678	**0.5597**	0.5598
5	BEDFORD	15	1.7	0.6348	0.6246	**0.6223**	0.4481	**0.4478**	0.4484
6	BERKS	910	79.1	1.3674	1.3356	**1.3282**	0.7501	0.7471	**0.7405**
7	BLAIR	715	53.7	0.9590	0.9600	**0.9561**	0.6318	0.6317	**0.6291**
8	BRADFORD	70	5.3	0.5900	**0.5693**	0.5701	0.4170	**0.4095**	0.4117
9	BUCKS	2,385	219.5	1.3974	1.3900	**1.3836**	0.8411	0.8378	**0.8367**
10	BUTLER	675	60.8	1.1225	**1.1148**	1.1149	0.6177	0.6108	**0.6099**
11	CAMBRIA	570	49.5	0.8029	0.7955	**0.7923**	0.4802	0.4773	**0.4737**
12	CAMERON	---	---	---	---	---	---	---	---
13	CARBON	265	24.0	0.9278	0.9385	**0.9241**	0.6114	0.6144	**0.6052**
14	CENTRE	400	30.7	0.8561	0.7873	**0.7762**	0.5479	0.5259	**0.5188**
15	CHESTER	2,715	257.3	1.1552	1.1623	**1.1519**	0.6712	0.6767	**0.6680**
16	CLARION	20	2.0	**1.0612**	1.0932	1.0895	**0.5786**	0.5920	0.5911
17	CLEARFIELD	165	13.7	0.6908	**0.6730**	0.6764	0.3953	0.3872	**0.3832**
18	CLINTON	295	23.5	0.6842	0.5840	**0.5482**	0.4481	0.4252	**0.4195**
19	COLUMBIA	390	28.6	0.8206	0.7982	**0.7947**	0.5161	0.5118	**0.5101**
20	CRAWFORD	240	21.5	0.8285	0.8020	**0.7974**	0.5223	0.5093	**0.5008**
21	CUMBERLAND	960	76.3	1.1087	1.1100	**1.1002**	0.6670	0.6629	**0.6625**
22	DAUPHIN	625	49.1	1.2839	1.2826	**1.2806**	0.6991	0.6996	**0.6987**
23	DELAWARE	1,365	126.7	1.4605	**1.4475**	1.4492	0.8438	**0.8398**	0.8495
24	ELK	110	8.4	0.7352	0.6545	**0.6428**	0.5376	0.5165	**0.5138**
25	ERIE	400	33.7	1.0483	1.0262	**1.0179**	0.6534	0.6458	**0.6432**
26	FAYETTE	890	79.9	0.8089	**0.8043**	0.8046	**0.5330**	0.5341	0.5354
27	FOREST	---	---	---	---	---	---	---	---
28	FRANKLIN	1,080	98.2	1.0383	1.0366	**1.0343**	0.6794	**0.67871**	0.67874
29	FULTON	---	---	---	---	---	---	---	---
30	GREENE	50	4.2	0.9160	0.9013	**0.8634**	0.6112	0.6104	**0.5999**
31	HUNTINGDON	40	2.9	0.6514	0.6201	**0.6091**	0.4536	**0.4503**	0.4505
32	INDIANA	240	19.9	**0.8154**	0.8265	0.8238	0.5120	0.5039	**0.5037**
33	JEFFERSON	50	3.7	0.6432	**0.6272**	0.6282	0.3504	0.3311	**0.3204**
34	JUNIATA	---	---	---	---	---	---	---	---
35	LACKAWANNA	620	54.2	1.0775	1.0762	**1.0665**	0.6967	0.6960	**0.6948**
36	LANCASTER	2,160	172.3	1.1306	1.1298	**1.1295**	0.6995	0.6986	**0.6976**
37	LAWRENCE	295	22.5	0.9844	0.9761	**0.9672**	0.6075	0.6073	**0.6016**
38	LEBANON	645	50.0	1.1205	1.1172	**1.1055**	0.6661	0.6610	**0.6541**
39	LEHIGH	945	87.5	1.3196	1.3130	**1.3068**	0.7506	0.7483	**0.7474**
40	LUZERNE	1,055	93.7	1.1142	1.1090	**1.1020**	0.6766	0.6753	**0.6737**
41	LYCOMING	315	22.1	0.7951	0.7947	**0.7905**	0.4377	0.4344	**0.4332**
42	MCKEAN	75	5.7	0.8216	**0.7835**	0.7849	0.5691	0.5639	**0.5662**
43	MERCER	290	23.9	1.2035	1.2223	**1.1450**	0.7401	0.7508	**0.7214**
44	MIFFLIN	175	10.8	**0.6617**	0.6884	0.6662	0.3942	**0.3974**	0.3918
45	MONROE	705	64.8	1.8213	1.7461	**1.6796**	1.0987	1.0637	**1.0270**
46	MONTGOMERY	1,920	181.0	1.3712	**1.3677**	1.3689	0.8546	0.8525	**0.8571**
47	MONTOUR	75	5.9	0.8679	0.8350	**0.8180**	0.6119	0.6031	**0.6011**
48	NORTHAMPTON	1,105	103.3	1.4228	1.4023	**1.4023**	0.8338	**0.8252**	0.8260
49	NORTHUMBERLAND	255	17.8	0.6480	0.5730	**0.5546**	0.3957	0.3713	**0.3620**
50	PERRY	25	2.1	0.6858	0.6851	**0.6671**	0.4993	**0.4989**	0.4995

#	County	Seg # (5-yr)	Mileage	Total crash SPF prediction RMSE			Fatal + injury SPF prediction RMSE		
				Statewide	Statewide w/ district indicators	District	Statewide	Statewide w/ district indicators	District
51	PIKE	80	7.1	1.0928	1.0721	**1.0339**	0.6788	0.6749	**0.6645**
52	POTTER	---	---	---	---	---	---	---	---
56	SULLIVAN	---	---	---	---	---	---	---	---
57	SUSQUEHANNA	75	6.2	0.7158	0.7478	**0.6847**	0.5317	0.5380	**0.5232**
58	TIOGA	---	---	---	---	---	---	---	---
59	UNION	160	12.7	0.7981	**0.7599**	0.7647	0.4769	**0.4680**	0.4682
60	VENANGO	170	15.5	0.7484	**0.7377**	0.7514	0.4870	**0.4787**	0.4873
61	WARREN	65	5.5	**0.8580**	0.8686	0.8590	0.5531	0.5483	**0.5481**
62	WASHINGTON	925	84.7	0.8385	0.8217	**0.8078**	0.5327	0.5311	**0.5278**
63	WAYNE	75	6.7	0.9025	0.9129	**0.8946**	0.5209	0.5300	**0.5083**
64	WESTMORELAND	2,425	237.6	**0.9982**	1.0007	1.0016	**0.6231**	0.6236	0.6237
65	WYOMING	30	2.2	0.4679	0.4807	**0.4548**	0.3071	0.3112	**0.3023**
66	YORK	2,235	197.8	1.3910	1.3934	**1.3861**	**0.7295**	0.7308	0.7317
67	PHILADELPHIA	205	17.3	2.6625	2.6411	**2.4873**	2.5215	2.4985	**2.2697**
Totals		37,460	33,16.3	1.1730	1.1638	**1.1546**	0.7138	0.7102	**0.7034**

Recommended SPFs

Based on the regionalization process, the research team recommends using **district-level SPFs with county-specific adjustments** for two-lane undivided roadway segments. The final recommended regional SPFs for two-lane undivided roadway segments for total and fatal + injury crash frequency are shown in Table 9, along with the overdispersion parameter for each negative binomial regression model. These equations provide the baseline SPF for each district, and each SPF should be further modified by the county-specific adjustments provided in Table 10 to account for difference in safety performance across individual counties.

Table 9. Summary of district-level SPFs for two-lane undivided roadway segments

District 1:

$$N_{T,pr} = Length^{0.994} \times AADT^{0.447} \times e^{-3.204} \times e^{-0.212PSL45P} \quad (12)$$

over-dispersion parameter: 0.598

$$N_{FI,pr} = Length^{0.852} \times AADT^{0.543} \times e^{-4.969} \quad (13)$$

over-dispersion parameter: 0.924

District 2:

$$N_{T,pr} = Length^{0.514} \times AADT^{0.456} \times e^{-3.896} \times e^{0.0015DCPM} \times e^{0.301parking} \times e^{-0.180PSL45P} \quad (14)$$

over-dispersion parameter: 0.218

$$N_{FI,pr} = Length^{0.673} \times AADT^{0.513} \times e^{-5.083} \times e^{0.0031DCPM} \times e^{0.333parking} \times e^{-0.359PSL45P} \quad (15)$$

over-dispersion parameter: 0.518

District 3:

$$N_{T,pr} = Length^{0.498} \times AADT^{0.479} \times e^{-3.996} \quad (16)$$

over-dispersion parameter: 0.582

$$N_{FI,pr} = Length^{0.564} \times AADT^{0.506} \times e^{-4.900} \quad (17)$$

over-dispersion parameter: 0.657

District 4:

$$N_{T,pr} = Length^{0.720} \times AADT^{0.597} \times e^{-4.352} \times e^{0.309curb} \times e^{-0.539PSL45P} \quad (18)$$

over-dispersion parameter: 0.363

$$N_{FI,pr} = Length^{0.554} \times AADT^{0.622} \times e^{-5.520} \times e^{0.371curb} \times e^{-0.346PSL45P} \quad (19)$$

over-dispersion parameter: 0.436

District 5:

$$N_{T,pr} = Length^{0.509} \times AADT^{0.669} \times e^{-4.917} \times e^{0.0028DCPM} \times e^{-0.260PSL45P} \quad (20)$$

over-dispersion parameter: 0.577

$$N_{FI,pr} = Length^{0.562} \times AADT^{0.679} \times e^{-5.740} \times e^{0.0024DCPM} \times e^{-0.240PSL45P} \quad (21)$$

over-dispersion parameter: 0.611

District 6:

$$N_{T,pr} = Length^{0.615} \times AADT^{0.610} \times e^{-4.789} \times e^{0.0020DCPM} \times e^{0.118parking} \times e^{0.134curb} \quad (22)$$

over-dispersion parameter: 0.517

$$N_{FI,pr} = Length^{0.626} \times AADT^{0.685} \times e^{-6.323} \times e^{0.0021DCPM} \times e^{0.304parking} \times e^{0.161curb} \quad (23)$$

over-dispersion parameter: 0.578

District 8:

$$N_{T,pr} = Length^{0.636} \times AADT^{0.557} \times e^{-4.060} \times e^{0.103curb} \times e^{-0.192PSL45P} \times e^{0.279short\_seg} \quad (24)$$

over-dispersion parameter: 0.586

$$N_{FI,pr} = Length^{0.665} \times AADT^{0.581} \times e^{-5.122} \times e^{-0.209PSL45P} \times e^{0.329short\_seg} \quad (25)$$

over-dispersion parameter: 0.700

District 9:

$$N_{T,pr} = Length^{0.716} \times AADT^{0.669} \times e^{-5.007} \times e^{0.0008DCPM} \times e^{-0.121PSL45P} \quad (26)$$

over-dispersion parameter: 0.343

$$N_{FI,pr} = Length^{0.729} \times AADT^{0.635} \times e^{-5.495} \quad (27)$$

over-dispersion parameter: 0.412

District 10:

$$N_{T,pr} = Length^{0.694} \times AADT^{0.666} \times e^{-5.168} \quad (28)$$

over-dispersion parameter: 0.643

$$N_{FI,pr} = Length^{0.789} \times AADT^{0.634} \times e^{-5.741} \quad (29)$$

over-dispersion parameter: 0.523

District 11:

$$N_{T,pr} = Length^{0.390} \times AADT^{0.631} \times e^{-5.301} \times e^{0.0010DCPM} \times e^{0.205curb} \quad (30)$$

over-dispersion parameter: 0.752

$$N_{FI,pr} = Length^{0.461} \times AADT^{0.614} \times e^{-5.868} \times e^{0.212curb} \quad (31)$$

over-dispersion parameter: 0.813

District 12:

$$N_{T,pr} = Length^{0.585} \times AADT^{0.578} \times e^{-4.506} \times e^{0.304curb} \quad (32)$$

over-dispersion parameter: 0.387

$$N_{FI,pr} = Length^{0.627} \times AADT^{0.621} \times e^{-5.570} \times e^{0.252curb} \quad (33)$$

over-dispersion parameter: 0.245

$N_{T,pr}$	= predicted total crash frequency on the segment (crashes/year);
$N_{FI,pr}$	= predicted fatal + injury crash frequency on the segment (crashes/year);
$Length$	= segment length (mi);
$AADT$	= average annual daily traffic volume on the segment (veh/day);
$DCPM$	= 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)
$parking$	= presence of on-street parking (1 if present, 0 otherwise);
$curb$	= presence of a raised curb (1 if present, 0 otherwise);
$PSL45P$	= posted speed limit set to 45 mph or greater (1 if true, 0 otherwise); and,
$short\_seg$	= segment is less than 0.1 mile long (1 if true, 0 otherwise).

Table 10. County-specific adjustments for district-level SPFs for two-lane undivided roadway segments

District	SPF	County	County-specific adjustment for total crash SPF	County-specific adjustment for fatal + injury SPF
1	Equations (12, 13)	Crawford (20), Erie (25), Forest (27), Venango (60), Warren (61)	No modification necessary	No modification necessary
		Mercer (43)	Multiply estimate by 1.553	Multiply estimate by 1.756
2	Equations (14, 15)	Cameron (12), Centre (14), Clearfield (17), Elk (24), Juniata (34), Potter (52)	No modification necessary	No modification necessary
		Clinton (18)	Multiply estimate by 0.653	No modification necessary
		McKean (42), Mifflin (44)	Multiply estimate by 1.316	Multiply estimate by 1.276
3	Equations (16, 17)	Bradford (8), Columbia (19), Lycoming (41), Montour (47), Snyder (54), Tioga (58), Sullivan (56), Union (59)	No modification necessary	No modification necessary
		Northumberland (49)	Multiply estimate by 0.705	Multiply estimate by 0.702
4	Equations (18, 19)	Lackawanna (35), Luzerne (40), Pike (51)	No modification necessary	No modification necessary
		Susquehanna (57), Wayne (63), Wyoming (65)	Multiply estimate by 0.720	Multiply estimate by 0.690
5	Equations (20, 21)	Northampton (48)	No modification necessary	No modification necessary
		Berks (6), Lehigh (39)	Multiply estimate by 0.899	Multiply estimate by 0.872
		Carbon (13), Schuylkill(53)	Multiply estimate by 0.683	Multiply estimate by 0.661
		Monroe (45)	Multiply estimate by 1.403	Multiply estimate by 1.449
6	Equations (22, 23)	Chester (15)	No modification necessary	No modification necessary

District	SPF	County	County-specific adjustment for total crash SPF	County-specific adjustment for fatal + injury SPF
		Bucks (9), Montgomery (46)	Multiply estimate by 1.205	Multiply estimate by 1.328
		Delaware (23), Philadelphia (67)	Multiply estimate by 1.439	Multiply estimate by 1.681
8	Equations (24, 25)	Dauphin (22), York(66)	No modification necessary	No modification necessary
		Cumberland (21)	Multiply estimate by 0.813	Multiply estimate by 0.842
		Franklin (28)	Multiply estimate by 0.893	No modification necessary
		Lancaster (36)	Multiply estimate by 0.902	No modification necessary
		Adams (1), Lebanon (38), Perry (50)	Multiply estimate by 0.744	Multiply estimate by 0.784
9	Equations (26, 27)	Blair (7), Fulton (29)	No modification necessary	No modification necessary
		Bedford (5), Cambria (11), Huntingdon (31)	Multiply estimate by 0.792	Multiply estimate by 0.752
		Somerset (55)	Multiply estimate by 0.815	Multiply estimate by 0.729
10	Equations (28, 29)	Butler (10), Clarion (16), Indiana (32)	No modification necessary	No modification necessary
		Armstrong (3) , Jefferson (33)	Multiply estimate by 0.759	No modification necessary
11	Equations (30, 31)	Allegheny (2), Beaver (4), Lawrence (37)	No modification necessary	No modification necessary
12	Equations (32, 33)	Westmoreland (64)	No modification necessary	No modification necessary
		Fayette (26), Greene (30)	Multiply estimate by 0.872	No modification necessary
		Washington (62)	Multiply estimate by 0.768	Multiply estimate by 0.786

A sample interpretation of these SPFs is now provided for the District 2 SPF to illustrate the relationship between safety performance and independent variables. Equations (14) and (15) reveal that the relationship between total and fatal + injury crash frequency and the independent variables in District 2 are consistent with engineering expectations. Both expected total and fatal + injury crash frequencies are positively correlated with segment length, traffic volumes, the total degree of horizontal curvature per mile within the segment, and the presence of on-street parking. Both expected total and fatal + injury crash frequencies are negatively correlated with the presence of posted speed limits set 45 mph and above. Note that the expected total crash frequency is not directly proportional to the segment length. This is reasonable for urban environments in which segments are defined based on the presence of traffic control devices and other features; in this case, the length appears to be capturing the impact of some unobserved features. Furthermore, the county-specific adjustments in

Table 10 associated with Equations (14) and (15) reveal that, compared to other counties in District 2, total crash frequencies are generally lower for roadway segments in Clinton County, while both total and fatal + injury crash frequencies are generally higher in McKean and Mifflin counties.

