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SUBJECT:

Pennsylvania Safety Predictive Analysis Methods Manual

INFORMATION AND SPECIAL INSTRUCTIONS:

The 2021 Edition of Publication 638A: *Pennsylvania Safety Predictive Analysis Methods Manual* supersedes the May 2018 Edition and all subsequent changes. These new guidelines should be adopted in all District/County highway safety practices as soon as practical without affecting any letting schedules.

This release includes the addition of three new chapters:

- Chapter 3: Freeway and Ramp PA Calibration Factors
- Chapter 4: PA Network Screening Process
- Chapter 5: HSM Part D CMF Methods

Additions, deletions, and revisions to each chapter/appendix are as follows:

GENERAL REVISIONS

- Revised term overdispersion factor to overdispersion parameter throughout
- Revised term local adjustment factor to calibration factor throughout where applicable to differentiate from adjustment factors used in SPF equations and to be consistent with HSM terminology.
- All references to Part C CMFs were revised to SPF adjustment factors or base condition factors.
- References to the PA CMF Guide were deleted and redirected to the CMF Clearinghouse website
- Removed all old hyperlinks and added new hyperlinks where appropriate.
- Updated references and links to current, and applicable highway safety-oriented websites and tools such as PCIT, PennDOT HSM tools, CMF Clearinghouse, etc.
- Updated VideoLog screen captures to reflect current version of VideoLog.

TABLE OF CONTENTS

- Updated to reflect the changes being implemented and for consistency

CHAPTER 1 – BASICS

- Section 1.1. Added concept of "excess crash frequency' explanation and diagram.
- Section 1.2. Added terms to Acronyms, Glossary, and Equation Variables lists.
- Section 1.5. Added reference to freeway and ramp calibration factors method of local adjustment to HSM.
- Section 1.5. Added urban-suburban collector segment and urban-suburban collector intersections facility type references to Table 1.5. Removed freeway segment facility type reference from Table 1.5.
- Section 1.7 through 1.9. Relocated content in former Section 1.7 (Countermeasure Evaluation) to new Chapter 5 and replaced Section 1.7 with new content on basics of network screening. Relocated remaining basics of countermeasure evaluation introductory information from former Section 1.7 to Section 1.8 and reassigned remaining sections.

CHAPTER 2 – UTILIZING PENNSYLVANIA REGIONALIZED SAFETY PERFORMANCE FUNCTIONS FOR THE HSM PART C PREDICTIVE METHOD

- Section 2.1. Added urban-suburban collector segment and collector intersections facility type references to Table 2.1-1. Removed Freeway Segment facility type reference from Table 2.1-1.
- Section 2.1. Removed former Step 3 from Pennsylvania Highway Safety Predictive Analysis Method process flow. Incorporated this step into existing steps. Relocated and reworded former Step 7 to Step 3 with guidance on gathering historical crash data.
- Section 2.2 through 2.13. Revised with new content by adding crash type and severity tables to each facility type reference section.
- Section 2.6 through 2.13. Added sections for urban-suburban collector segments and intersections and reassigned remaining sections.
- Section 2.11. Removed former Section 2.11 on PA specific SPFs for rural freeway segments. Added Chapter 3 to describe PA calibration factors for HSM predictive method for freeway and freeway ramp analysis.

CHAPTER 3 – UTILIZING PENNSYLVANIA CALIBRATION FACTORS FOR THE HSM PREDICTIVE METHOD FOR FREEWAYS AND RAMPS (new chapter)

- Section 3.1 through 3.4. New chapter added with new content.

CHAPTER 4 – PENNDOT NETWORK SCREENING (new chapter)

- Section 4.1 through 4.5. New chapter added with new content.

CHAPTER 5 – COUNTERMEASURE EVALUATION AND CMF COMBINATION METHODS (new chapter)

- Section 5.1 through 5.4. New chapter added with new content and incorporated former Section 1.7: Countermeasure Evaluation into new Chapter 5, Sections 5.1 and 5.2.
- Section 5.3 and 5.4. Added new content on CMF combination methods.

APPENDIX A – ROADSIDE HAZARD RATING DETERMINATION

- Added footnotes to clarify pavement edgeline references.
- Updated all video log screen captures to reflect current edition of VideoLog.

APPENDIX B – DEGREE OF CURVATURE PER MILE DETERMINATION

- Updated hyperlinks.
- Corrected graphics error in figure B-10.

APPENDIX C – EXAMPLE CALCULATIONS

- Updated. Replaced old example problem with new example problems to provide more specific detail for intersection analysis and segment analysis.

CANCEL AND DESTROY THE FOLLOWING:

May 2018 and any other previous editions of Publication 638A

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Pennsylvania Safety
Predictive Analysis Methods Manual

pennsylvania
DEPARTMENT OF TRANSPORTATION

PUB 638A (5-21)

Chapter 1 — Basics

1.1 Introduction

The predictive method provides a quantitative measure included in the 2010 American Association of State Highway and Transportation Officials (AASHTO), *Highway Safety Manual* (HSM), for estimating the predicted and expected average crash frequency of a network, corridor, or individual location. Beginning with the release of the 2010 HSM, the predictive method has been adopted as the preferred method for conducting crash analysis, identifying crash locations that could most benefit from corrective measures, and evaluating the potential effectiveness of particular countermeasures. Outcomes of the predictive method can also be used to inform network screening and project prioritization.

The purpose of this document is to detail Pennsylvania's interpretation, adjustments, and applications of the 2010 HSM so that highway safety practitioners have Pennsylvania specific guidance to apply when conducting the predictive method. PennDOT has contracted with the Pennsylvania State University and engineering consulting firms to develop the specific modifications necessary to enable Pennsylvania practitioners to generate accurate results when using the HSM predictive method. The research and reports, which this publication is based upon, are referenced in Section 1.9.

The PennDOT Highway Safety Analysis Tool, which automates the PA regionalized HSM predictive method calculations, and the Pennsylvania calibrated Freeway and Ramp Analysis Tool (ISATe (PA Calibrated)), which automates freeway and ramp HSM predictive method calculations, are available on the PennDOT Safety Infrastructure Improvement Program website, which can be accessed at the following link https://www.penndot.gov/TravelInPA/Safety/Pages/Safety-Infrastructure-Improvement-Programs.aspx.

The following is an introduction to the HSM predictive method process along with commonly used terms derived from the Federal Highway Administration (FHWA) document *Scale and Scope of Safety Assessment Methods in the Project Development Process*, https://safety.fhwa.dot.gov/rsdp/hsm.aspx.

A **safety performance function (SPF)** is a statistically derived equation that estimates (or predicts) the average number of crashes per year likely to occur considering roadway type (e.g., two-way two-lane roadways or urban arterial) and traffic volume. Using SPFs can enhance predictive reliability by taking advantage of crash information for other similar roadways and not relying solely on recent crash history (observed crashes) for the specific roadway to be treated.

When site-specific geometric conditions are known, adjustment factors can be used with SPFs to provide more refined insights into the predicted safety performance (resulting in a calculated predicted number of crashes for roadways with similar conditions).

Combining observed crash data with predicted crash values (calculated using the adjustment factors and SPF combination) can further improve the predictive reliability of crash prediction methods for a specific location (resulting in a calculated expected number of crashes).

This general process of the HSM predictive method is illustrated in Figure 1-1.