Table 11 provides the elasticities and pseudo-elasticities for each independent variable included in the District 2 SPF, as well as the county-specific adjustments. The elasticities provide the percent change in expected crash frequency when the independent variable is increased by one percent (for continuous variables such as segment length, AADT, and degree of curve per mile) or changed from zero to one (for indicator variables such as presence of on-street parking, posted speed limit set to 45 mph, or county indicators). As expected, there is a positive relationship between traffic volume and crash frequency in District 2: a one percent change in AADT is expected to increase the expected total crash frequency by 0.456 percent and the fatal + injury crash frequency by 0.513 percent, holding all other variables constant. As previously mentioned, the relationship between segment length and crash frequency is non-linear: a one-percent change in segment length is expected to increase total crash frequency by 0.516 percent and fatal + injury crash frequency by 0.673 percent. At the mean values in the dataset, an increase in horizontal curvature per mile by one percent is expected to increase total crash frequency by 0.031 percent and fatal + injury crash frequency by 0.064 percent.

Segments with on-street parking are associated with a 35.1 percent increase in total crash frequency and a 39.5 percent increase in fatal + injury crash frequency in District 2. Segments with higher posted speed limits (45 mph or greater) are associated with a 16.5 percent decrease in total crash frequency and a 30.2 percent decrease in fatal + injury crash frequency compared with segments that have lower posted speed limits. Total crash frequency is generally 34.7 percent lower in Clinton County, while total crash frequency is 31.6 percent higher and fatal + injury crash frequency is 27.6 percent higher in McKean and Mifflin counties compared to the remaining counties in District 2.

Table 11. Elasticities and pseudo-elasticities for independent variables in District 2 roadway segment models

Variable	Total crashes	Fatal + injury crashes
Natural logarithm of segment length	0.514	0.673
Natural logarithm of AADT	0.456	0.513
Degree of curvature per mile	0.031	0.064
Presence of on-street parking (1 if present; 0 otherwise)	0.351	0.395
Posted speed limit 45 mph or above (1 if present; 0 otherwise)	-0.165	-0.302
Segment is in Clinton County (1 if true; 0 otherwise)	-0.347	---
Segment is in McKean or Mifflin County (1 if true; 0 otherwise)	0.316	0.276

SPFs for other districts can be interpreted in a similar fashion.

INTERSECTION RESULTS

This section of the report describes the development of SPFs for at-grade intersections on urban-suburban collector roads. The remainder of this section summarizes the data available for SPF development, assesses the level of regionalization that can be provided for roadway segment SPFs, and then provides the final SPF recommendations.

Statewide Data Summary

Roadway inventory files for urban-suburban collector intersections were created by combining PennDOT's RMS datafiles with data collected by the research team using PennDOT's VideoLog software and Google Earth images. These data elements were described previously in the Data and Data Structures section of this report. A total of 783 unique intersections were identified in the data analysis file. The distribution of these intersections based on the number of intersection legs and traffic control, as well as a summary of 5-year crash histories for each intersection type, is provided in Table 12.

Table 12. Urban-suburban collector intersections in Pennsylvania

Intersection type	Count	5-year crashes
3L MS	522	1,378
3L AWS	46	88
3L SIG	33	206
4L MS	45	355
4L AWS	55	230
4L SIG	77	719
Other	5	18
Total	783	2,994

Based on this information, the research team developed statewide SPFs for the following intersection types:

- 3-leg minor-street stop-controlled intersections (3L MS)
- 3-leg all-way stop-controlled intersections (3L AWS)
- 4-leg minor-street stop-controlled intersections (4L MS)
- 4-leg all-way stop-controlled intersections (4L AWS)
- 4-leg signalized intersections (4L SIG)

Appendix C provides additional details on how some of the data elements were obtained for these intersection types, including how the major and minor roads were identified.

A reliable statewide SPF is not possible for 3-leg signalized intersections due to the small sample size. However, an adjustment factor is provided in Appendix D that can be used to estimate crash frequencies for this intersection type after applying another SPF type (3-leg minor-street stop-controlled intersection) to 3-leg signalized intersections.

Table 13 provides summary statistics for total crashes and fatal + injury crashes for each intersection type in the analysis database. Note that the number of observations in each category is five times the number of intersections, since five years of crash data (2013-2017) were available for each intersection. As expected, the total crash frequency is higher than the fatal + injury crash frequency. The signalized intersection forms have the highest total and fatal + injury crash frequencies for both 3-leg and 4-leg intersections. All-way stop-controlled intersections have the lowest total and fatal + injury crash frequencies for both 3-leg and 4-leg intersections.

Table 13. Summary statistics for total and fatal + injury crash frequencies by intersection type for urban-suburban collector intersections

Intersection Type	Number of observations	Mean	Standard deviation	Minimum	Maximum
Total crash frequency					
3-leg, two-way stop	2,610	0.528	0.884	0	6
3-leg, all-way stop	230	0.383	0.719	0	4
4-leg, two-way stop	225	1.578	1.905	0	16
4-leg, all-way stop	275	0.836	1.146	0	6
4-leg, signalized	385	1.868	1.744	0	8
ALL	3,890	0.765	1.230	0	16
Fatal + injury crash frequency					
3-leg, two-way stop	2,610	0.227	0.526	0	5
3-leg, all-way stop	230	0.178	0.447	0	3
4-leg, two-way stop	225	0.698	1.097	0	9
4-leg, all-way stop	275	0.356	0.625	0	4
4-leg, signalized	385	0.899	1.131	0	7
ALL	3,890	0.342	0.717	0	9

Table 14 through Table 18 provide summary statistics for the independent variables considered in the SPF development for each of the five intersection types under consideration for SPF development, as well as for annual crash frequencies by severity. As expected, traffic volumes are generally higher at the signalized intersections compared to stop-controlled intersections. The signalized intersections also tend to have more exclusive turn lanes. Posted speed limits vary considerably across all intersection types. Note that variables omitted from a table suggest a lack of variability in that data element.

Table 14. Summary statistics for 3-leg minor-street stop-controlled intersections

Continuous variable	Mean	Standard deviation	Minimum	Maximum
Total crashes per year	0.528	0.884	0	6
Total fatal + injury crashes per year	0.227	0.526	0	5
Total fatal crashes per year	0.003	0.055	0	1
Total injury crashes per year	0.224	0.523	0	5
Total PDO crashes per year	0.289	0.620	0	5
Major road AADT (veh/day)	3,910.893	2,495.614	139	15,710
Minor road AADT (veh/day)	2,176.349	1,791.351	50	11,381
Paved width on major road (feet)	22.746	4.067	16	58
Paved width on minor road (feet)	21.874	4.409	12	68
Left shoulder total width on major road (feet)	1.915	1.921	0	12
Left shoulder total width on minor road (feet)	1.197	1.809	0	12
Right shoulder total width on major road (feet)	1.952	1.960	0	10
Right shoulder total width on minor road (feet)	1.240	1.854	0	10
Categorical variable	**Category**		**Proportion (%)**	
Presence of exclusive left-turn lanes on major road approach	Yes		2.30	
	No		97.70	
Presence of exclusive left-turn lane on minor road approach	Yes		1.15	
	No		98.85	
Presence of exclusive right-turn lanes on major road approach	Yes		0.19	
	No		99.81	
Presence of exclusive right-turn lane on minor road approach	Yes		1.15	
	No		98.85	
Presence of pedestrian crosswalk on major road approach	Yes		3.07	
	No		96.93	
Presence of pedestrian crosswalk on minor road approach	Yes		1.72	
	No		98.28	
Channelized right-turn lane on major or minor road approach	Yes		2.87	
	No		97.13	
Presence of bus stop on major road approach	Yes		0.19	
	No		99.81	
Presence of bus stop on minor road approach	Yes		0.19	
	No		99.81	
Posted speed limit on major road (mph)	20		0.19	
	25		6.32	
	30		3.26	
	35		37.36	
	40		27.01	
	45		22.03	
	50		0.38	
	55		3.45	
Posted speed limit on minor road (mph)	15		0.19	
	20		0.38	
	25		8.05	
	30		6.9	
	35		36.4	
	40		29.5	
	45		10.73	
	50		0.38	
	55		7.47	

Table 15. Summary statistics for 3-leg all-way stop-controlled intersections

Continuous Variable	Mean	Standard deviation	Minimum	Maximum
Total crashes per year	0.383	0.719	0	4
Total fatal + injury crashes per year	0.178	0.447	0	3
Total fatal crashes per year	0.000	0.000	0	0
Total injury crashes per year	0.178	0.447	0	3
Total PDO crashes per year	0.191	0.493	0	3
Major road AADT (veh/day)	3,373.074	1,871.505	628	10,305
Minor road AADT (veh/day)	2,723.326	1,640.447	312	7,079
Paved width on major road (feet)	22.739	3.457	18	36
Paved width on minor road (feet)	23.087	5.022	16	44
Left shoulder total width on major road (feet)	0.826	1.206	0	4
Left shoulder total width on minor road (feet)	0.761	1.186	0	4
Right shoulder total width on major road (feet)	0.902	1.199	0	4
Right shoulder total width on minor road (feet)	0.641	1.089	0	4
Categorical variable	**Category**		**Proportion (%)**	
Presence of pedestrian crosswalk on major road approach	Yes		6.52	
	No		93.48	
Presence of pedestrian crosswalk on minor road approach	Yes		2.17	
	No		97.83	
Posted speed limit on major road (mph)	25		21.74	
	30		2.17	
	35		36.96	
	40		28.26	
	45		8.7	
	55		2.17	
Posted speed limit on minor road (mph)	25		17.39	
	30		6.52	
	35		43.48	
	40		21.74	
	45		10.87	

Table 16. Summary statistics for 4-leg minor-street stop-controlled intersections

Continuous variable	Mean	Standard deviation	Minimum	Maximum
Total crashes per year	1.578	1.905	0	16
Total fatal + injury crashes per year	0.698	1.097	0	9
Total fatal crashes per year	0.004	0.067	0	1
Total injury crashes per year	0.693	1.093	0	9
Total PDO crashes per year	0.840	1.181	0	6
Major road AADT (veh/day)	4,307.349	3,024.978	708	19,002
Minor road AADT (veh/day)	1,574.729	935.044	273	4,533
Paved width on major road (feet)	24.022	5.172	19	40.5
Paved width on minor road (feet)	21.689	3.620	16	32
Left shoulder total width on major road (feet)	1.844	1.751	0	6
Left shoulder total width on minor road (feet)	0.844	1.034	0	4
Right shoulder total width on major road (feet)	2.244	2.185	0	8
Right shoulder total width on minor road (feet)	0.811	0.923	0	3
Categorical variable	**Category**		**Proportion (%)**	
Presence of exclusive left-turn lanes on major road approach	Yes		6.67	
	No		93.33	
Presence of exclusive left-turn lane on minor road approach	Yes		2.22	
	No		97.78	
Presence of exclusive right-turn lanes on major road approach	Yes		2.22	
	No		97.78	
Presence of exclusive right-turn lane on minor road approach	Yes		4.44	
	No		95.56	
Presence of pedestrian crosswalk on major road approach	Yes		8.89	
	No		91.11	
Presence of pedestrian crosswalk on minor road approach	Yes		4.44	
	No		95.56	
Channelized right-turn lane on major or minor road approach	Yes		4.44	
	No		95.56	
Posted speed limit on major road (mph)	25		6.67	
	30		2.22	
	35		24.44	
	40		31.11	
	45		28.89	
	55		6.67	
Posted speed limit on minor road (mph)	15		2.22	
	25		8.89	
	30		2.22	
	35		28.89	
	40		37.78	
	45		15.56	
	55		4.44	

Table 17. Summary statistics for 4-leg all-way stop-controlled intersections

Continuous variable	Mean	Standard deviation	Minimum	Maximum
Total crashes per year	0.836	1.146	0	6
Total fatal + injury crashes per year	0.356	0.625	0	4
Total fatal crashes per year	0.007	0.085	0	1
Total injury crashes per year	0.349	0.618	0	4
Total PDO crashes per year	0.455	0.859	0	5
Major road AADT (veh/day)	4,187.251	2,025.034	755	8,836
Minor road AADT (veh/day)	2,306.195	1,465.963	537	5,984
Paved width on major road (feet)	22.535	2.597	19	32
Paved width on minor road (feet)	22.765	5.290	18	50
Left shoulder total width on major road (feet)	1.967	2.032	0	10
Left shoulder total width on minor road (feet)	1.287	1.463	0	5
Right shoulder total width on major road (feet)	1.995	2.064	0	10
Right shoulder total width on minor road (feet)	1.387	1.662	0	8
Categorical variable	**Category**		**Proportion (%)**	
Presence of pedestrian crosswalk on major road approach	Yes		3.64	
	No		96.36	
Presence of pedestrian crosswalk on minor road approach	Yes		7.27	
	No		92.73	
Channelized right-turn lane on major or minor road approach	Yes		1.82	
	No		98.18	
Posted speed limit on major road (mph)	25		2.18	
	30		3.64	
	35		32.36	
	40		30.55	
	45		20.36	
	55		10.91	
Posted speed limit on minor road (mph)	25		3.27	
	30		1.82	
	35		34.91	
	40		40.36	
	45		12.36	
	55		7.27	

Table 18. Summary statistics for 4-leg signalized intersections

Continuous variable	Mean	Standard deviation	Minimum	Maximum
Total crashes per year	1.868	1.744	0	8
Total fatal + injury crashes per year	0.899	1.131	0	7
Total fatal crashes per year	0.010	0.102	0	1
Total injury crashes per year	0.888	1.121	0	7
Total PDO crashes per year	0.927	1.023	0	6
Major road AADT (veh/day)	8,772.488	4,197.669	3,011	28,200
Minor road AADT (veh/day)	4,905.785	2,283.501	349	12,841
Paved width on major road (feet)	29.156	7.534	20	52
Paved width on minor road (feet)	28.113	6.602	20	50
Left shoulder total width on major road (feet)	1.755	2.323	0	10
Left shoulder total width on minor road (feet)	1.388	1.930	0	8
Right shoulder total width on major road (feet)	1.818	2.496	0	12
Right shoulder total width on minor road (feet)	1.578	2.002	0	8
Categorical variable	**Category**		**Proportion (%)**	
Presence of exclusive left-turn lanes on major road approach	Yes		41.56	
	No		58.44	
Presence of exclusive left-turn lane on minor road approach	Yes		35.06	
	No		64.94	
Presence of exclusive right-turn lanes on major road approach	Yes		12.99	
	No		87.01	
Presence of exclusive right-turn lane on minor road approach	Yes		11.69	
	No		88.31	
Presence of pedestrian crosswalk on major road approach	Yes		66.23	
	No		33.77	
Presence of pedestrian crosswalk on minor road approach	Yes		67.53	
	No		32.47	
Channelized right-turn lane on major or minor road approach	Yes		12.99	
	No		87.01	
Posted speed limit on major road (mph)	25		17.66	
	30		1.3	
	35		35.06	
	40		21.56	
	45		16.62	
	55		7.79	
Posted speed limit on minor road (mph)	25		20	
	35		38.96	
	40		21.3	
	45		13.25	
	55		6.49	

Table 19 through Table 23 provide a summary of crash types and severities for all crashes identified at each of these intersection types.

Table 19. Distribution of collision type and severity for crashes at 3-leg minor-street stop-controlled intersections

Collision type	Crash severity level							
	Fatal (K)	Suspected serious injury (A)	Suspected minor injury (B)	Possible injury (C)	Injury/ unknown severity	Unknown (U)	Not injured (O)	Sum
Non-collision	0.00%	0.15%	0.51%	0.51%	0.29%	0.00%	1.31%	**2.76%**
Rear-end	0.07%	0.00%	1.02%	2.18%	2.18%	0.07%	10.23%	**15.75%**
Head-on	0.15%	0.29%	0.94%	1.60%	0.87%	0.00%	1.52%	**5.37%**
Rear-to-rear (backing)	0.00%	0.00%	0.00%	0.22%	0.07%	0.00%	0.00%	**0.29%**
Angle	0.00%	0.87%	4.28%	6.60%	4.86%	0.73%	18.43%	**35.78%**
Sideswipe (same direction)	0.00%	0.15%	0.15%	0.15%	0.22%	0.07%	0.94%	**1.67%**
Sideswipe (opposite direction)	0.07%	0.00%	0.15%	0.44%	0.51%	0.00%	1.09%	**2.25%**
Hit fixed object	0.15%	0.51%	2.83%	5.15%	3.19%	1.45%	19.30%	**32.58%**
Hit pedestrian	0.15%	0.15%	0.15%	0.29%	0.36%	0.00%	0.00%	**1.09%**
Other or unknown	0.00%	0.07%	0.15%	0.15%	0.22%	0.00%	1.89%	**2.47%**
Total	**0.58%**	**2.18%**	**10.16%**	**17.27%**	**12.77%**	**2.32%**	**54.72%**	**100%**

Table 20. Distribution of collision type and severity for crashes at 3-leg all-way stop-controlled intersections

Collision type	Crash severity level							
	Fatal (K)	Suspected serious injury (A)	Suspected minor injury (B)	Possible injury (C)	Injury/ unknown severity	Unknown (U)	Not injured (O)	Sum
Non-collision	0.00%	1.14%	0.00%	0.00%	1.14%	0.00%	2.27%	**4.55%**
Rear-end	0.00%	0.00%	1.14%	2.27%	6.82%	0.00%	3.41%	**13.64%**
Head-on	0.00%	0.00%	0.00%	1.14%	1.14%	0.00%	2.27%	**4.55%**
Rear-to-rear (backing)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
Angle	0.00%	0.00%	1.14%	3.41%	0.00%	1.14%	14.77%	**20.45%**
Sideswipe (same direction)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	2.27%	**2.27%**
Sideswipe (opposite direction)	0.00%	0.00%	0.00%	4.55%	0.00%	0.00%	2.27%	**6.82%**
Hit fixed object	0.00%	1.14%	7.95%	2.27%	11.36%	2.27%	22.73%	**47.73%**
Hit pedestrian	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
Other or unknown	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
Total	**0.00%**	**2.27%**	**10.23%**	**13.64%**	**20.45%**	**3.41%**	**50.00%**	**100%**

Table 21. Distribution of collision type and severity for crashes at 4-leg minor-street stop-controlled intersections

Collision type	Crash severity level							
	Fatal (K)	Suspected serious injury (A)	Suspected minor injury (B)	Possible injury (C)	Injury/ unknown severity	Unknown (U)	Not injured (O)	Sum
Non-collision	0.00%	0.00%	0.28%	0.56%	0.28%	0.28%	0.28%	**1.69%**
Rear-end	0.00%	0.00%	1.41%	1.69%	0.85%	0.28%	5.35%	**9.58%**
Head-on	0.28%	0.00%	1.13%	0.56%	0.28%	0.00%	0.56%	**2.82%**
Rear-to-rear (backing)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.28%	**0.28%**
Angle	0.00%	1.41%	11.27%	12.68%	8.73%	1.97%	38.87%	**74.93%**
Sideswipe (same direction)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1.41%	**1.41%**
Sideswipe (opposite direction)	0.00%	0.00%	0.00%	0.28%	0.28%	0.00%	1.13%	**1.69%**
Hit fixed object	0.00%	0.00%	0.28%	1.41%	0.28%	0.00%	5.07%	**7.04%**
Hit pedestrian	0.00%	0.00%	0.00%	0.00%	0.28%	0.00%	0.00%	**0.28%**
Other or unknown	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.28%	**0.28%**
Total	**0.28%**	**1.41%**	**14.37%**	**17.18%**	**10.99%**	**2.54%**	**53.24%**	**100%**

Table 22. Distribution of collision type and severity for crashes at 4-leg all-way stop-controlled intersections

Collision type	Crash severity level							
	Fatal (K)	Suspected serious injury (A)	Suspected minor injury (B)	Possible injury (C)	Injury/ unknown severity	Unknown (U)	Not injured (O)	Sum
Non-collision	0.00%	0.00%	0.00%	0.00%	0.43%	0.00%	1.30%	**1.74%**
Rear-end	0.00%	0.00%	1.74%	0.43%	1.30%	0.00%	7.39%	**10.87%**
Head-on	0.00%	0.43%	1.30%	1.74%	0.43%	0.43%	1.74%	**6.09%**
Rear-to-rear (backing)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
Angle	0.87%	0.00%	6.52%	13.91%	9.13%	1.74%	36.96%	**69.13%**
Sideswipe (same direction)	0.00%	0.00%	0.43%	0.00%	0.00%	0.00%	0.43%	**0.87%**
Sideswipe (opposite direction)	0.00%	0.00%	0.00%	1.30%	0.00%	0.00%	1.74%	**3.04%**
Hit fixed object	0.00%	0.00%	0.43%	0.43%	0.87%	0.87%	4.78%	**7.39%**
Hit pedestrian	0.00%	0.00%	0.43%	0.43%	0.00%	0.00%	0.00%	**0.87%**
Other or unknown	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
Total	**0.87%**	**0.43%**	**10.87%**	**18.26%**	**12.17%**	**3.04%**	**54.35%**	**100%**

Table 23. Distribution of collision type and severity for crashes at 4-leg signalized intersections

Collision type	Crash severity level							
	Fatal (K)	Suspected serious injury (A)	Suspected minor injury (B)	Possible injury (C)	Injury/ unknown severity	Unknown (U)	Not injured (O)	Sum
Non-collision	0.00%	0.14%	0.00%	0.14%	0.14%	0.00%	0.97%	**1.39%**
Rear-end	0.00%	0.14%	2.09%	4.87%	4.45%	0.28%	10.71%	**22.53%**
Head-on	0.00%	0.14%	0.70%	1.81%	1.25%	0.14%	3.76%	**7.79%**
Rear-to-rear (backing)	0.00%	0.00%	0.00%	0.14%	0.00%	0.00%	0.00%	**0.14%**
Angle	0.56%	0.28%	4.17%	8.48%	8.62%	0.97%	21.70%	**44.78%**
Sideswipe (same direction)	0.00%	0.14%	0.00%	0.28%	0.42%	0.00%	2.78%	**3.62%**
Sideswipe (opposite direction)	0.00%	0.00%	0.28%	0.56%	0.14%	0.28%	0.28%	**1.53%**
Hit fixed object	0.00%	0.14%	0.97%	2.36%	1.81%	0.56%	9.46%	**15.30%**
Hit pedestrian	0.00%	0.56%	0.70%	0.70%	0.97%	0.00%	0.00%	**2.92%**
Other or unknown	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
Total	**0.56%**	**1.53%**	**8.90%**	**19.33%**	**17.80%**	**2.23%**	**49.65%**	**100%**

Regionalization Assessment

The statewide data summary reveals that only statewide models can be developed for 3-leg all-way stop-controlled, 4-leg minor-street stop-controlled, 4-leg all-way stop-controlled, and 4-leg signalized intersections. Regionalization is only possible for 3-leg minor-street stop-controlled intersections. Table 24 provides a summary of the 3-leg minor-street stop-controlled intersections and 5-year crash frequencies by PennDOT engineering district. As shown, most districts have fewer than 50 intersections, which would preclude district-level or county-level SPF estimation (Steps 4 and 7 of the regionalization process). Instead, regionalization would consider district-specific indicators incorporated into the statewide SPFs for 3-leg minor-street stop-controlled intersections (Step 8 of the regionalization process).

Table 24. 3-leg minor-street stop-controlled intersections and crash frequencies by engineering district

District No.	Number of intersections	5-year crash frequency
1	7	10
2	17	15
3	20	26
4	29	66
5	65	221
6	116	404
8	103	307
9	20	25
10	10	11
11	47	99
12	88	194
Total	**522**	**1378**

Based on this information, both a statewide and a statewide model with district indicators were developed for 3-leg minor-street stop-controlled intersections. The RMSE values for the two versions of the statewide SPFs (without and with district indicators) were calculated for comparison. Table 25 provides a summary of these RMSE values for total and fatal + injury crash frequency. For each county, the bolded value under the total crash frequency and fatal + injury crash frequency columns represent the smallest RMSE value across the different regionalized SPFs estimated. The results in Table 25 reveal that for total crash frequency, the statewide model performs best (i.e., produces the lowest RMSE values) in 19 of the 52 counties, while the statewide model with district indicators performs best in 33 out of 52 counties. For fatal + injury crash frequency, the statewide model performs best in 23 out of 52 counties, while the statewide model with district indicators performs best in 29 out of 52 counties. The last row of Table 25 also provides the average RMSE value measured across the entire commonwealth. As shown, the statewide SPF with district indicators provides the lowest RMSE values for both total and fatal + injury crash frequency of the three SPFs considered. Overall, the results suggest that the statewide SPF with district-level indicators is generally preferred for 3-leg minor-street stop-controlled intersections on urban-suburban collectors.

Table 25. County RMSE summary for 3-leg minor-street stop-controlled intersection SPFs

No.	County	Intersection # (5-yr)	Total crash SPF Prediction RMSE		Fatal + injury SPF Prediction RMSE	
			Statewide	Statewide district indicators	Statewide	Statewide district indicators
1	ADAMS	30	**1.0971**	1.1005	0.3986	**0.3951**
2	ALLEGHENY	150	0.7859	**0.7698**	0.5039	**0.4972**
3	ARMSTRONG	10	**0.2759**	0.2796	0.0692	**0.0548**
4	BEAVER	70	0.6290	**0.6085**	0.4566	**0.4551**
5	BEDFORD	---	---	---	---	---
6	BERKS	75	0.9069	**0.8923**	0.4997	**0.4989**
7	BLAIR	40	0.7781	**0.7757**	0.4075	**0.4070**
8	BRADFORD	5	**0.8105**	0.9193	**0.3999**	0.4088
9	BUCKS	115	0.9315	**0.9158**	0.5671	**0.5647**
10	BUTLER	25	0.5965	**0.4702**	0.2413	**0.1840**
11	CAMBRIA	40	0.5001	**0.4564**	0.2809	**0.2781**
12	CAMERON	---	---	---	---	---
13	CARBON	15	**0.4985**	0.5270	**0.3945**	0.3976
14	CENTRE	20	0.5163	**0.3686**	0.3254	**0.2983**
15	CHESTER	210	1.1423	**1.1302**	0.7305	**0.7273**
16	CLARION	---	---	---	---	---
17	CLEARFIELD	20	0.3623	**0.2368**	0.1678	**0.0857**
18	CLINTON	15	0.5203	**0.4047**	0.2983	**0.2548**
19	COLUMBIA	45	0.6359	**0.5950**	0.3157	**0.3075**
20	CRAWFORD	15	0.5365	**0.4551**	0.3637	**0.3473**
21	CUMBERLAND	50	0.7924	**0.7886**	0.5160	**0.5148**
22	DAUPHIN	50	0.8513	**0.8485**	**0.5110**	0.5118
23	DELAWARE	115	**0.8211**	0.8231	**0.5493**	0.5509
24	ELK	20	0.3876	**0.2768**	0.1533	**0.0802**
25	ERIE	10	0.6904	**0.6383**	**0.6287**	0.6353
26	FAYETTE	105	**0.5910**	0.5926	**0.4872**	0.4874
27	FOREST	---	---	---	---	---
28	FRANKLIN	95	**0.7194**	0.7249	**0.4655**	0.4664
29	FULTON	---	---	---	---	---
30	GREENE	15	0.3642	**0.3373**	0.1695	**0.1662**
31	HUNTINGDON	---	---	---	---	---
32	INDIANA	5	**1.4484**	1.5231	**0.6565**	0.6814
33	JEFFERSON	10	0.4689	**0.3469**	0.1967	**0.1528**
34	JUNIATA	---	---	---	---	---
35	LACKAWANNA	40	**0.6713**	0.6737	**0.4706**	0.4715
36	LANCASTER	85	**0.7303**	0.7320	0.4454	**0.4441**
37	LAWRENCE	15	0.6972	**0.6899**	**0.5944**	0.6037
38	LEBANON	40	0.9216	**0.9161**	0.6521	**0.6507**
39	LEHIGH	65	0.7710	**0.7611**	**0.4865**	0.4875
40	LUZERNE	65	**0.9359**	0.9449	**0.4651**	0.4657
41	LYCOMING	10	0.3930	**0.3929**	**0.4021**	0.4197
42	MCKEAN	5	**0.4982**	0.6621	**0.6242**	0.6931
43	MERCER	5	0.4850	**0.4267**	**0.4006**	0.4032
44	MIFFLIN	5	**1.2281**	1.2628	**0.4065**	0.4174
45	MONROE	65	0.9888	**0.9630**	0.6309	**0.6232**
46	MONTGOMERY	140	**0.9556**	0.9666	**0.5516**	0.5533
47	MONTOUR	5	**1.2147**	1.2462	0.2370	**0.1211**
48	NORTHAMPTON	80	0.9611	**0.9455**	0.5771	**0.5726**
49	NORTHUMBERLAND	5	0.2988	**0.1632**	0.1317	**0.0686**
50	PERRY	---	---	---	---	---

No.	County	Intersection # (5-yr)	Total crash SPF Prediction RMSE		Fatal + injury SPF Prediction RMSE	
			Statewide	Statewide district indicators	Statewide	Statewide district indicators
51	PIKE	---	---	---	---	---
52	POTTER	---	---	---	---	---
53	SCHUYLKILL	25	**1.1939**	1.1984	**0.6965**	0.6977
54	SNYDER	20	0.5259	**0.4820**	0.2923	**0.2870**
55	SOMERSET	20	0.3999	**0.3793**	0.3043	**0.3041**
56	SULLIVAN	---	---	---	---	---
57	SUSQUEHANNA	20	0.4950	**0.4737**	**0.3627**	0.3692
58	TIOGA	---	---	---	---	---
59	UNION	10	0.2224	**0.1255**	0.0984	**0.0530**
60	VENANGO	5	0.4539	**0.4228**	**0.4148**	0.4171
61	WARREN	---	---	---	---	---
62	WASHINGTON	75	**0.6327**	0.6356	**0.4772**	0.4779
63	WAYNE	20	0.3427	**0.3301**	**0.2379**	0.2482
64	WESTMORELAND	245	**0.8364**	0.8383	0.4705	**0.4701**
65	WYOMING	---	---	---	---	---
66	YORK	165	**1.0178**	1.0205	**0.5686**	0.5714
67	PHILADELPHIA	---	---	---	---	---
Total		2,610	0.8399	**0.8324**	0.5132	**0.5115**

Recommended SPFs

3-leg minor-street stop-controlled intersections

Based on the regionalization process, the research team recommends using a **statewide SPF with district-specific adjustments** for 3-leg minor-street stop-controlled intersections. The final recommended regional SPFs for two-lane undivided roadway segments for total and fatal + injury crash frequency are shown in Table 26, along with the overdispersion parameter for each negative binomial regression model. These equations provide the baseline SPF for the state, and each SPF should be further modified by the district-specific adjustments provided in Table 27 to account for difference in safety performance across individual districts.