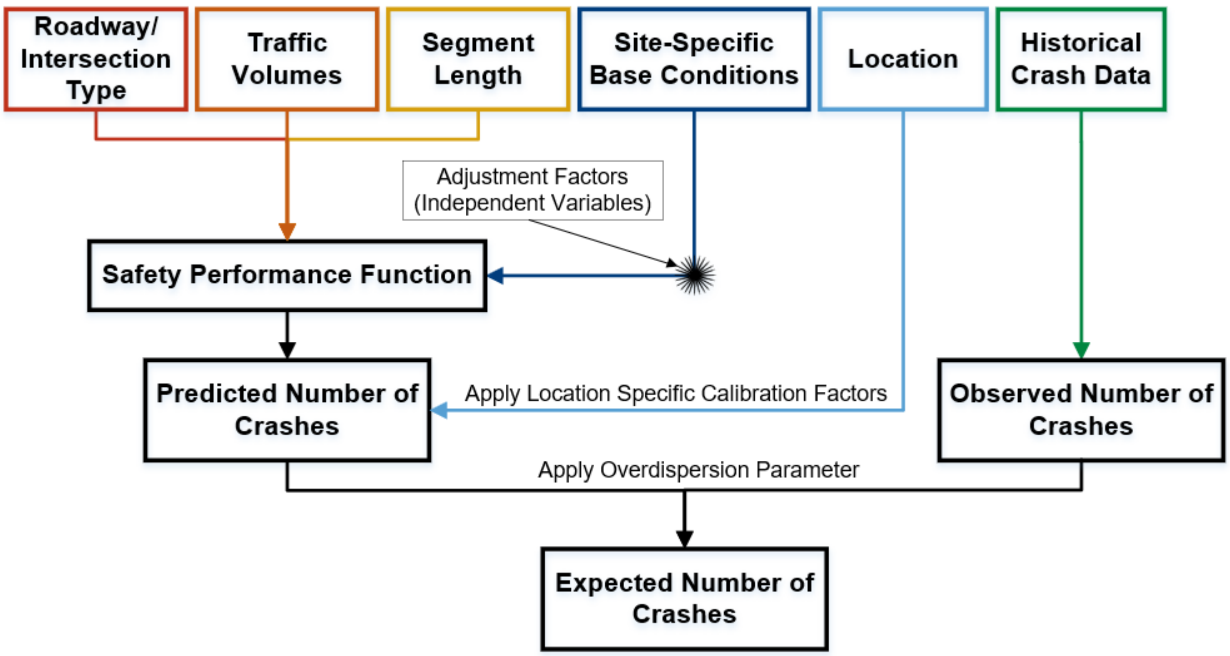

Figure 1-1: HSM Predictive Method Process

In summary, the three levels of analysis presented in the HSM are observed, predicted, and expected:

Observed (Basic): Historical crash data for a location will tend to fluctuate over time, but an average (or mean) value can be calculated using data from multiple years. These average historical crash values are referred to as observed crashes.

Predicted (Intermediate): Using information from facilities with similar roadway types and volumes is likely to strengthen the reliability of the estimation of future crashes by considering the performance of more sites with more crashes. This additional information is presented in the format of SPFs, site-specific equation adjustments, and location specific calibration factors, and captures the effects of varying traffic volumes and road geometry. This type of data strengthens the estimate for typical roads with the varying volumes and geometry and so is referred to as predicted crashes.

Expected (Advanced): Weighting the site-specific crashes (observed) with the crash estimates for similar roads (predicted) further improves the reliability for predicted crashes. The 2010 HSM refers to these estimates as expected crashes.

Using the HSM predictive method can yield both a predicted number of crashes from the SPF equation and an expected number of crashes by considering predicted and observed crashes together through the use of the Empirical Bayes (EB) method. The expected number of crashes is a statistical adjustment or 'correction' of the observed number of crashes at the location to account for the unpredictable nature of actual crash occurrences (due to such things as driver behavior, annual fluctuation, etc.). The potential for safety improvement for a particular location (or network) will be reflected in the difference between the expected number of crashes and the predicted number of crashes. This is graphically represented in Figure 1-2. This difference in expected number of crashes and predicted number of crashes is computed as an 'excess crash frequency'. A positive excess crash frequency shows a potential for safety improvement, while a negative excess crash frequency indicates there are fewer expected crashes than predicted. The greater the difference between the expected number of crashes and the predicted number of crashes (excess crash frequency), the greater the potential for safety improvement. If the expected number of crashes is fewer than the predicted number of crashes, the excess crash frequency will be negative and it is assumed there is little room for safety improvement.

Safety can be improved at sites with low or negative excess crash frequencies if changes associated with base conditions in the model are changed. For example, the PA regionalized SPF for a three-leg signalized intersection includes a term for the presence of an exclusive left-turn lane. If such an intersection did not have an exclusive left-turn lane, the SPF would account for this and predict a different number of crashes than if the intersection did have an exclusive left-turn lane. Expected crashes associated with the exclusive left-turn lane would not be 'excess', but the expected number of crashes would be different if an exclusive left-turn lane were implemented.

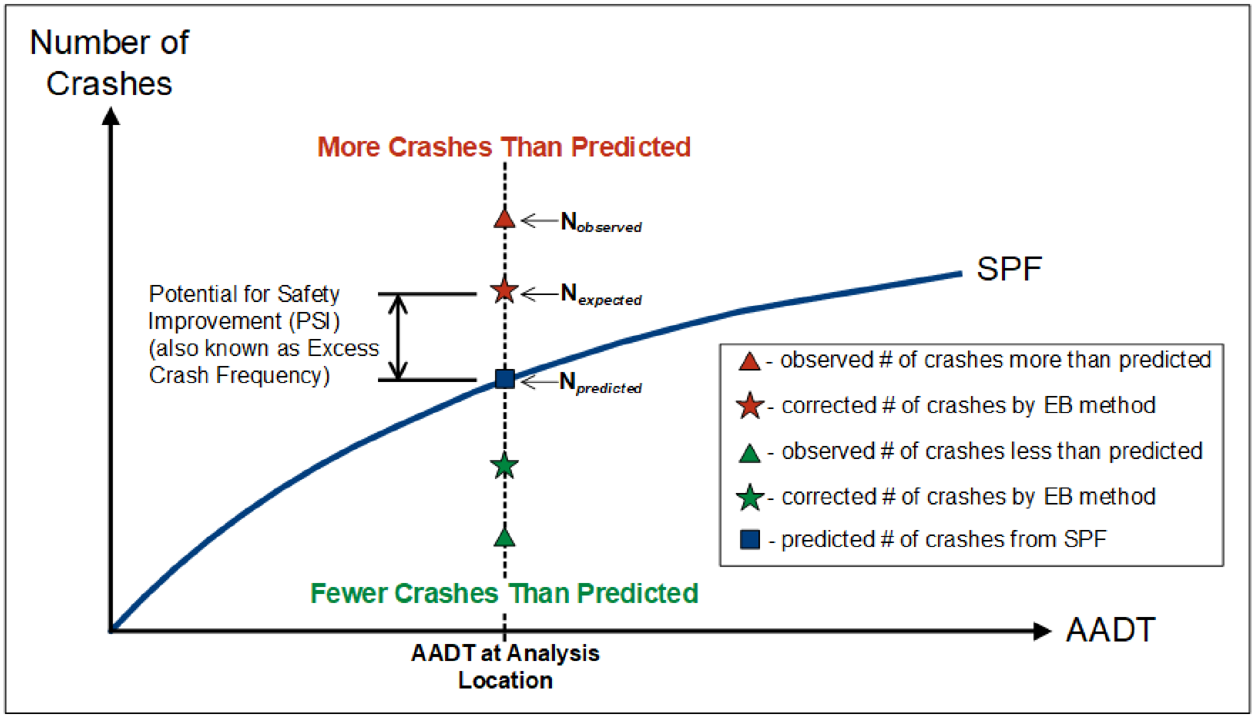

Figure 1-2: HSM Method – Potential for Safety Improvement

More detailed explanations of the HSM predictive method concepts and their applicability in project development and alternatives analysis are provided in PennDOT Publication 638, *District Highway Safety Guidance Manual*, Chapter 5, the HSM, and FHWA's *Scale and Scope of Safety Assessment Methods in the Project Development Process*, FHWA-SA-16-106.