Table 26. Summary of statewide SPFs for 3-leg minor-street stop-controlled intersections

$N_{T,3LMS} = \left(AADT_{major}\right)^{0.517} \times \left(AADT_{minor}\right)^{0.254} \times e^{-6.643} \times e^{-0.314 Major\_Crosswalk} \times e^{0.158 Major\_PSL40P}$ (34) over-dispersion parameter: 0.454 $N_{FI,3LMS} = \left(AADT_{major}\right)^{0.513} \times \left(AADT_{minor}\right)^{0.251} \times e^{-7.547} \times e^{0.218 Major\_PSL40P}$ (35) over-dispersion parameter: 0.496	
$N_{T,3LMS}$	= predicted total crash frequency at 3-leg minor-street stop-controlled intersection (crashes/year);
$N_{FI,3LMS}$	= predicted fatal + injury crash frequency at 3-leg minor-street stop-controlled intersection (crashes/year);
$AADT_{major}$	= annual average daily traffic volume on the major road approach (veh/day);
$AADT_{minor}$	= annual average daily traffic volume on the minor road approach (veh/day);
$Major\_Crosswalk$	= presence of a crosswalk on the major road approach (1 if present, 0 otherwise); and
$Major\_PSL40P$	= posted speed limit set to 40 mph or greater on the major road approach (1 if true, 0 otherwise).

Table 27. District-specific adjustments for statewide SPFs for 3-leg minor-street stop-controlled intersections

District	District-specific adjustment for total crash SPF	District-specific adjustment for fatal + injury SPF
1	Multiply estimate by 0.580	Multiply estimate by 0.661
2	Multiply estimate by 0.434	Multiply estimate by 0.442
3	Multiply estimate by 0.434	Multiply estimate by 0.442
4	Multiply estimate by 0.731	No modification necessary
5	No modification necessary	No modification necessary
6	No modification necessary	No modification necessary
8	Multiply estimate by 0.813	Multiply estimate by 0.844
9	Multiply estimate by 0.727	Multiply estimate by 0.844
10	Multiply estimate by 0.580	Multiply estimate by 0.661
11	Multiply estimate by 0.580	Multiply estimate by 0.661
12	Multiply estimate by 0.727	Multiply estimate by 0.844

3-leg all-way stop-controlled intersections

Due to sample size limitations, only statewide models could be developed for 3-leg all-way stop-controlled intersections. The recommended SPF is as follows:

$$N_{T,3LAWS} = \left(AADT_{major}\right)^{0.618} \times \left(AADT_{minor}\right)^{0.534} \times e^{-10.160} \quad (36)$$

$$N_{FI,3LAWS} = \left(AADT_{major}\right)^{0.867} \times \left(AADT_{minor}\right)^{0.498} \times e^{-12.692} \quad (37)$$

where:

$N_{T,3LAWS}$	= predicted total crash frequency at 3-leg all-way stop-controlled intersection (crashes/year); and
$N_{FI,3LAWS}$	= predicted fatal + injury crash frequency at 3-leg all-way stop-controlled intersection (crashes/year).

4-leg minor-street stop-controlled intersections

Due to sample size limitations, only statewide models could be developed for 4-leg minor-street stop-controlled intersections. The recommended SPF is as follows:

$$N_{T,4LMS} = \left(AADT_{major}\right)^{0.286} \times \left(AADT_{minor}\right)^{0.643} \times e^{-6.594} \quad (38)$$

$$N_{FI,4LMS} = \left(AADT_{major}\right)^{0.377} \times \left(AADT_{minor}\right)^{0.526} \times e^{-7.309} \quad (39)$$

where:

$N_{T,4LMS}$	= predicted total crash frequency at 4-leg minor-street stop-controlled intersection (crashes/year); and
$N_{FI,4LMS}$	= predicted fatal + injury crash frequency at 4-leg minor-street stop-controlled intersection (crashes/year).

4-leg all-way stop-controlled intersections

Due to sample size limitations, only statewide models could be developed for 4-leg all-way stop-controlled intersections. The recommended SPF is as follows:

$$N_{T,4LAWS} = \left(AADT_{major} + AADT_{minor}\right)^{1.233} \times e^{-11.032} \quad (40)$$

$$N_{FI,4LAWS} = \left(AADT_{major} + AADT_{minor}\right)^{0.830} \times e^{-8.297} \quad (41)$$

where:

$N_{T,4LAWS}$	= predicted total crash frequency at 3-leg all-way stop-controlled intersection (crashes/year); and
$N_{FI,4LAWS}$	= predicted fatal + injury crash frequency at 3-leg all-way stop-controlled intersection (crashes/year).

<u>4-leg signalized intersections</u>

Due to sample size limitations, only statewide models could be developed for 4-leg signalized intersections. The recommended SPF is as follows:

$$N_{T,4LSIG} = \left(AADT_{major}\right)^{0.542} \times \left(AADT_{minor}\right)^{0.308} \times e^{-6.884} \quad (42)$$

$$N_{FI,4LSIG} = \left(AADT_{major}\right)^{0.684} \times \left(AADT_{minor}\right)^{0.333} \times e^{-9.127} \quad (43)$$

where:

$N_{T,4LSIG}$	= predicted total crash frequency at 4-leg signalized intersection (crashes/year); and
$N_{FI,4LSIG}$	= predicted fatal + injury crash frequency at 4-leg signalized intersection (crashes/year).

CHAPTER 5

Summary and Recommendations for Implementation

In this project, Pennsylvania-specific SPFs were developed for roadway segments and intersections on urban-suburban collector roads. These SPFs were developed in a manner consistent with the first edition of the HSM, but represent Pennsylvania driving conditions and regional differences in safety performance across the commonwealth. The level of regionalization is based on both available data and observed safety performance and differs for each roadway segment and intersection type. Models were developed to predict both total crash frequency and the frequency of fatal + injury crashes. A summary of all recommended SPFs is provided in Appendix E for ease of use.

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.

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Appendix A: VideoLog Data Collection Instructional Guide

The VideoLog 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 person-hours are required to collect field data that can be obtained visually. In this project, the VideoLog system was used to collect the following pieces of information:

- Roadway segments:
  - Presence of bicycle lanes
  - Presence of on-street parking
  - Presence of curb/sidewalk combinations
  - Driveway density
  - Presence of auxiliary lanes (e.g., turn lanes, bus lanes, etc.)
- Intersections:
  - Presence of intersection auxiliary lanes: left- or right-turn lanes
  - Type of intersection control: signalized or stop-controlled intersections
  - Presence of pedestrian crosswalk on intersection approach

This document will demonstrate how these data elements can be identified using the VideoLog system. Prior to demonstrating the methods used to collect the data of interest to the present study, the procedure necessary to access the PennDOT VideoLog system is described.

Step 1: Access the PennDOT Online VideoLog system at the following link:

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

The web browser may display a "pop-up blocker" for state.pa.us – allow this to display.

Step 2. After gaining access to the Pennsylvania VideoLog Application, click "I Accept" (Figure 1).

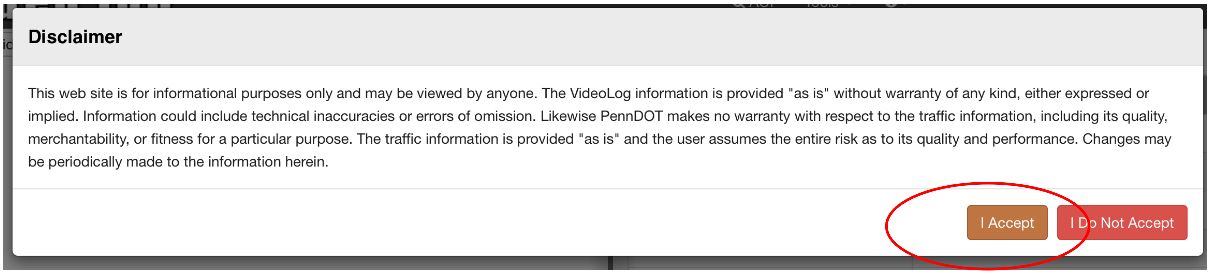

Figure 1. Screenshot of "I Accept" icon

Step 3. In the "Select Area of Interest" box that is shown in Figure 2, select "route segment." Click "Go" when finished.

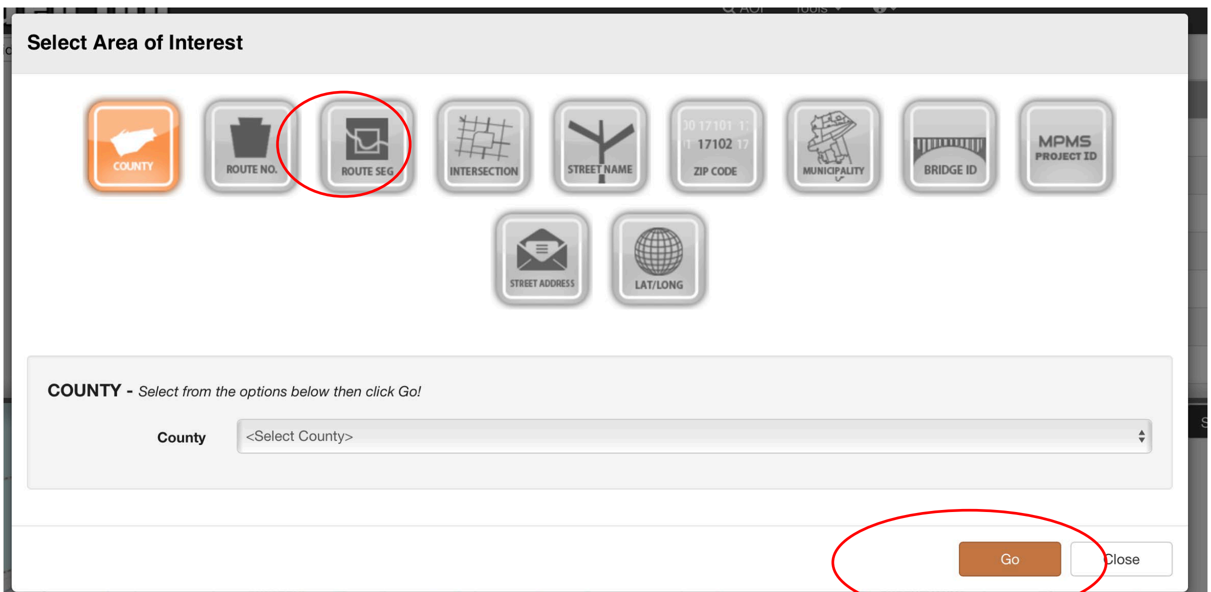

Figure 2. Screenshot for selecting area of interest

Step 4. In the "County" and "Select a State Route" boxes, select the county and roadway of interest. An example using Segment 470 on SR 4009 in Bedford County is shown in Figure 3 through Figure 5.

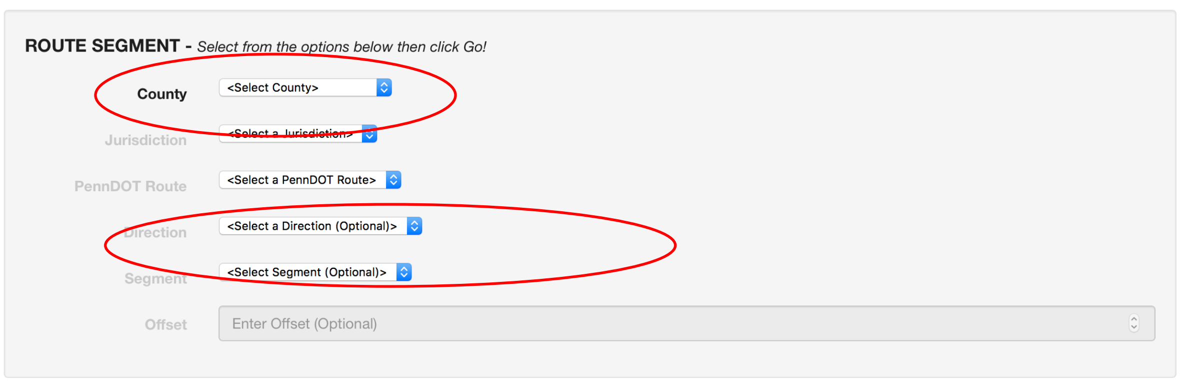

Figure 3. Selecting a county and select a route screen capture

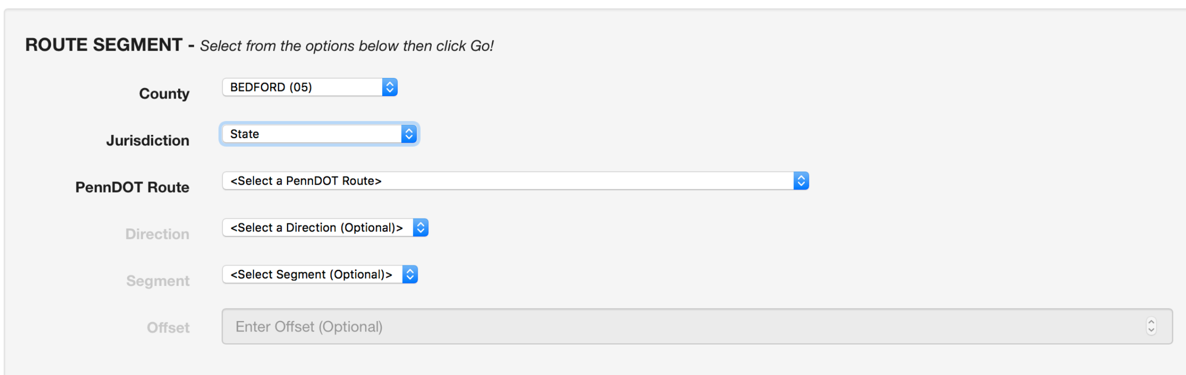

Figure 4. Selecting state routes in Bedford County

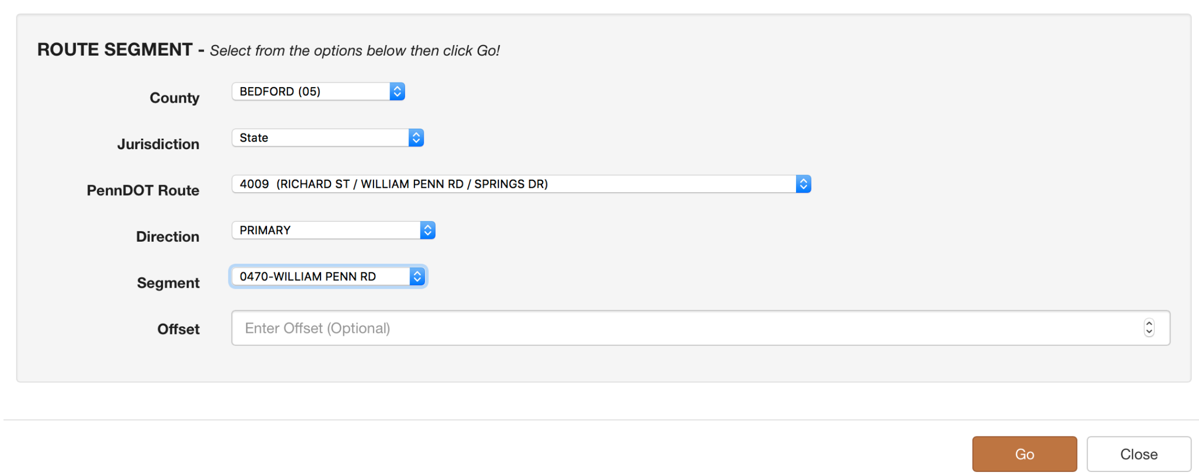

Figure 5. Selecting segment 470 on SR 4009

Step 5. When you gain access to the VideoLog, a map should also appear that provides a localized area map of the subject route, in this case SR 4009 (see Figure 6).