1.2 Acronyms, Glossary, Equation Variables

1.2.1 Acronyms

AADT – Annual Average Daily Traffic
AASHTO – American Association of State Highway and Transportation Officials
C-D Road – Collector-Distributor Road
CDART – PennDOT Crash Data Analysis and Retrieval Tool
CMF – Crash Modification Factor
CRF – Crash Reduction Factor
EB – Empirical Bayes
F&I – Fatal and Injury
FHWA – Federal Highway Administration
HSM – *Highway Safety Manual*
HSTOD – PennDOT Highway Safety and Traffic Operations Division
IHSDM – Interactive Highway Safety Design Module
ISATe – Enhanced Interchange Safety Analysis Tool
KABCO – Highway Crash Injury Classification Scale

- K – Fatal Injury
- A – Suspected Serious Injury
- B – Suspected Minor Injury
- C – Possible Injury & Unknown Injury
- O – No Injury (Property Damage Only)

PDO – Property Damage Only
PennDOT – Pennsylvania Department of Transportation
PSI – Potential for Safety Improvement
RHR – Roadside Hazard Rating (see Appendix A)
SPF – Safety Performance Function
VPD – Vehicles Per Day

1.2.2 Glossary

Adjustment Factor – Adjustment factors are used in the predictive method (2010 HSM Part C). They are applied within the SPF to adjust the assumed base conditions from which the original SPF equation was derived. In the 2010 HSM these are referred to as Crash Modification Factors (CMFs). However, they are not in the same format, nor are they applied in the same manner, as the 2010 HSM Part D CMFs.

Calibration Factor – A factor applied to crash frequency estimates produced from SPFs to adjust for local conditions (such as variations in police reporting, local driver behavior, etc.). The factors have been computed by comparing existing crash data at the state, regional, or local level to estimates generated with predictive models (SPFs).

CMF – Crash Modification Factor – A statistically derived adjustment factor used to determine the expected outcome of applying a particular countermeasure (2010 HSM Part D). CMFs are applied to the expected crash frequency to reflect the implementation of specific countermeasures. A CMF value between 0 and 1.00 indicates a countermeasure is expected to reduce crashes, and a value greater than 1.00 indicates the countermeasure is expected to increase crashes.

Countermeasure – Changes or modifications implemented to address a particular crash type, location, or element. Countermeasures can address physical attributes, operational attributes, or education and enforcement efforts.

CRF – Crash Reduction Factor – A statistically derived adjustment factor used to estimate the predicted reduction in expected crashes as a result of implementing a particular countermeasure.

EB – Empirical Bayes Method – Statistical method most applicable for adjusting the observed number of crashes at a particular location to account for the random nature of crash occurrences. This is accomplished by using the overdispersion parameter (*k)* to derive an adjustment factor (*w)* as described in Section 1.4.

Excess Crash Frequency – The difference between the expected number of crashes ($\mathbf{N}_{expected}$) and the predicted number of crashes ($\mathbf{N}_{predicted}$) from an SPF is referred to as Excess Crash Frequency. This is also known as the PSI. This value estimates how much the long-term crash frequency could be reduced at a particular site.

Expected Crashes – An estimated number of crashes determined by weighting the predicted and observed crash frequencies using the Empirical Bayes (EB) Method.

$N_{expected}$ – The annual number of crashes expected utilizing the 2010 HSM Part C predictive method after applying the EB method.

$N_{observed}$ – The annual average number of crashes observed at the location being studied based on historical crash data.

$N_{predicted}$ – The annual number of crashes predicted using the SPF equations, base condition adjustments, and calibration factors during the 2010 HSM Part C predictive method.

Observed Crashes – The historical number of crashes that are reported at a site of interest.

Overdispersion Parameter (*k*) – A statistical measure which represents the accuracy of SPF calibration. Used to compute *w* in the EB method

PSI – Potential for Safety Improvement – The difference between the expected number of crashes (**$N_{expected}$**) and the predicted number of crashes (**$N_{predicted}$**) from an SPF is referred to as potential for safety improvement, or PSI. This is also known as the Excess Crash Frequency. This value estimates how much the long-term crash frequency could be reduced at a particular site.

Predicted Crashes – An estimate of number of crashes that may typically occur on a roadway. Prediction is arrived at using equations that consider crash trends for similar traffic volumes and road geometry (presented in the form of SPFs and adjustment factors). This type of data strengthens the estimate for typical roads with the varying volumes and geometry so is referred to as Predicted Crashes.

Predictive Method – A mathematical, statistically derived, method for predicting estimated crash rates based on roadway characteristics, annual average daily traffic (AADT) and the area being evaluated.

SPF – Safety Performance Function – The basic equation developed for each type of roadway location which is used as the preliminary estimate (prior to applying calibration factors) for the predictive method.

2016 PSU Report – The Pennsylvania Department of Transportation report entitled *Regionalized Safety Performance Functions Final Report,* January 8, 2016, by Eric Donnell, Vikash Gayah, and Lingyu Li, The Pennsylvania State University.

2019 PSU Report – The Pennsylvania Department of Transportation report entitled *Regionalized Urban-suburban Collector Road Safety Performance Functions Final Report,* March 14, 2019, by Eric Donnell, Vikash Gayah, Lingyu Li and Houjun Tang, The Pennsylvania State University.

1.2.3 Equation Variables

More detailed definitions of equation variables and how they are used in the SPF equations are provided at the beginning of each applicable section of Chapter 2.

AADT – Annual Average Daily Traffic (veh/day)
AD – Access Density (access points/mile)
Barrier – Presence of Median Barrier
Curb – Presence of Raised Curb
CRS – Presence of Centerline Rumble Strips
CTL – Presence of Center Two-way Left-turn Lane
DCPM – Degree of Curvature per Mile (in the segment – deg/100 ft./mile)
e – Euler's Number (used in natural exponential function/natural logarithm)
ELT – Presence of Exclusive Left-Turn Lane
ERT – Presence of Exclusive Right-Turn Lane
HCD – Horizontal Curve Density (number of curves/ mile)
k – Overdispersion Parameter
L – Length of Segment (miles)
LTL – Presence of Median Left-turn Lane
N – Number of Crashes

- $N_{expected}$ is the annual number of crashes expected utilizing the 2010 HSM Part C predictive method after applying the EB method.
- $N_{observed}$ is the annual average number of crashes observed at the location being studied based on historical crash data.
- $N_{predicted}$ is the annual number of crashes predicted using the SPF (including base condition adjustments) and location specific calibration factors during the 2010 HSM Part C predictive method.
- N_{spf} is the annual number of crashes generated utilizing an SPF equation.

Parking Lane – Presence of Formal Parking Lane
PSL – Posted Speed Limit (miles/hour)
PSL## – Presence of Posted Speed Limit (greater than ## or within ## range)
PZ – Presence of Passing Zone
RHR## – Presence of Roadside Hazard Rating (of ## or within ## range)
Seg## – Presence of Roadway Segment (less than ## mile long or within ## mile range)
Skew – Intersection Skew (90-angle in degrees)
SRS – Presence of Shoulder Rumble Strips
w – Adjustment factor used in the EB equation (calculated using the given SPF overdispersion parameter (*k*))
Walk – Presence of Pedestrian Crosswalk

1.3 Basics of the Predictive Method

At the most basic level, the predictive method of crash analysis involves applying site-specific information to predetermined equations to estimate a predicted and an expected crash frequency for a particular location. Lengths of roadways (referred to as segments) or intersections can be analyzed. Locations can be aggregated to determine predicted and expected crash frequencies for a network or corridor. The equations used in this process are called Safety Performance Functions (SPFs) and have a basic format of:

Predicted Number of Crashes using SPF = Short Preliminary Equation x Base Condition Adjustment Factors

The PennDOT Regionalized SPF equations typically take the following form:

$$N_{spf} = (e^{x_1} \times L \times AADT^{x_2}) \times e^{x_3 \times AF_1} \times e^{x_4 \times AF_3} \times e^{x_5 \times AF_3} \ldots$$

Unique SPF equations are developed for each type of roadway facility, for example the total crash SPF equation for a two-lane rural roadway segment in PennDOT District 12 is the following:

$$N_{spf} = (e^{-4.948} \times L \times AADT^{0.630}) \times e^{-0.153PZ} \times e^{0.015AD} \times e^{0.002DCPM}$$

The development of the SPF equations assumes a particular set of base conditions (which vary by roadway type). When the site-specific base conditions are different than the SPF assumed base conditions, the adjustment factors (AF_1, AF_2, AF_3) are accounted for in modifications to the '*e*' exponents.