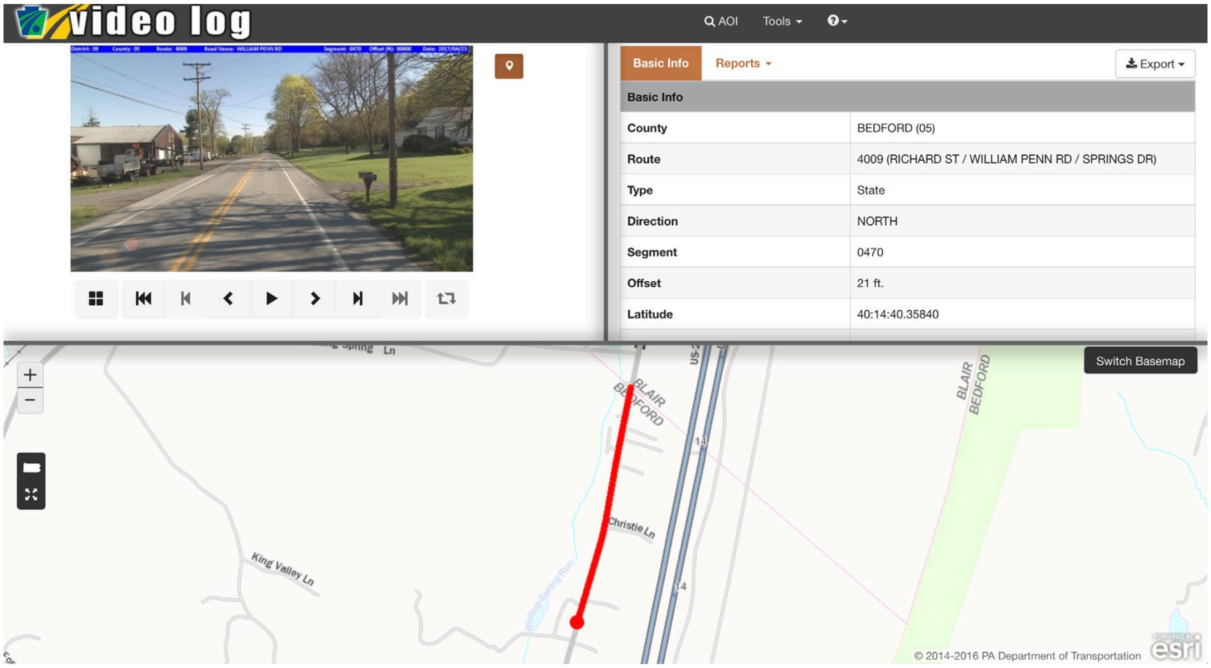

Figure 6. Screenshot for "Show-up Map" to locate beginning point for SR 3009

Figure 7 through Figure 17 provide examples of the data elements that will be collected using the VideoLog system.

Figure 7. Example of an exclusive bicycle lane (County 67, Route 2010, Segment 40)

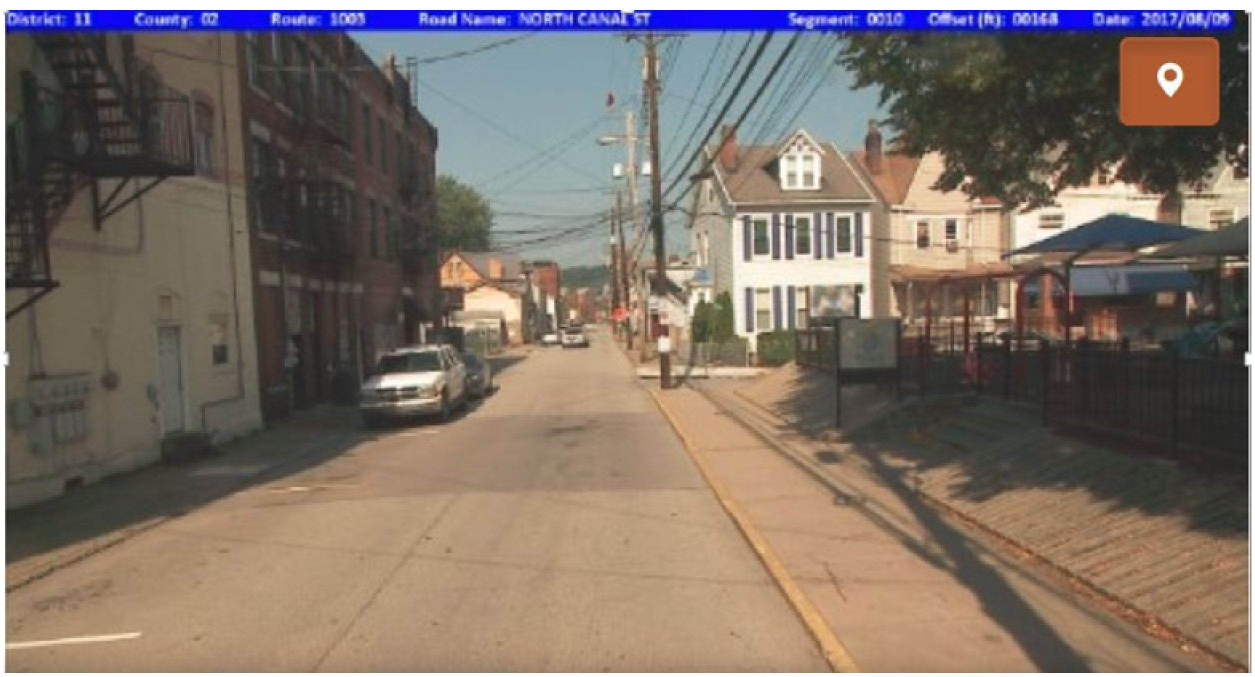

Figure 8. Example of on-street parking (County 2, Route 1003, Segment 10)

Figure 9. Example of curb without sidewalk (Count 2, Route 4007, Segment 24)

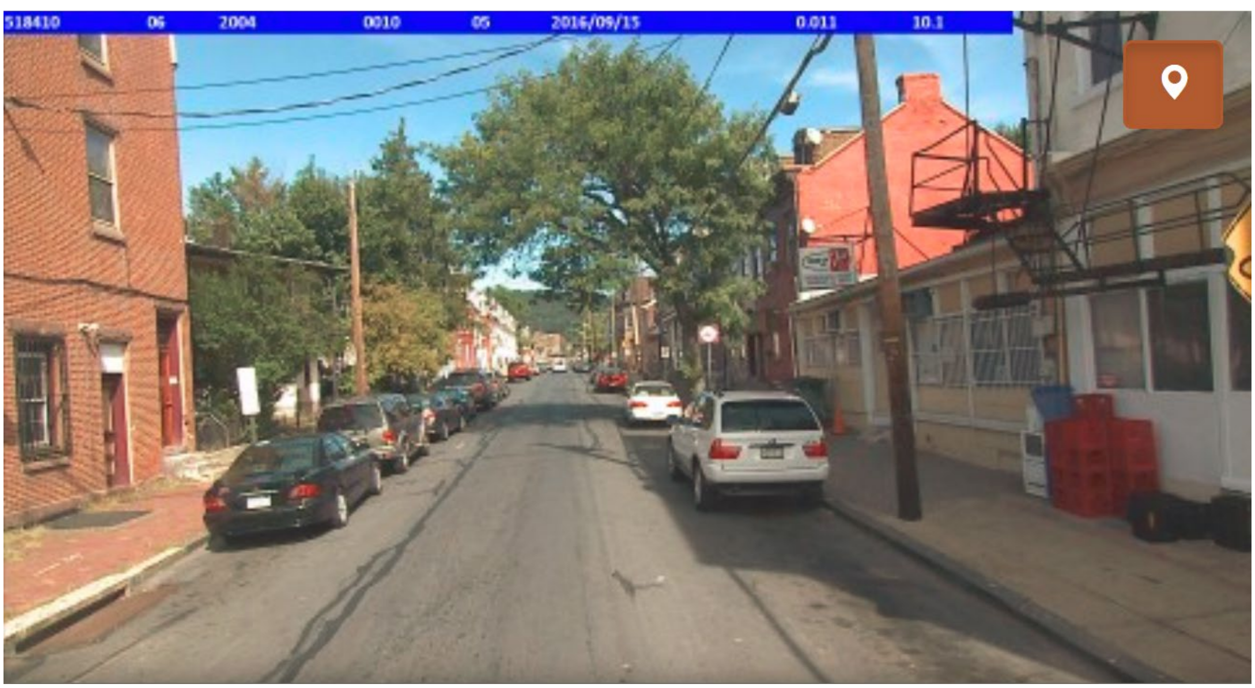

Figure 10. Example of curb with sidewalk (County 6, Route 2004, Segment 10)

Figure 11. Example of sidewalk without curb (County 36, Route 18, Segment 20)

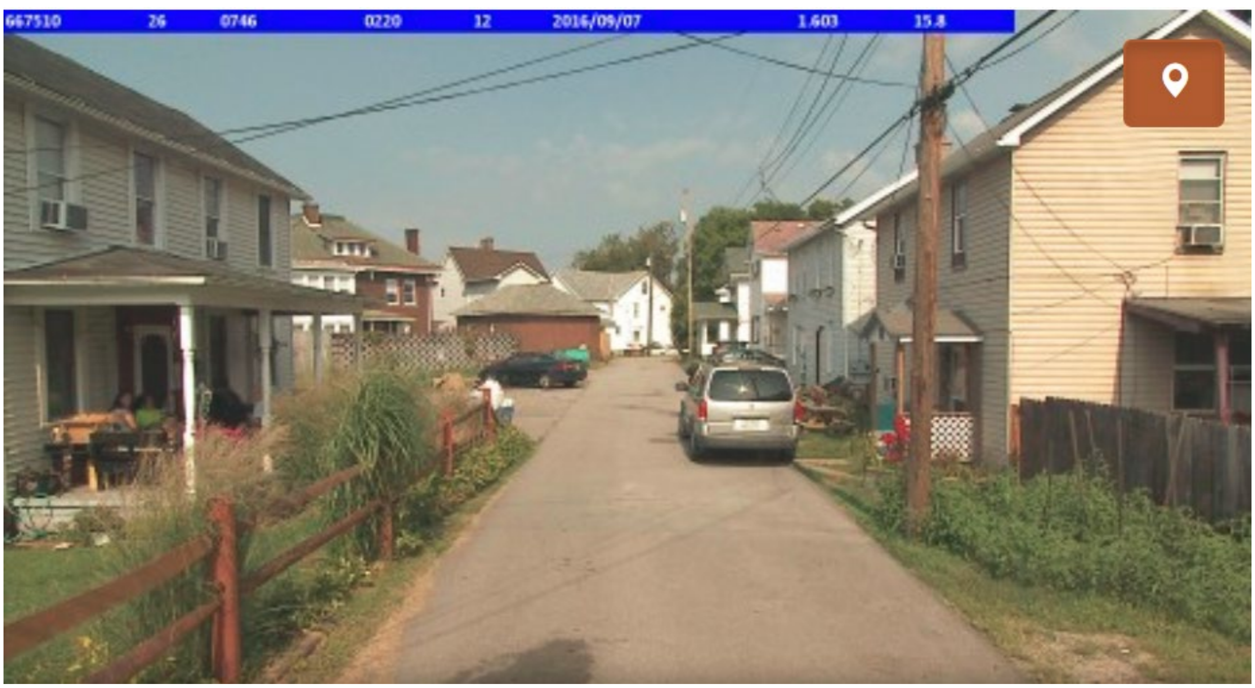

Figure 12. Example of no curb or sidewalk (County 26, Route 746, Segment 220)

Figure 13. Example of access driveways to obtain access density (County 7, Route 2004, Segment 10)

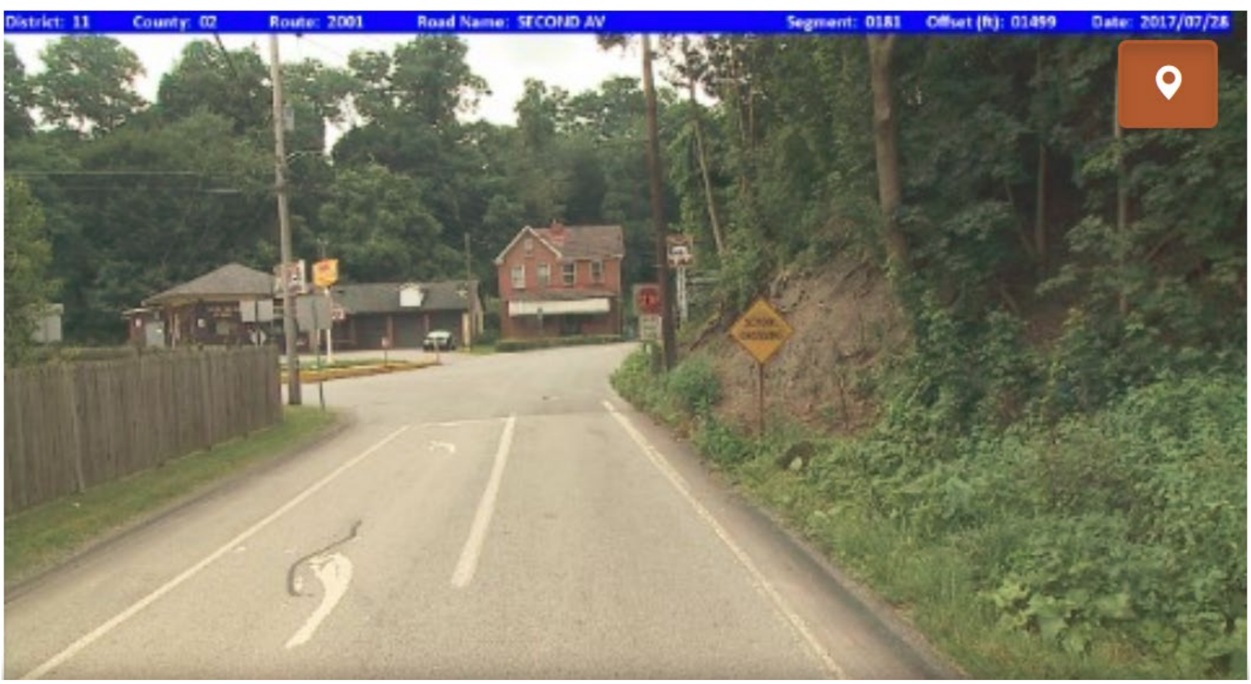

Figure 14. Example of left-turn lane (County 2, Route 2001, Segment 181)

Figure 15. Example of right-turn lane (County 35, Route 6307, Segment 240)

Figure 16. Example of a shared bicycle space (County 67, Route 3017, Segment 60)

Figure 17. Example of bus lane (image obtained from Google Maps street view)

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 sometimes results in variability in the definition of these horizontal curves among various data collectors. To alleviate this issue, the research team also made use of PennDOT's VideoLog system to help define the curve limits from a driver's perspective (available at http://www.dot7.state.pa.us/VideoLog/Open.aspx).

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 these horizontal curve data. It should be noted that, if the highway is divided, users should measure the length and radius of the smallest curve (inside edge of traveled) and then add the median width to determine the radius of the larger curve.

Step 1: Drawing the route path in Google Earth

Horizontal curve data are defined within the PennDOT roadway 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 18) . A window will appear to create a new path (see Figure 19). 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).