There are three basic steps to estimating expected crash frequency using the Pennsylvania Regionalized HSM Part C predictive method equations (SPFs):

- Step 1 – Define study location (e.g., intersection, analysis segment, network, etc.) and gather data needed to input into associated SPF equation(s). Note that analysis segments are **not** the same as the 'segments' referred to in the PennDOT roadway (segment/offset) inventory system. Section 1.6 describes the criteria for establishing a segment for analysis purposes.

- Step 2 – Calculate the estimated number of crashes ($\mathbf{N}_{predicted}$) using the SPF equation ($\mathbf{N}_{spf}$) and location specific calibration factors. The short preliminary equation and base condition adjustment factors are included in the PA regionalized SPF equations; as a result, the computation of both a preliminary crash estimate based on basic inputs (L and AADT) and adjustments based on the site's differences from base conditions occurs simultaneously. This step includes making the base condition variable modifications to the exponents in the equation and applying the location specific calibration factor(s).
- Step 3 – Use the Empirical Bayes (EB) statistical method to adjust the observed crash history based on the 'predicted' number of crashes estimated at the location being analyzed. The EB method is described in more detail in Section 1.4 below. Basically, EB involves applying an overdispersion parameter (which is given with each SPF equation) to a 2-step equation which uses the predicted number of crashes determined in Step 2 and the observed number of crashes from the site's crash history (information that was gathered during the preparation phase(Step 1)). The EB adjusted observed crash history will yield an 'expected' number of crashes for the specific location ($\mathbf{N}_{expected}$).

Following these three steps, this method will estimate both the 'predicted' ($\mathbf{N}_{predicted}$) and the 'expected' ($\mathbf{N}_{expected}$) number of crashes which can then be used to compare projects for prioritization purposes. A location that experiences more 'expected' crashes than 'predicted' will likely benefit from implementation of countermeasures more than a site that experiences fewer 'expected' crashes than 'predicted'. The three-step process is summarized in Figure 1-3.

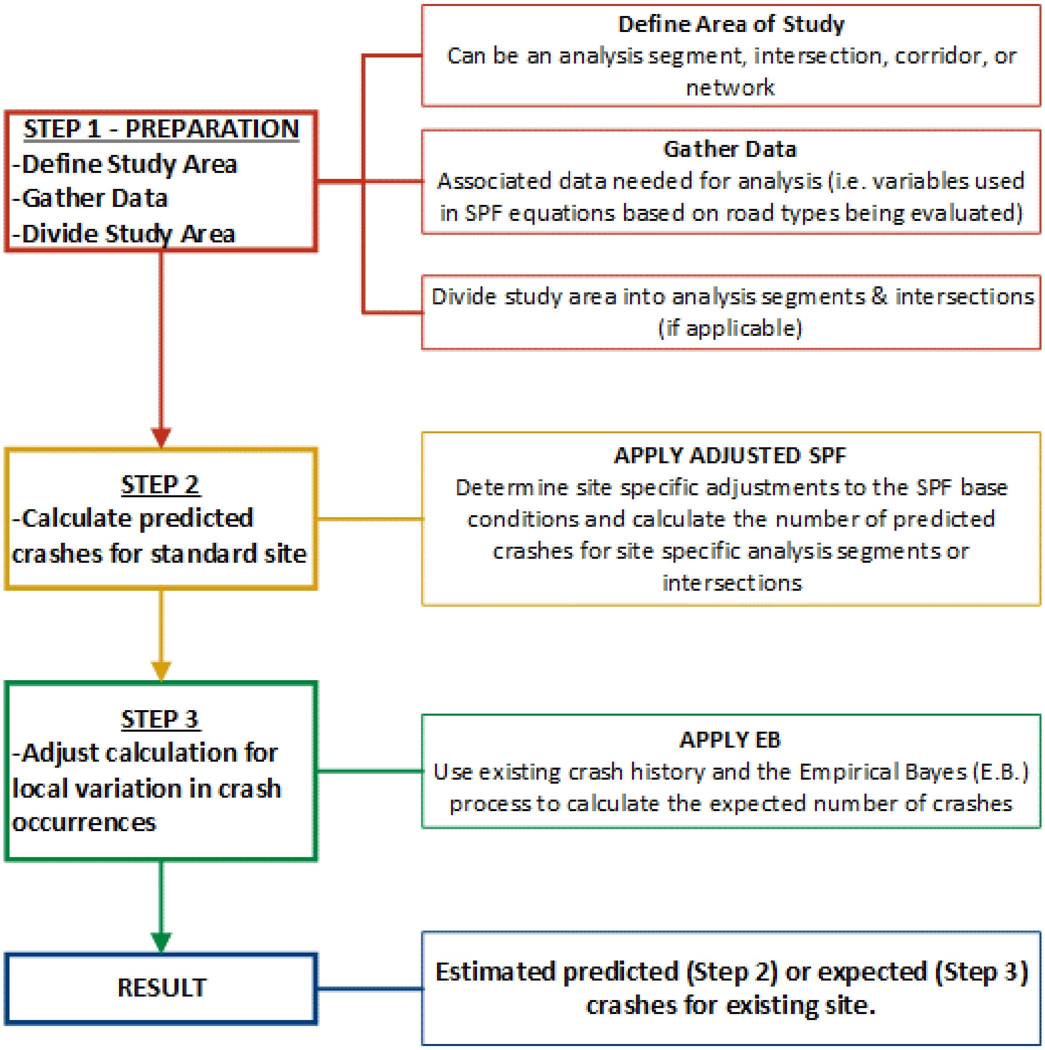

Figure 1-3: Pennsylvania Regionalized Predictive Method Analysis Process

For limitations on HSM analysis, please refer to the HSM or the 2016 PSU Report.

1.4 Basics of Using the Empirical Bayes Method

When historical observed crash data is available for a location being analyzed, the 2010 HSM Part C predictive method includes statistically weighing the observed and predicted number of crashes to derive an expected number of crashes using the Empirical Bayes (EB) method. When more years of historical crash data are available, more weight/credence is given to the observed data. When an SPF equation with little overdispersion is available, more reliance will be placed on the predictive model. The rationale and details of this method are described in more detail in Chapter C.6.6 of the 2010 HSM and in Appendix A of Volume 2 of the 2010 HSM.

There are two equations utilized when applying the EB Method to the Pennsylvania HSM Part C predictive method (Step 3 in Figure 1-3 above) to determine the expected number of crashes ($\mathbf{N}_{expected}$). These equations have been adapted from the 2010 HSM equations A-4 and A-5 (Volume 2, page A-19). The equations take the basic form:

Equation 1:

$$w = \frac{1}{1 + \frac{k}{L} \times \left(\sum_{\text{all study years}} N_{predicted} \right)}$$

Equation 2:

$$N_{expected} = w \text{ x } N_{predicted} + (1.00 - w) \text{ x } N_{observed}$$

- $\mathbf{N}_{expected}$ is the annual number of crashes expected utilizing the 2010 HSM Part C predictive method after applying the EB method.
- $\mathbf{N}_{predicted}$ is the annual number of crashes predicted using the SPF equation(s), base condition adjustments, and location specific calibration factors during the 2010 HSM Part C predictive method.
- $\mathbf{N}_{observed}$ is the annual average number of crashes observed at the location being studied based on historical crash data.
- ***k*** is the overdispersion parameter (given with each SPF equation).
- ***w*** is the adjustment factor used in the EB equation (calculated using the given SPF overdispersion parameter (k)).
- ***L*** is the length (miles) of the segment being analyzed (when analyzing an intersection use L=1).