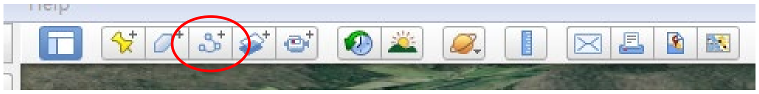

Figure 18. "Add Path" icon

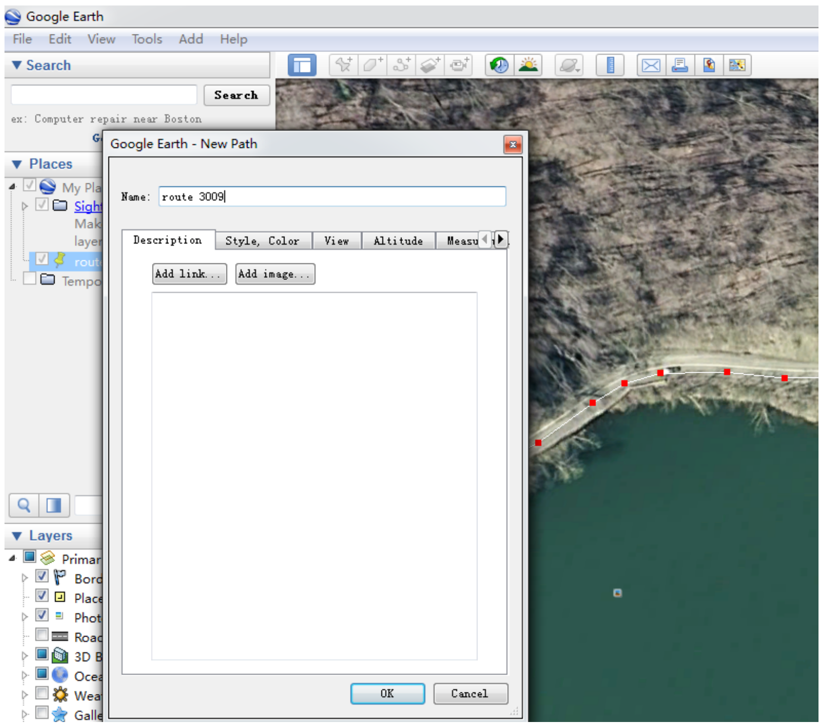

Figure 19. Screenshot for adding path

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. Table 28 provides 18 contiguous segments on State Route (SR) 3009 in Bedford County as an example. 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 VideoLog, which was illustrated in the VideoLog sheet, a map will appear that provides a localized area map of the subject route, SR 3009 (see Figure 20). 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 21) and change the unit of length to "Feet," as shown in Figure 22.

Table 28. Length of segments in PennDOT profiles for example data collection

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 20. Screenshot for "Show-up Map" to locate beginning point for SR 3009

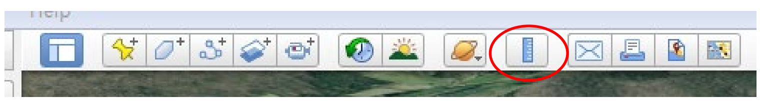

Figure 21. The "Show Ruler" icon

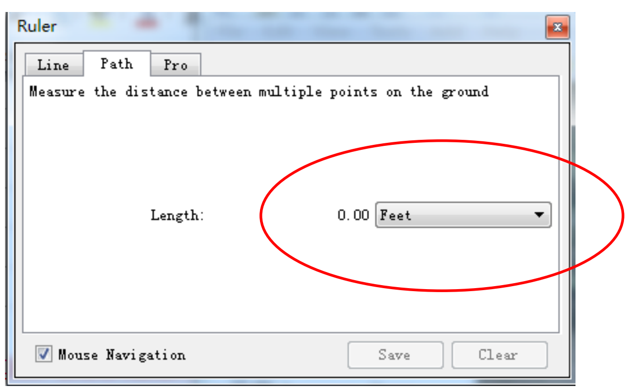

Figure 22. Screenshot for "Show Ruler" in the starting location

As shown in Table 28, the end of the first segment (0010) is 2,472 ft from the start of the route in Bedford County. Using the ruler, measure a distance 2,472 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 Figure 23 and Figure 24). This will create a placemark that denotes the starting/ending point (see Figure 25 and Figure 26).

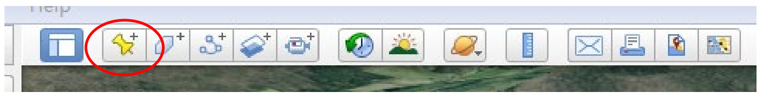

Figure 23. The "Add Placemark" Icon

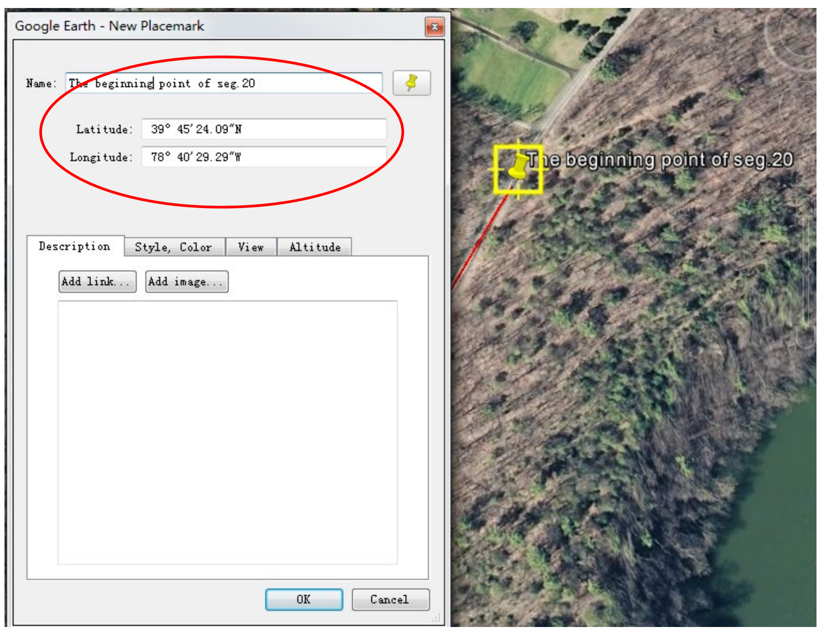

Figure 24. Screenshot for "Add Placemark"

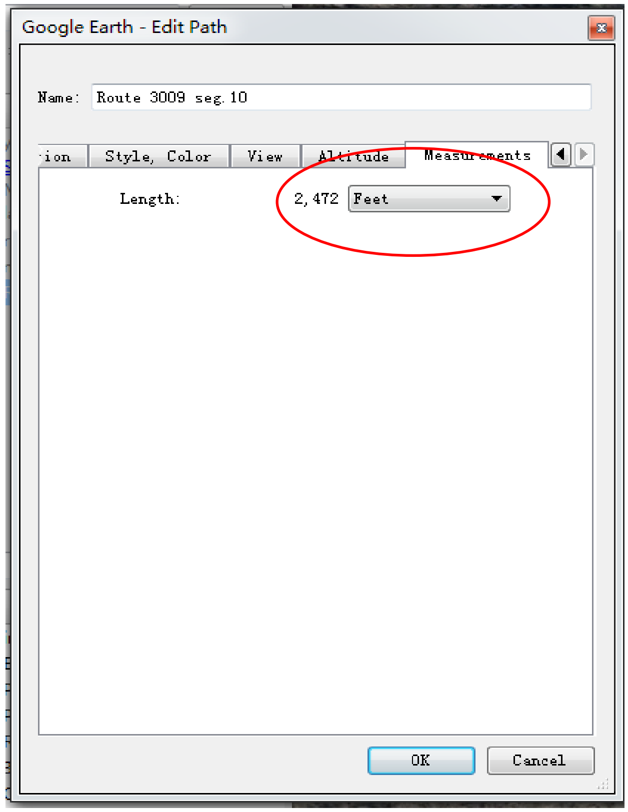

Figure 25. Locating the ending points of segment 10

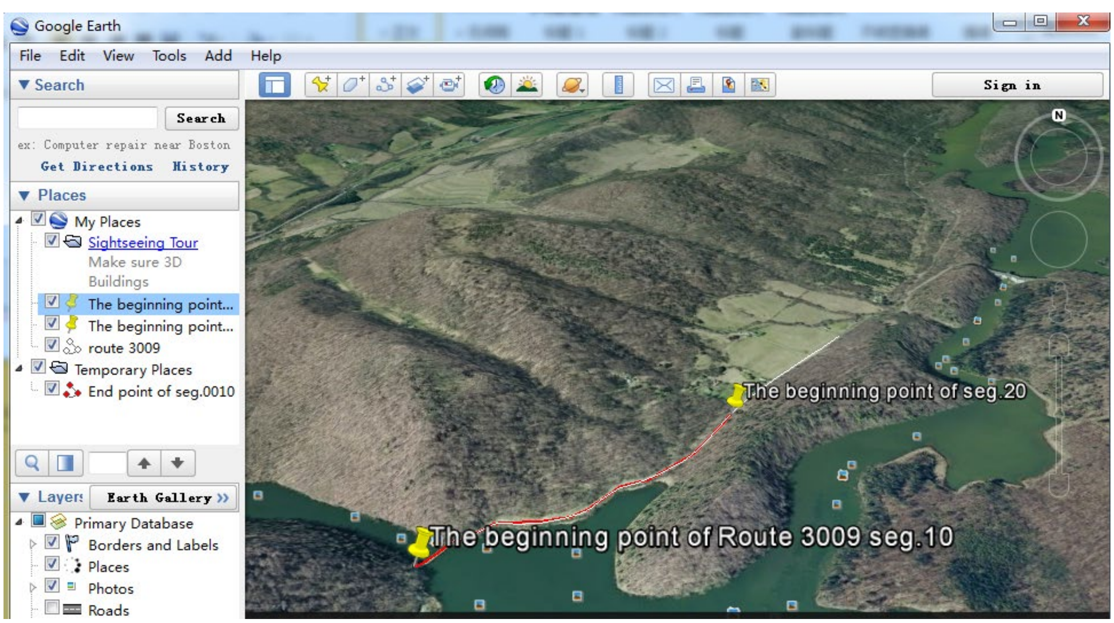

Figure 26. The starting and ending points for segment 10

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 VideoLog. Once a curve has been identified from a driver's perspective, check the map below the VideoLog 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 consistency across individuals, we set up 1:1592.5 cm (4 cm: 209 ft) as scale legend because the segment almost covers the whole screen in this zooming level (See Figure 27). 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 28 shows the various components of a simple horizontal curve (AASHTO, 2011). Figure 29 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 27. "Zooming resolution" level

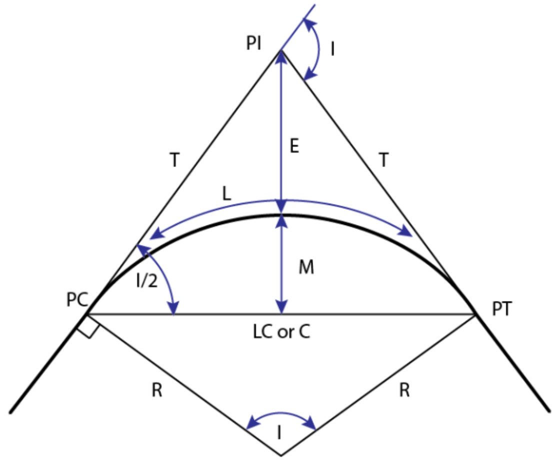

Figure 28. Measuring the length of arc and radius of the curve.

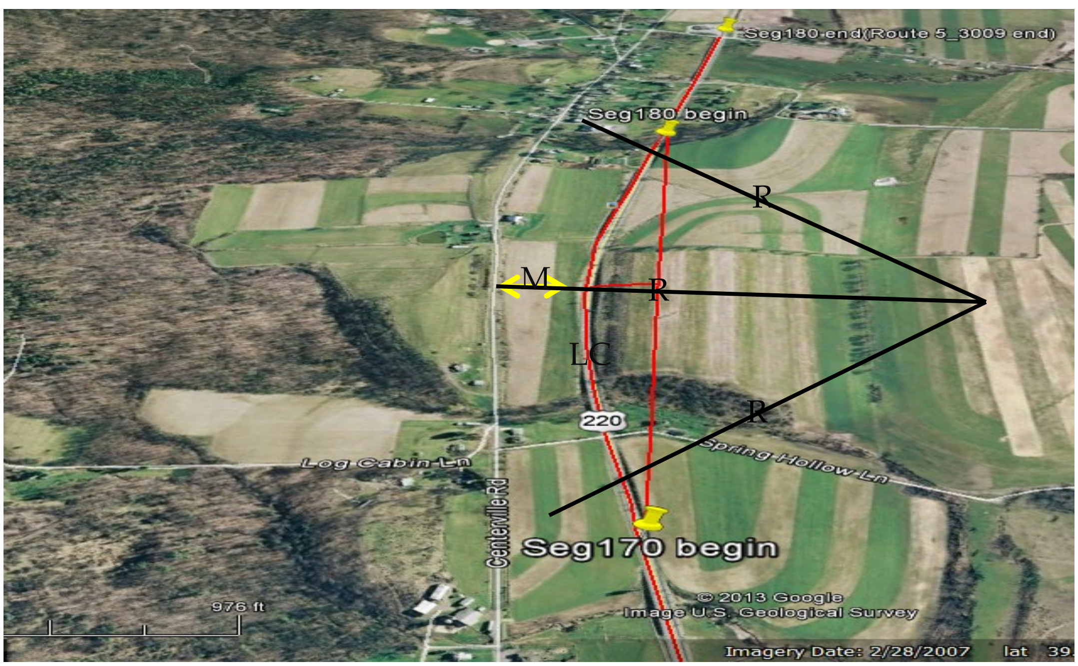

Figure 29. The relationship between LC, M, and R

Based on the geometry of Figure 28 and Figure 29, the relationship between LC, M, and radius *R* is as follows:

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

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

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 28), 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 30). Record the coordinates of these two points as shown in

Table 29. The second procedure to measure the curve is to draw a chord (line LC or C in Figure 28) to connect the PC and PT. Then, draw a perpendicular line from the chord to the midpoint of the arc (line M in Figure 28), which is illustrated in Figure 31 and Figure 32, respectively. Table 30 and Table 31 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 was noted above.