The calculation for $\mathbf{N}_{expected}$ is completed by plugging data obtained in the Preparation Step and Step 2 (shown in Figure 1-3) into Equations 1 and 2. Note that once w is computed using the given overdispersion parameter (k), $\mathbf{N}_{expected}$ is the only unknown variable and is easily computed.

For more information on the applicability of using the EB method in the analysis process refer to FHWA Publication SA-16-106, *Scale and Scope of Safety Assessment Methods in the Project Development Process*. This FHWA publication explains when improvements are different enough from the existing condition that it is not appropriate to consider observed crashes and use the EB method.

1.5 Pennsylvania Revisions to HSM Predictive Method

The HSM predictive method (2010 HSM Part C) requires adjustments for local conditions to yield accurate results. There are two options for adjustment:

> **Option 1** - Create local adjustment factors to approximate local conditions by comparing existing crash data at the state, regional or local level with crash frequency estimates obtained from the HSM predictive models. The location based factors are referred to as 'calibration' factors and are used to adjust modify the HSM SPF equations. These are referred to as C_x in the 2010 HSM basic SPF equations (See page C-4 of the 2010 HSM).

OR

> **Option 2** - Create location specific SPFs and adjustment factors.

PennDOT has chosen '**Option 1 –** Create local adjustment factors (calibration factors) to modify HSM SPF equations utilizing these calibration factors' for freeways, freeway ramps, and ramp terminals (intersections). Chapter 3 of this document provides details on the PA specific calibration factors for freeways, as well as instructions for implementing calibration factors.

For all other roadway types, PennDOT has chosen '**Option 2** – Create location specific variations to the base SPF equations' using the 2016 PSU Report and the 2019 PSU Report. These reports provide the Pennsylvania SPF equations and corresponding assumed base conditions to be utilized in lieu of the HSM roadway facility type SPFs. The regionalized PA specific equations, corresponding base conditions, and location specific calibration factors from the reports, as well as instructions for implementing the predictive method utilizing the PA equations and calibration factors, are provided in Chapter 2 of this publication. The PA specific SPFs provided are shown in Table 1.5-1.

Table 1.5-1: Roadway Facility Types with PA Regionalized SPFs Developed

Roadway Facility Type	
Two-lane rural roadway segments	All segments
Two-lane rural roadway intersections	3-leg intersections with minor-street stop control
	4-leg intersections with minor-street stop control
	4-leg intersections with all-way stop control
	3-leg intersections with signal control
	4-leg intersections with signal control
Rural multilane highway segments	All segments
Rural multilane highway intersections	3-leg intersections with minor-street stop control
	4-leg intersections with minor-street stop control
	4-leg intersections with signal control
Urban-suburban collector segments	Two-lane undivided collectors
Urban-suburban collector intersections	3-leg intersection with minor-street stop control
	3-leg intersection with signal control
	3-leg intersection with all-way stop control
	4-leg intersection with minor-street stop control
	4-leg intersection with all-way stop control
	4-leg intersection with signal control
Urban-suburban arterial segments	Two-lane undivided arterials
	Four-lane undivided arterials
	Four-lane divided arterials
Urban-suburban arterial intersections	3-leg intersections with minor-street stop control
	4-leg intersections with minor-street stop control
	3-leg signalized intersections
	4-leg signalized intersections
	4-leg all-way stop-controlled intersections
	5-leg signalized intersections

1.6 Determining Analysis Segments

A study area can be comprised of a short or long length of roadway, an intersection, a corridor (a combination of roadway segments and/or intersections), or a network of roadways. SPF equations can only be used on homogenous segments, meaning that the study area may need to be broken into multiple segments, with different SPF inputs for each segment.

Segments in a study area must be divided/separated when any of the base conditions change (e.g. roadway type, number of lanes, or AADT) across the study area or when any of the base condition independent variables (adjustment factors) change across the study area. Because the base conditions and adjustment factors are different between the HSM SPF equations and the Pennsylvania regionalized SPF equations, the sectioning of an analysis area will also be different.

In the predictive method an analysis segment is a length of roadway that is consistent in roadway type, number of lanes, AADT, and adjustment factors. (An analysis segment is NOT related to the PennDOT roadway inventory ‘segment/offset’ system.) There is a notable difference in the sectioning of analysis segments when utilizing the Pennsylvania regionalized SPFs versus the HSM SPFs.

For rural two-lane roadway Pennsylvania SPFs, the length of the segment can include many curves (which is included in the DCPM adjustment factor), as well as intersections. Intersections can be accounted for in the access density (AD) adjustment factor when conducting higher level or network screening type analysis in the Pennsylvania SPF analysis, however, intersection crashes must be removed from the observed crash data when analyzing the segment. Intersections must be separated and analyzed independently with their own SPF equation for more focused analysis.

In contrast, for the HSM SPF analysis, segments must be separated at horizontal curves and at intersections; since these attributes are not accounted for in the HSM adjustment factors. Thus, utilizing the PA SPFs typically require fewer analysis segments than utilizing the HSM SPFs for the same roadway length. These particular differences in separating analysis segments between the Pennsylvania SPFs and the HSM SPFs are illustrated in Figure 1-4 and Figure 1-5.