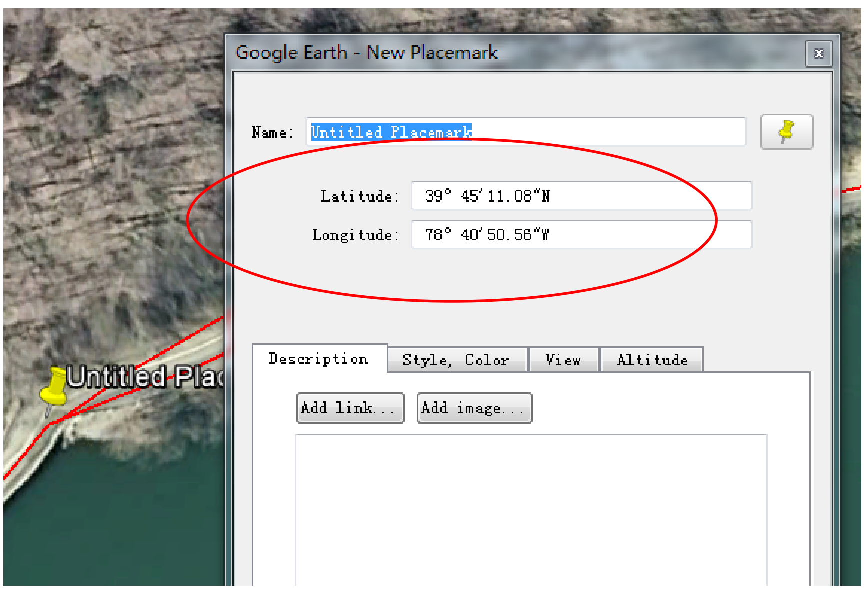

Figure 30. Example of displaying coordinates

Table 29. 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

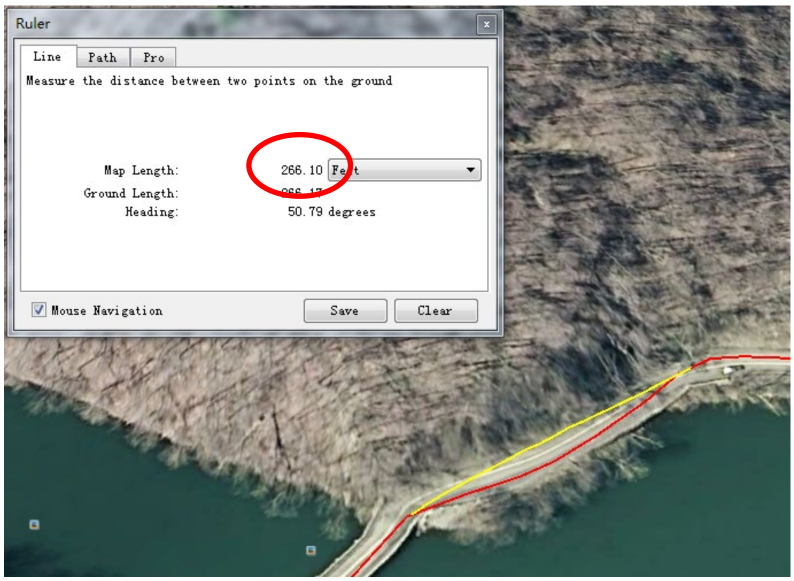

Figure 31. Example of drawing the chord

Table 30. 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

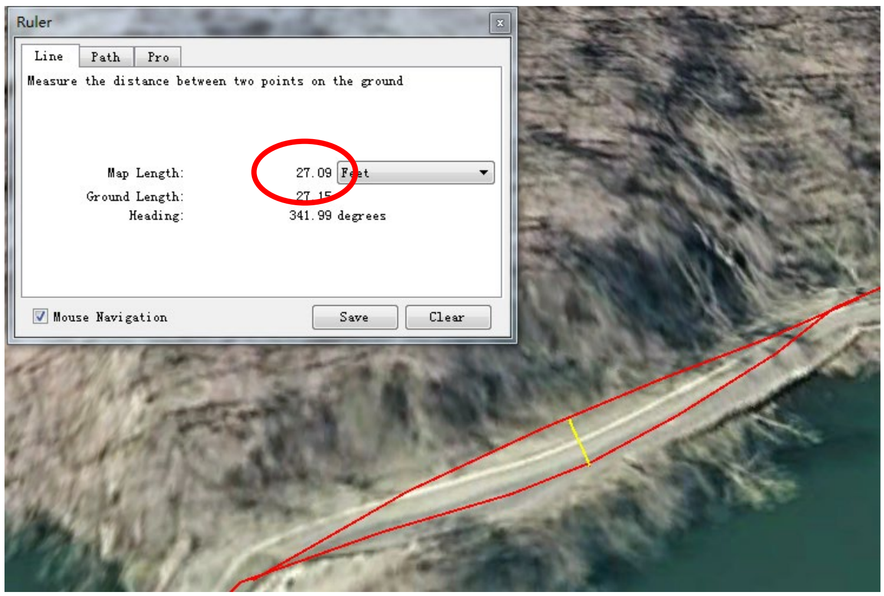

Figure 32. Example of drawing the mid-line

Table 31. Filling in the 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 32 for several segments on SR 3009. 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 32. 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	2,472	(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)	1,119.32	113.50	1,436.57
5	3009	20	2,769	(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	3,918	(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	2,929	(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 SKEW ANGLE DATA COLLECTION

Google Maps can be used to measure the skew angle of an intersection. First, the Google Map image of the intersection should be enlarged, and a protractor may be placed on the computer screen to measure the skew angle of the intersection; an example is shown in Figure 33. The skew angle is the absolute value of the difference between 90 degrees and the actual intersection angle. If the skew angle differs for the two minor road legs at a four-legged intersection, separate CMFs should be computed for each skew angle, and the CMF values should then be averaged.

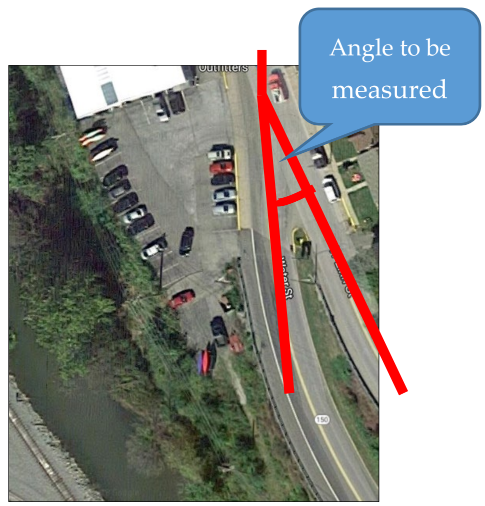

Figure 33. Intersection skew angle of SR 144 and SR 150.

Appendix C: Description of Intersection Data Elements

Figure 34 through Figure 37 provide a graphical depiction of various intersection configurations. These figures can be used to help identify the approaches coded as the major and minor street for all intersections identified in the analysis database.

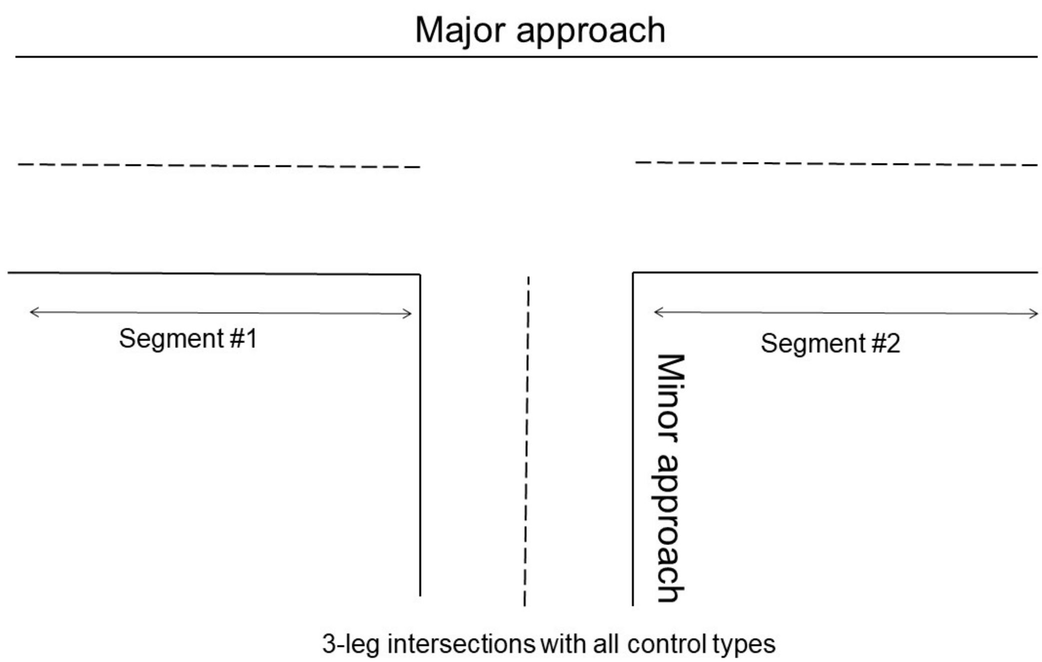

Figure 34. Graphical depiction of a 3-leg intersection

For all 3-leg intersections, the two continuous (i.e., non-ending) approaches are designated as the major approaches, while the remaining approach is designated as the minor street. In some cases, the two major approaches belong to two different roadway segments in PennDOT's RMS database. For example, in Figure 34, the eastbound major approach belongs to segment #1 while the westbound major approach belongs to segment #2. In these situations, the major approach AADT is defined as the average AADT of segment #1 and segment #2. For the cross-section features such as paved width, left- or right-shoulder width, the average value of segment #1 and segment #2 is defined for the major road feature. For posted speed limit, the larger value of posted speed limit of segment #1 or segment #2 is defined as the major road posted speed limit.

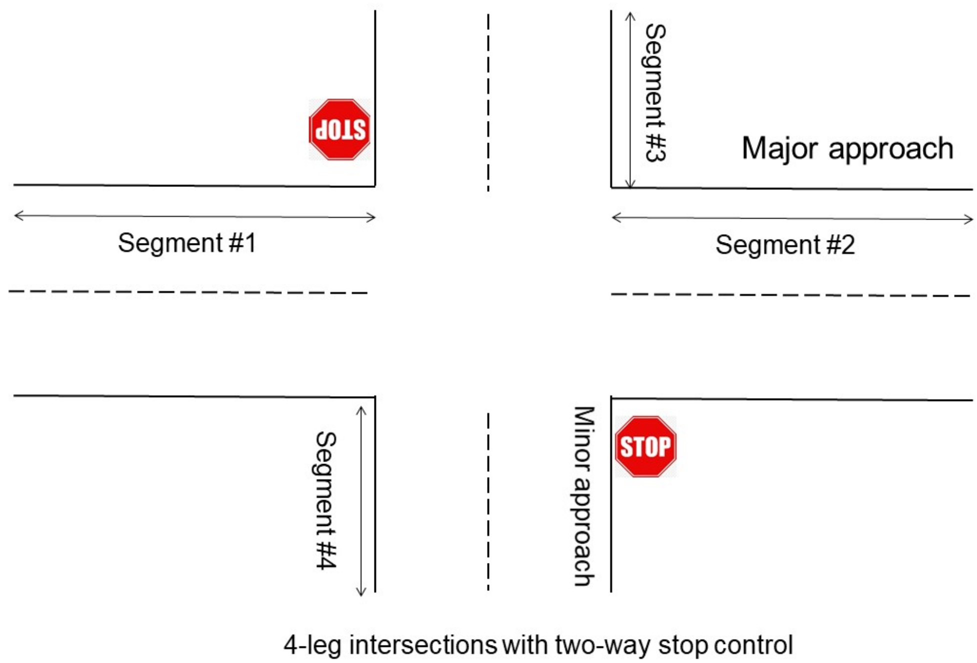

Figure 35. Graphical depiction of a 4-leg intersection with two-way stop control

For 4-leg intersections with two-way stop control, the approaches that do not have stop control are considered major approaches, and the approaches with stop control are considered minor streets. In some cases, the two major approaches or two minor streets belong to two different roadway segments in PennDOT's RMS database. For example, in Figure 35, the eastbound major approach belongs to segment #1 and the westbound major approach belongs to segment #2. The major approach AADT is defined as the average AADT of segment #1 and segment #2. For the cross-section features such as paved width, left- or right-shoulder width, the average value of segment #1 and segment #2 is defined as the major road features. For posted speed limit, the larger value of posted speed limit of segment #1 or segment #2 is defined as the major road posted speed limit. The same definition of variables is used for minor streets with two different roadway segments.

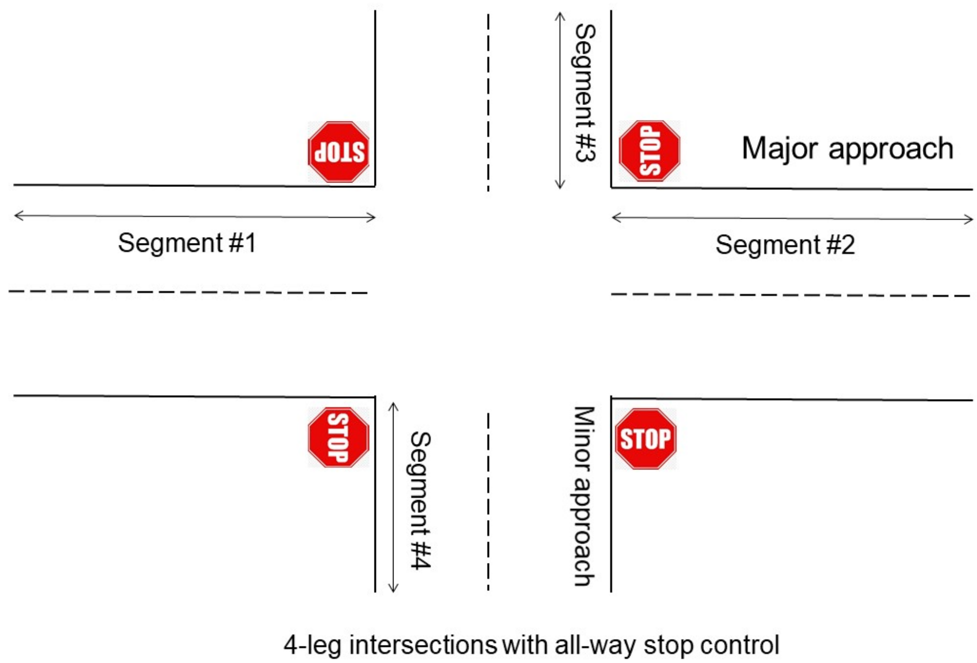

Figure 36. Graphical depiction of a 4-leg intersection with all-way stop control

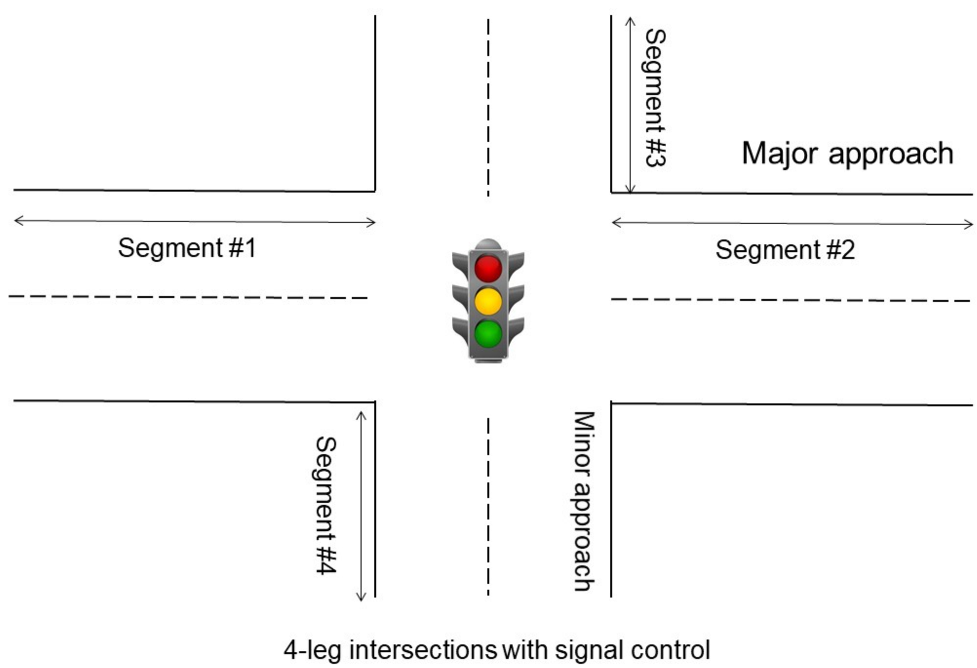

Figure 37. Graphical depiction of a 4-leg signalized intersection

For 4-leg all-way stop-controlled or signalized intersections, the major road is defined as the road with higher AADT and minor road is defined as the road with lower AADT. However, there are some cases in which the two approaches from the opposite directions are not the same roadway segment. For example, segment #1 and segment #2 (or segment #3 and segment #4) in Figure 36 and Figure 37 belong to two different roadway segments in PennDOT's RMS database. In this case, the average AADT of segment #1 and segment #2 is defined as the AADT of this approach. In this situation, the eastbound and westbound approaches are defined as the major road if the average AADT of segments #1 and #2 is higher than the average AADT of segments #3 and #4, and vice versa. In addition, for cross-section features such as paved width, left- or right-shoulder width, the average values from the two segments making up the major approaches are used. For posted speed limit, the larger value of posted speed limit of the two segments making up the major approach is defined as the major posted speed limit. The same definition of variables is used for minor streets with two different roadway segments.

Appendix D: Modification Factor for 3-leg Signalized Intersections

Due to data limitations, reliable safety models were not possible for 3-leg signalized intersections. Only 33 intersections were available across Pennsylvania, and preliminary models suggests that any SPFs developed for these intersection types would be unreliable.

To help provide PennDOT with guidance on how to predict crash frequencies for this intersection form, the research team has estimated calibration coefficients to modify the outputs of the 3-leg minor-street stop-controlled intersection SPF to predict crash frequencies on this intersection type. The calibration coefficients were determined as follows:

1. For each available observation, the estimated crash frequency was computed using the base SPF (3-leg minor-street stop-controlled intersection).
2. For the entire set of observations, the sum of the total estimated crash frequency and the total reported crash frequency is computed.
3. 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 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 33. As shown in Table 33, the calibration coefficient appears to have significant variation across the 5-year period, although both total and fatal + injury crash frequencies are generally higher for 3-leg signalized intersections when compared to estimates obtained from the 3-leg minor-street stop-controlled intersection SPF. This suggests that the relationship between reported crash frequency on 3-leg signalized intersections 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 somewhat from the predictions using this method.

Table 33. Calibration factors for 3-leg signalized intersections

Total crash frequency			
Year	Reported crash frequency	Predicted crash frequency (3-leg minor stop-controlled SPF)	Calibration factor
2013	34	30.75	1.11
2014	37	30.43	1.22
2015	50	29.84	1.68
2016	41	29.64	1.38
2017	44	30.19	1.46
TOTAL	**206**	**150.85**	**1.37**
Fatal + injury crash frequency			
2013	15	13.25	1.13
2014	18	13.12	1.37
2015	25	12.87	1.94
2016	20	12.79	1.56
2017	17	13.02	1.31
TOTAL	**95**	**65.05**	**1.46**

If estimates of crash frequency on 3-leg signalized intersections are needed, we recommend first using the SPF for 3-leg minor stop-controlled intersections and then adjusting the estimates from the SPF by a multiplicative calibration factor to obtain the estimate of crash frequency at the 3-leg signalized intersection. The calibration factor for total crash frequency is 1.37 and the calibration factor for fatal + injury crash frequency is 1.46.

Appendix E: SPF Summary

TWO-LANE UNDIVIDED ROADWAY SEGMENTS

Table 34 and Table 35 provide the SPFs and county-specific adjustment factors for prediction of crash frequency on two-lane undivided roadway segments on urban-suburban collectors.

Table 34. Summary of district-level SPFs for two-lane undivided roadway segments

District 1:

$$N_{T,pr} = Length^{0.994} \times AADT^{0.447} \times e^{-3.204} \times e^{-0.212PSL45P} \quad \text{(E1)}$$

over-dispersion parameter: 0.598

$$N_{FI,pr} = Length^{0.852} \times AADT^{0.543} \times e^{-4.969} \quad \text{(E2)}$$

over-dispersion parameter: 0.924

District 2:

$$N_{T,pr} = Length^{0.514} \times AADT^{0.456} \times e^{-3.896} \times e^{0.0015DCPM} \times e^{0.301parking} \times e^{-0.180PSL45P} \quad \text{(E3)}$$

over-dispersion parameter: 0.218

$$N_{FI,pr} = Length^{0.673} \times AADT^{0.513} \times e^{-5.083} \times e^{0.0031DCPM} \times e^{0.333parking} \times e^{-0.359PSL45P} \quad \text{(E4)}$$

over-dispersion parameter: 0.518

District 3:

$$N_{T,pr} = Length^{0.498} \times AADT^{0.479} \times e^{-3.996} \quad \text{(E5)}$$

over-dispersion parameter: 0.582

$$N_{FI,pr} = Length^{0.564} \times AADT^{0.506} \times e^{-4.900} \quad \text{(E6)}$$

over-dispersion parameter: 0.657

District 4:

$$N_{T,pr} = Length^{0.720} \times AADT^{0.597} \times e^{-4.352} \times e^{0.309curb} \times e^{-0.539PSL45P} \quad \text{(E7)}$$

over-dispersion parameter: 0.363

$$N_{FI,pr} = Length^{0.554} \times AADT^{0.622} \times e^{-5.520} \times e^{0.371curb} \times e^{-0.346PSL45P} \quad \text{(E8)}$$

over-dispersion parameter: 0.436

District 5:

$$N_{T,pr} = Length^{0.509} \times AADT^{0.669} \times e^{-4.917} \times e^{0.0028DCPM} \times e^{-0.260PSL45P} \quad \text{(E9)}$$

over-dispersion parameter: 0.577

$$N_{FI,pr} = Length^{0.562} \times AADT^{0.679} \times e^{-5.740} \times e^{0.0024DCPM} \times e^{-0.240PSL45P} \quad \text{(E10)}$$

over-dispersion parameter: 0.611

District 6:

$$N_{T,pr} = Length^{0.615} \times AADT^{0.610} \times e^{-4.789} \times e^{0.0020DCPM} \times e^{0.118parking} \times e^{0.134curb} \quad \text{(E11)}$$

over-dispersion parameter: 0.517

$$N_{FI,pr} = Length^{0.626} \times AADT^{0.685} \times e^{-6.323} \times e^{0.0021DCPM} \times e^{0.304parking} \times e^{0.161curb} \quad \text{(E12)}$$

over-dispersion parameter: 0.578

District 8:

$$N_{T,pr} = Length^{0.636} \times AADT^{0.557} \times e^{-4.060} \times e^{0.103curb} \times e^{-0.192PSL45P} \times e^{0.279short\_seg} \quad \text{(E13)}$$

over-dispersion parameter: 0.586

$$N_{FI,pr} = Length^{0.665} \times AADT^{0.581} \times e^{-5.122} \times e^{-0.209PSL45P} \times e^{0.329short\_seg} \quad \text{(E14)}$$

over-dispersion parameter: 0.700

District 9:

$$N_{T,pr} = Length^{0.716} \times AADT^{0.669} \times e^{-5.007} \times e^{0.0008DCPM} \times e^{-0.121PSL45P} \quad \text{(E15)}$$

over-dispersion parameter: 0.343

$$N_{FI,pr} = Length^{0.729} \times AADT^{0.635} \times e^{-5.495} \quad \text{(E16)}$$

over-dispersion parameter: 0.412

District 10:

$$N_{T,pr} = Length^{0.694} \times AADT^{0.666} \times e^{-5.168} \quad \text{(E17)}$$

over-dispersion parameter: 0.643

$$N_{FI,pr} = Length^{0.789} \times AADT^{0.634} \times e^{-5.741} \quad \text{(E18)}$$

over-dispersion parameter: 0.523

District 11:

$$N_{T,pr} = Length^{0.390} \times AADT^{0.631} \times e^{-5.301} \times e^{0.0010DCPM} \times e^{0.205curb} \quad \text{(E19)}$$

over-dispersion parameter: 0.752

$$N_{FI,pr} = Length^{0.461} \times AADT^{0.614} \times e^{-5.868} \times e^{0.212curb} \quad \text{(E20)}$$

over-dispersion parameter: 0.813

District 12:

$$N_{T,pr} = Length^{0.585} \times AADT^{0.578} \times e^{-4.506} \times e^{0.304curb} \quad \text{(E21)}$$

over-dispersion parameter: 0.387

$$N_{FI,pr} = Length^{0.627} \times AADT^{0.621} \times e^{-5.570} \times e^{0.252curb} \quad \text{(E22)}$$

over-dispersion parameter: 0.245

$N_{T,pr}$	= predicted total crash frequency on the segment (crashes/year);
$N_{FI,pr}$	= predicted fatal + injury crash frequency on the segment (crashes/year);
$Length$	= segment length (mi);
$AADT$	= average annual daily traffic volume on the segment (veh/day);
$DCPM$	= 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)
$parking$	= presence of on-street parking (1 if present, 0 otherwise);
$curb$	= presence of a raised curb (1 if present, 0 otherwise);
$PSL45P$	= posted speed limit set to 45 mph or greater (1 if true, 0 otherwise); and
$short\_seg$	= segment is less than 0.1 mile long (1 if true, 0 otherwise).

Table 35. County-specific adjustments for district-level SPFs for two-lane undivided roadway segments

District	SPF	County	County-specific adjustment for total crash SPF	County-specific adjustment for fatal + injury SPF
1	Equations (E1, E2)	Crawford (20), Erie (25), Forest (27), Venango (60), Warren (61)	No modification necessary	No modification necessary
		Mercer (43)	Multiply estimate by 1.553	Multiply estimate by 1.756
2	Equations (E3, E4)	Cameron (12), Centre (14), Clearfield (17), Elk (24), Juniata (34), Potter (52)	No modification necessary	No modification necessary
		Clinton (18)	Multiply estimate by 0.653	No modification necessary
		McKean (42), Mifflin (44)	Multiply estimate by 1.316	Multiply estimate by 1.276
3	Equations (E5, E6)	Bradford (8), Columbia (19), Lycoming (41), Montour (47), Snyder (54), Tioga (58), Sullivan (56), Union (59)	No modification necessary	No modification necessary
		Northumberland (49)	Multiply estimate by 0.705	Multiply estimate by 0.702
4	Equations (E7, E8)	Lackawanna (35), Luzerne (40), Pike (51)	No modification necessary	No modification necessary
		Susquehanna (57), Wayne (63), Wyoming (65)	Multiply estimate by 0.720	Multiply estimate by 0.690
5	Equations (E9, E10)	Northampton (48)	No modification necessary	No modification necessary
		Berks (6), Lehigh (39)	Multiply estimate by 0.899	Multiply estimate by 0.872
		Carbon (13), Schuylkill (53)	Multiply estimate by 0.683	Multiply estimate by 0.661
		Monroe (45)	Multiply estimate by 1.403	Multiply estimate by 1.449
6	Equations (E11, E12)	Chester (15)	No modification necessary	No modification necessary

District	SPF	County	County-specific adjustment for total crash SPF	County-specific adjustment for fatal + injury SPF
		Bucks (9), Montgomery (46)	Multiply estimate by 1.205	Multiply estimate by 1.328
		Delaware (23), Philadelphia (67)	Multiply estimate by 1.439	Multiply estimate by 1.681
8	Equations (E13, E14)	Dauphin (22), York (66)	No modification necessary	No modification necessary
		Cumberland (21)	Multiply estimate by 0.813	Multiply estimate by 0.842
		Franklin (28)	Multiply estimate by 0.893	No modification necessary
		Lancaster (36)	Multiply estimate by 0.902	No modification necessary
		Adams (1), Lebanon (38), Perry (50)	Multiply estimate by 0.744	Multiply estimate by 0.784
9	Equations (E15, E16)	Blair (7), Fulton (29)	No modification necessary	No modification necessary
		Bedford (5), Cambria (11), Huntingdon (31)	Multiply estimate by 0.792	Multiply estimate by 0.752
		Somerset (55)	Multiply estimate by 0.815	Multiply estimate by 0.729
10	Equations (E17, E18)	Butler (10), Clarion (16), Indiana (32)	No modification necessary	No modification necessary
		Armstrong (3) , Jefferson (33)	Multiply estimate by 0.759	No modification necessary
11	Equations (E19, E20)	Allegheny (2), Beaver (4), Lawrence (37)	No modification necessary	No modification necessary
12	Equations (E21, E22)	Westmoreland (64)	No modification necessary	No modification necessary
		Fayette (26), Greene (30)	Multiply estimate by 0.872	No modification necessary
		Washington (62)	Multiply estimate by 0.768	Multiply estimate by 0.786

3-LEG MINOR-STREET STOP-CONTROLLED INTERSECTIONS

Table 36 and Table 37 provide the SPFs and district-specific adjustment factors for prediction of crash frequency on 3-leg minor-street stop-controlled intersections on urban-suburban collectors.

Table 36. Summary of statewide SPFs for 3-leg minor-street stop-controlled intersections

$$N_{T,3LMS} = (AADT_{major})^{0.517} \times (AADT_{minor})^{0.254} \times e^{-6.643} \times e^{-0.314 Major\_Crosswalk} \times e^{0.158 Major\_PSL40P} \quad \text{(E23)}$$

over-dispersion parameter: 0.454

$$N_{FI,3LMS} = (AADT_{major})^{0.513} \times (AADT_{minor})^{0.251} \times e^{-7.547} \times e^{0.218 Major\_PSL40P} \quad \text{(E24)}$$

over-dispersion parameter: 0.496

$N_{T,3LMS}$	= predicted total crash frequency at 3-leg minor-street stop-controlled intersection (crashes/year);
$N_{FI,3LMS}$	= predicted fatal + injury crash frequency at 3-leg minor-street stop-controlled intersection (crashes/year);
$AADT_{major}$	= annual average daily traffic volume on the major road approach (veh/day);
$AADT_{minor}$	= annual average daily traffic volume on the minor road approach (veh/day);
$Major\_Crosswalk$	= presence of a crosswalk on the major road approach (1 if present, 0 otherwise); and,
$Major\_PSL40P$	= posted speed limit set to 40 mph or greater on the major road approach (1 if true, 0 otherwise).

Table 37. District-specific adjustments for statewide SPFs for 3-leg minor-street stop-controlled intersections

District	District-specific adjustment for total crash SPF	District-specific adjustment for fatal + injury SPF
1	Multiply estimate by 0.580	Multiply estimate by 0.661
2	Multiply estimate by 0.434	Multiply estimate by 0.442
3	Multiply estimate by 0.434	Multiply estimate by 0.442
4	Multiply estimate by 0.731	No modification necessary
5	No modification necessary	No modification necessary
6	No modification necessary	No modification necessary
8	Multiply estimate by 0.813	Multiply estimate by 0.844
9	Multiply estimate by 0.727	Multiply estimate by 0.844
10	Multiply estimate by 0.580	Multiply estimate by 0.661
11	Multiply estimate by 0.580	Multiply estimate by 0.661
12	Multiply estimate by 0.727	Multiply estimate by 0.844

3-LEG ALL-WAY STOP-CONTROLLED INTERSECTIONS

Equations (E25) and (E26) provide the SPFs for prediction of crash frequency on 3-leg all-way stop-controlled intersections on urban-suburban collectors.

$$N_{T,3LAWS} = (AADT_{major})^{0.618} \times (AADT_{minor})^{0.534} \times e^{-10.160} \quad \text{(E25)}$$

$$N_{FI,3LAWS} = (AADT_{major})^{0.867} \times (AADT_{minor})^{0.498} \times e^{-12.692} \quad \text{(E26)}$$

where:

$N_{T,3LAWS}$ = predicted total crash frequency at 3-leg all-way stop-controlled intersection (crashes/year); and

$N_{FI,3LAWS}$ = predicted fatal + injury crash frequency at 3-leg all-way stop-controlled intersection (crashes/year).

4-LEG MINOR-STREET STOP-CONTROLLED INTERSECTIONS

Equations (E27) and (E28) provide the SPFs for prediction of crash frequency on 4-leg minor-street stop-controlled intersections.

$$N_{T,4LMS} = (AADT_{major})^{0.286} \times (AADT_{minor})^{0.643} \times e^{-6.594} \quad \text{(E27)}$$

$$N_{FI,4LMS} = (AADT_{major})^{0.377} \times (AADT_{minor})^{0.526} \times e^{-7.309} \quad \text{(E28)}$$

where:

$N_{T,4LMS}$ = predicted total crash frequency at 4-leg minor-street stop-controlled intersection (crashes/year); and

$N_{FI,4LMS}$ = predicted fatal + injury crash frequency at 4-leg minor-street stop-controlled intersection (crashes/year).

4-LEG ALL-WAY STOP-CONTROLLED INTERSECTIONS

Equations (E29) and (E30) provide the SPFs for prediction of crash frequency on 4-leg all-way stop-controlled intersections.

$$N_{T,4LAWS} = \left(AADT_{major} + AADT_{minor}\right)^{1.233} \times e^{-11.032} \quad \text{(E29)}$$

$$N_{FI,4LAWS} = \left(AADT_{major} + AADT_{minor}\right)^{0.830} \times e^{-8.297} \quad \text{(E30)}$$

where:

$N_{T,4LAWS}$ = predicted total crash frequency at 3-leg all-way stop-controlled intersection (crashes/year); and

$N_{FI,4LAWS}$ = predicted fatal + injury crash frequency at 3-leg all-way stop-controlled intersection (crashes/year).

4-LEG SIGNALIZED INTERSECTIONS

Equations (E31) and (E32) provide the SPFs for prediction of crash frequency on 4-leg signalized intersections. The recommended SPF is as follows:

$$N_{T,4LSIG} = \left(AADT_{major}\right)^{0.542} \times \left(AADT_{minor}\right)^{0.308} \times e^{-6.884} \quad \text{(E31)}$$

$$N_{FI,4LSIG} = \left(AADT_{major}\right)^{0.684} \times \left(AADT_{minor}\right)^{0.333} \times e^{-9.127} \quad \text{(E32)}$$

where:

$N_{T,4LSIG}$ = predicted total crash frequency at 4-leg signalized intersection (crashes/year); and

$N_{FI,4LSIG}$ = predicted fatal + injury crash frequency at 4-leg signalized intersection (crashes/year).