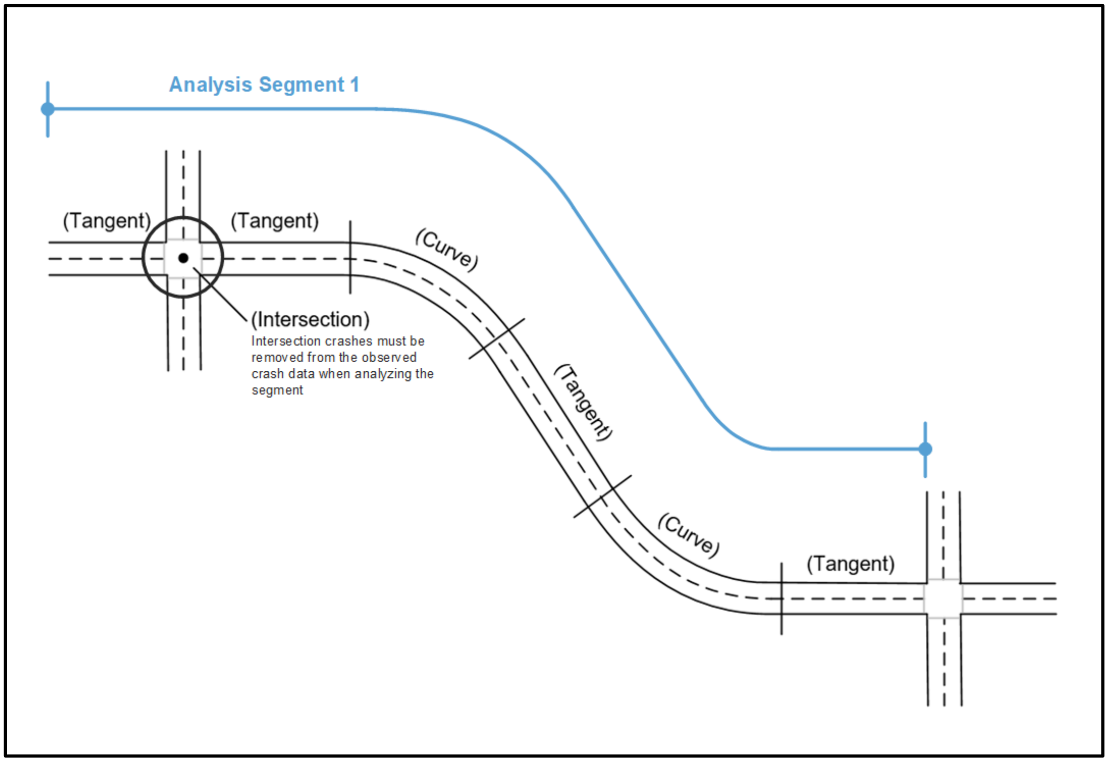

Figure 1-4: PA Regionalized SPF Segmentation

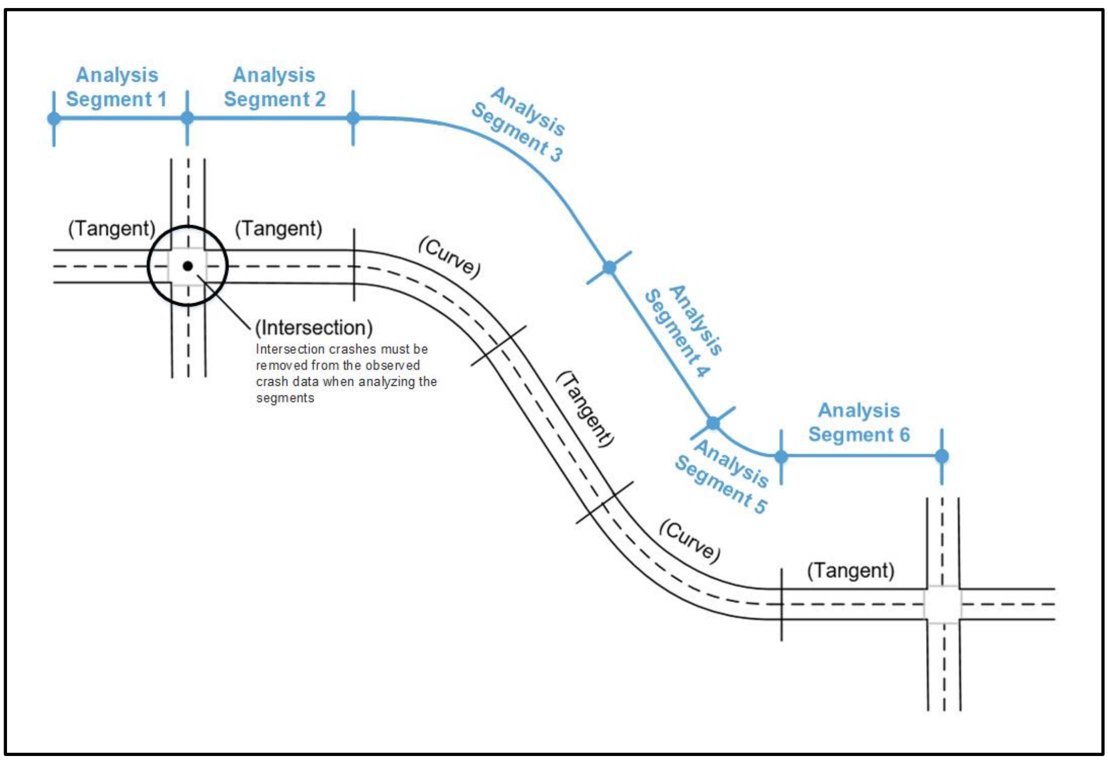

Figure 1-5: HSM SPF Segmentation

1.7 Basics of Network Screening

Network screening is a process for evaluating and ranking sites within a roadway network to identify those most likely to exhibit a reduction in crashes as a result of the implementation of countermeasures.

The predictive method (as described in Section 1.1) can be used to determine the excess crash frequency of sites across the network, which can then be used to identify sites with the greatest potential for safety improvements.

In general, the network screening process involves five major steps, shown in Figure 1-6.

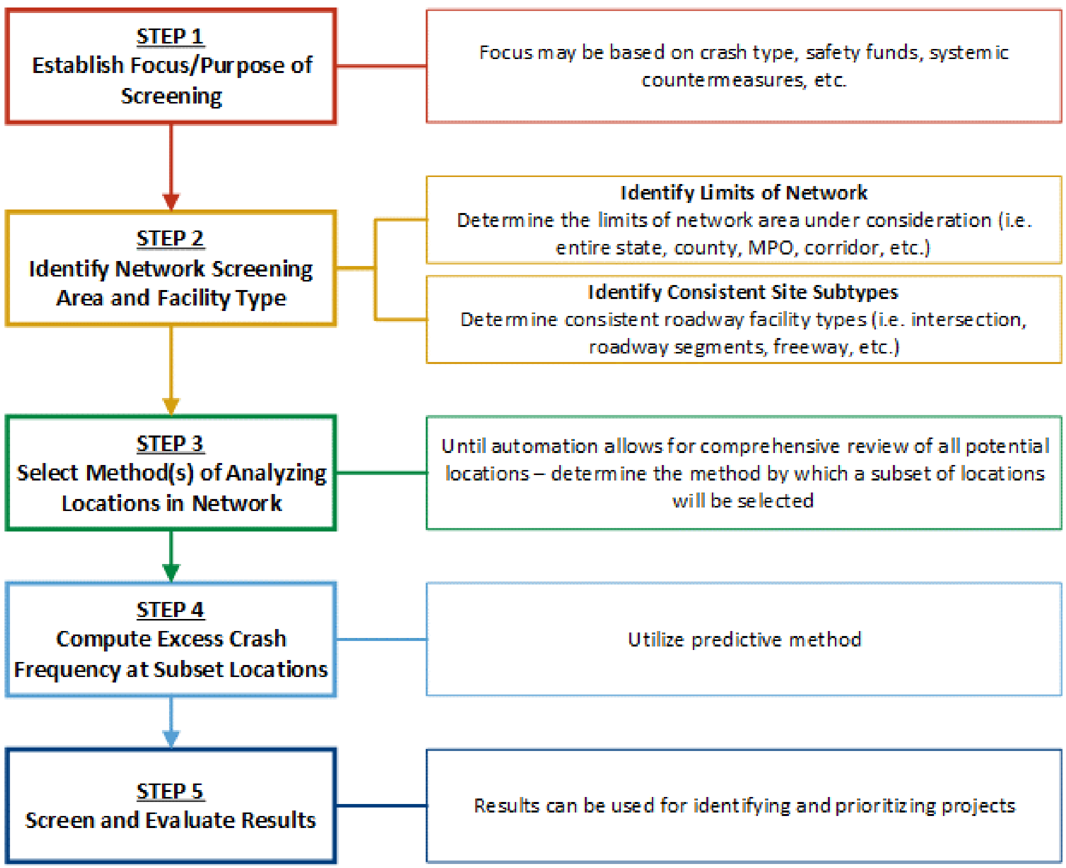

Figure 1-6: Network Screening Process

A detailed explanation of network screening methods is provided in Chapter 4 of the 2010 HSM.

PennDOT conducts a statewide, network screening for segments and a separate statewide, network screening for intersections. Details of this process, as well as details for conducting a more focused or localized network screening are provided in Chapter 4 of this document.

1.8 HSM Part D - Countermeasure Evaluation

Countermeasures are changes in roadway features or operation that are implemented to address a safety concern. Common countermeasures have been the subject of many safety studies, and the anticipated effect of those countermeasures has been quantified in the form of crash reduction factors (CRFs), crash modification factors (CMFs), and crash modification functions (CMFunctions). Additionally, CRFs, CMFs and CMFunctions have been developed for typical geometric changes and roadway conditions like lane and shoulder widths, turning lanes, and shoulder material.

Once the predictive method has been used to estimate the predicted and/or expected number of crashes for a particular location, CMFs and CMFunctions (herein referred to more simply as just CMFs) can be used to estimate the change in predicted or expected number of crashes when specific safety countermeasures or treatments are implemented. The evaluation of the effectiveness of implementing countermeasures is developed in Volume 3 of the 2010 HSM and the process for this estimation is typically referred to as HSM Part D – Countermeasure Evaluation.

Details on how to apply CMFs and where to find countermeasure and CMF information is provided in Chapter 5 of this document.

1.9 Additional Resources

This manual presents the basics of the HSM predictive method and the Pennsylvania calibration factors and/or regionalized SPF equations to apply when utilizing that method. For a more in-depth understanding of the predictive method and its applicability to safety analysis, the following resources provide additional information:

1. *Highway Safety Manual, 1st Edition, Volumes 1 thru 3 (Parts A, B, C and D).* AASHTO, 2010.
2. *Highway Safety Manual, 1st Edition, Supplement (Part C Supplement).* AASHTO, 2014.
3. *Scale and Scope of Safety Assessment Methods in the Project Development Process*. FHWA-SA-10-106, 2016
4. *Crash Costs for Highway Safety Analysis*. FHWA-SA-17-071, 2018
5. Donnell, E., Gayah, V., Jovanis, P. *Safety Performance Functions,* Final Report. Commonwealth of Pennsylvania Department of Transportation, October 8, 2014. The Pennsylvania State University.
6. Donnell, E., Gayah, V., Li, L. *Regionalized Safety Performance Functions*, Final Report. Commonwealth of Pennsylvania Department of Transportation, January 8, 2016. The Pennsylvania State University.

7. Donnell, E., Gayah, V., Li, L., Tang, H. *Regionalized Urban-suburban Collector Road Safety Performance Functions*, Final Report. Commonwealth of Pennsylvania Department of Transportation, March 14, 2019. The Pennsylvania State University. (https://www.penndot.gov/TravelInPA/Safety/Pages/Safety-Infrastructure-Improvement-Programs.aspx)
8. Crash Modification Factors Clearinghouse (http://www.cmfclearinghouse.org/) Federal Highway Administration.

PennDOT Predictive Crash Analysis Tools - PennDOT has developed Pennsylvania specific predictive crash analysis tools to aid in the application of the HSM predictive crash analysis method. These tools provide the option of utilizing the HSM SPFs or the PennDOT Regionalized SPFs and/or calibration factors. It is preferred that the PennDOT regionalized tools be used for all analysis conducted for Pennsylvania projects. The tools and information available are:

- PennDOT HSM Tool A
- PennDOT HSM Tool B
- PennDOT HSM Tool User Manual
- PennDOT HSM Freeway & Ramps Analysis Tool (ISATe (PA Calibrated))
- PennDOT SPF Collision Type & Severity Tables
- PennDOT SPF Illumination Level & Severity Tables
- Benefit Cost Analysis (BCA) Tool
- CMF Supplements (For Alternatives Analysis of Project Optimization)
- State Road Horizontal Curve Inventory (2017)
- Local Road Traffic Counts (2018)

The tools can be found on the PennDOT Safety Infrastructure Improvement Program website at the following location: https://www.penndot.gov/TravelInPA/Safety/Pages/Safety-Infrastructure-Improvement-Programs.aspx.

Chapter 2 — Utilizing Pennsylvania Regionalized Safety Performance Functions for the HSM Part C Predictive Method

2.1 General

Pennsylvania-specific regionalized Safety Performance Functions (SPFs) have been developed for 26 of the HSM roadway facility types. Each of the 26 roadway types have two SPF equations developed; one to generate the **total** number of predicted crashes ($\mathbf{N}_{total}$), and the other to generate the number of predicted crashes categorized as **fatal and injury** ($\mathbf{N}_{fatal\_inj}$)[1]. Each SPF equation has an associated **overdispersion parameter (*k*)** provided for use when applying the EB method to determine the expected number of crashes (either total or fatal and injury as the case may be).

Each of the SPF equations assumes a particular set of base conditions for the roadway type. Differences in the base conditions are incorporated into the SPF equation via exponential variables. The rural segment SPF equations incorporate the Roadside Hazard Rating (RHR) and total Degree of Curvature per Mile (DCPM) as part of their base condition variables. Consistency in determining the RHR and DCPM is important for the accuracy of the equations. Details on determining the RHR and DCPM for roadway facilities are provided in Appendix A and Appendix B of this document.

As a result of the amount of historical data available and the statistical analysis employed to generate the PA regionalized SPF equations, there are differing levels of regionalized specificity for the differing roadway types. For example, some regionalized SPFs differ by PennDOT Engineering District and then employ county-specific calibration factors. Other SPFs use the same equation statewide, regardless of county or District. Table 2.1-1 summarizes the regionalization level for SPF equations for the 26 roadway types and the reference section the roadway type is featured in.

Crash type and severity tables are provided for each roadway facility type following the SPF equation and regionalization information in each reference section. These tables provide Pennsylvania specific percentage summaries using the KABCO scale. The percentages provided in these tables can be useful to further estimate crash distribution based on severity, collision type, or illumination level.

[1] Property damage only (PDO) crash frequencies can be calculated by subtracting the fatal and injury (F&I) SPF crash frequency from the total SPF crash frequency. $\mathbf{N}_{PDO} = \mathbf{N}_{total} - \mathbf{N}_{fatal\_inj}$

Table 2.1-1: Summary of Regionalization Levels for SPFs Developed

Roadway Facility/SPF Type		Regionalization Level	Reference Section
Two-lane rural roadway segments	All Segments	District-level with county-specific calibration factors	2.2
Two-lane rural roadway intersections	3-leg intersections with minor-street stop control	Statewide	2.3
	4-leg intersections with minor-street stop control	Statewide	2.3
	4-leg intersections with all-way stop control	Statewide	2.3
	3-leg intersections with signal control	Statewide	2.3
	4-leg intersections with signal control	Statewide	2.3
Rural multilane highway segments	All Segments	Statewide with District-specific calibration factors	2.4
Rural multilane highway intersections	3-leg intersections with minor-street stop control	Statewide	2.5
	4-leg intersections with minor-street stop control	Statewide	2.5
	4-leg intersections with signal control	Statewide	2.5
Urban-suburban collector segments	Two-lane undivided collectors	District-level with county-specific calibration factors	2.6
Urban-suburban collector intersections	3-leg intersection with minor-street stop control	Statewide with District-specific calibration factors	2.7.1
	3-leg intersection with signal control	Statewide with District-specific calibration factors (adjustment to 3-leg intersection with minor-street stop control)	2.7.2
	3-leg intersection with all-way stop control	Statewide	2.8
	4-leg intersection with minor-street stop control	Statewide	2.8
	4-leg intersection with all-way stop control	Statewide	2.8
	4-leg intersection with signal control	Statewide	2.8
Urban-suburban arterial segments	Two-lane undivided arterials	District-level with county-specific calibration factors	2.9
	Four-lane undivided arterials	Statewide with District-specific calibration factors	2.10
	Four-lane divided arterials	Statewide with District-specific calibration factors	2.11

Table 2.1-1(Continued): Summary of Regionalization Levels for SPFs Developed

Roadway Facility/SPF Type		Regionalization Level	Reference Section
Urban-suburban arterial intersections	3-leg intersection with minor-street stop control	District-level with county-specific calibration factors	2.12
	4-leg intersections with minor-street stop control	Statewide with District-specific calibration factors	2.13.1
	3-leg signalized intersections	Statewide with District-specific calibration factors	2.13.2
	4-leg signalized intersection	Statewide with District-specific calibration factors	2.13.3
	4-leg all-way stop-controlled intersections	Statewide with District-specific calibration factors (adjustment to 4-leg intersections with minor-street stop control)	2.13.4
	5-leg signalized intersections	Statewide with District-specific calibration factors (adjustment to 4-leg signalized intersections)	2.13.5

Details for PA specific calibration factors as well as instructions for implementing calibration factors for freeways, freeway ramps and ramp terminals (intersections) are presented in Chapter 3.

2.1.1 Pennsylvania Highway Safety Predictive Analysis Method

To implement the 2010 HSM Part C predictive method utilizing the Pennsylvania Regionalized Safety Performance Functions the following steps should be followed:

1. Determine the location to be analyzed and identify District and county.
2. Categorize the analysis location into one of the roadway facility types from Table 2.1-1.

   Note: For roadway types not included in Table 1.5-1 (i.e., freeways, ramps, and ramp terminals) refer to the 2010 HSM Part C Supplement and use the nationwide SPF equations (with Pennsylvania calibration factors as described in Chapter 3 of this document) following the HSM predictive method.
3. Gather historical crash data and calculate $\mathbf{N}_{\boldsymbol{observed}}$ (historical crash data) for the location being analyzed, ensuring only the applicable crash data is included (i.e., If $\mathbf{N}_{\boldsymbol{total}}$ then include all crashes, if $\mathbf{N}_{\boldsymbol{f\&i}}$ then only include fatal and injury crashes).
4. Determine the SPF equation, base condition variables, and calibration factors (if applicable).
5. Gather all base condition data for the variables identified based on the location being analyzed (the base conditions are listed in the corresponding sections below for each SPF).
6. Calculate $\mathbf{N}_{\boldsymbol{predicted}}$ (Number of predicted crashes) using the corresponding SPF equation and location specific base condition adjustments (using data gathered in Step 4 and Step 5), and location specific calibration factors. Note that SPF equations are given to calculate $\mathbf{N}_{\boldsymbol{predicted}}$ for either total predicted crashes ($\mathbf{N}_{\boldsymbol{total}}$) or fatal and injury predicted crashes ($\mathbf{N}_{\boldsymbol{f\&i}}$).
7. Apply the Empirical Bayes method (EB Method) described in Sections 1.4 and 1.5 to obtain the number of expected crashes, $\mathbf{N}_{\boldsymbol{expected}}$, using the equations:

$$N_{expected} = w \ \text{x} \ N_{predicted} + (1.00 - w) \ \text{x} \ N_{observed}$$

Where *w* for segment SPF equations equals:

$$w = \frac{1}{1 + \frac{k}{L} \times \left(\sum_{\text{all study years}} N_{predicted} \right)}$$

And *w* for intersection SPF equations equals:

$$w = \frac{1}{1 + k \times \left(\sum_{\text{all study years}} N_{predicted}\right)}$$

8. Compare $\mathbf{N}_{observed}$, $\mathbf{N}_{predicted}$, and $\mathbf{N}_{expected}$ for the location being analyzed.

The following sections provide the SPF equations (total and F&I) to calculate $\mathbf{N}_{predicted}$. The assumed base conditions and overdispersion parameters (***k***) for each roadway facility type are included with the SPF equations.

Note: In lieu of hand calculations, PennDOT has developed automated SPF calculation tools: PennDOT HSM Tool A & B as described in 1.9. CMF supplements have also been developed to use in Tool B. The tools can be found on the PennDOT Safety Infrastructure Improvement Program website at the following location: https://www.penndot.gov/TravelInPA/Safety/Pages/Safety-Infrastructure-Improvement-Programs.aspx.

2.2 Two-lane Rural Roadway Segments

The regionalization level for SPF equations for two-lane rural roadway segments is:

District level with County Specific Calibration Factors

The county specific calibration factors are provided for both total and F&I crashes and should be applied to both the $\mathbf{N}_{total}$ and $\mathbf{N}_{fatal\_inj}$ predicted number of crashes respectively to yield an accurate estimate. The basic formula is:

$$N_{predicted} = N_{spf\ (total\ or\ F\&I)}\ \text{x}\ \text{County Calibration Factor}$$

The SPF equations for both total and F&I (N_{total} and N_{fatal_inj}) and related overdispersion parameters (*k*) are provided in Table 2.2-2, and County Calibration Factors are provided in Table 2.2-3. The base condition variables are defined in Table 2.2-1 and vary in the equations for each District. The X's show whether the base condition variable is used in the District SPF.

Table 2.2-1: Base Condition Variables for Two-lane Rural Roadway Segments

Base Condition Variables		District										
		1	2	3	4	5	6	8	9	10	11	12
L	length of segment (miles)	X	X	X	X	X	X	X	X	X	X	X
AADT	annual average daily traffic on the segment (veh/day)	X	X	X	X	X	X	X	X	X	X	X
RHR567	roadside hazard rating on the segment of 5, 6 or 7 (1 if RHR is 5, 6 or 7; 0 otherwise)	X	X			X			X	X		
RHR4	roadside hazard rating on the segment of 4 (1 if RHR is 4; 0 otherwise)		X							X		
RHR34	roadside hazard rating on the segment of 3 or 4 (1 if RHR is 3 or 4; 0 otherwise)	X										
RHR45	roadside hazard rating on the segment of 4 or 5 (1 if RHR is 4 or 5; 0 otherwise)						X					
RHR67	roadside hazard rating on the segment of 6 or 7 (1 if RHR is 6 or 7; 0 otherwise)						X				X	
RHR4567	roadside hazard rating on the segment of 4,5,6 or 7 (1 if RHR is 4,5,6 or 7; 0 otherwise)		X									
RHR5	roadside hazard rating on the segment of 5 (1 if RHR is 5; 0 otherwise)										X	
PZ	presence of a passing zone in the segment (1 if present; 0 otherwise)	X	X	X	X	X		X	X	X		X
SRS	presence of shoulder rumble strips in the segment (1 If present; 0 otherwise)	X		X					X	X		
AD	access density in the segment, total driveways and intersections per mile of segment length (Access Points/Mile)	X	X	X	X	X	X	X	X	X	X	X
HCD	horizontal curve density in the segment, number of curves in the segment per mile (Hor. Curves/Mile)	X	X	X	X	X	X	X	X	X	X	
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)	X	X	X	X	X	X	X	X	X	X	X

*Appendix A provides guidance on determining RHR and Appendix B provides guidance on using Google Earth to determine DCPM.

Table 2.2-2: Regionalized SPFs for Two-lane Rural Roadway Segments

Regionalized SPF Predictive Equations		Overdispersion Parameter
District 1		
Total Predicted	$\boldsymbol{N_{total}} = e^{-4.946} \times L \times AADT^{0.587} \times e^{0.333 \times RHR34} \times e^{0.435 \times RHR567} \times e^{-0.173 \times PZ} \times e^{-0.086 \times SRS} \times e^{0.009 \times AD} \times e^{0.056 \times HCD} \times e^{0.002 \times DCPM}$	*k*= 0.450
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-5.554} \times L \times AADT^{0.568} \times e^{0.551 \times RHR34} \times e^{0.632 \times RHR567} \times e^{-0.183 \times PZ} \times e^{-0.123 \times SRS} \times e^{0.010 \times AD} \times e^{0.055 \times HCD} \times e^{0.002 \times DCPM}$	*k*= 0.582
District 2		
Total Predicted	$\boldsymbol{N_{total}} = e^{-5.245} \times L \times AADT^{0.649} \times e^{0.091 \times RHR4} \times e^{0.101 \times RHR567} \times e^{-0.274 \times PZ} \times e^{0.010 \times AD} \times e^{0.017 \times HCD} \times e^{0.001 \times DCPM}$	*k*= 0.419
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-5.501} \times L \times AADT^{0.600} \times e^{0.104 \times RHR4567} \times e^{-0.242 \times PZ} \times e^{0.011 \times AD} \times e^{0.021 \times HCD} \times e^{0.001 \times DCPM}$	*k*= 0.617
District 3		
Total Predicted	$\boldsymbol{N_{total}} = e^{-5.345} \times L \times AADT^{0.664} \times e^{-0.136 \times PZ} \times e^{-0.145 \times SRS} \times e^{0.011 \times AD} \times e^{0.041 \times HCD} \times e^{0.001 \times DCPM}$	*k*= 0.480
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-5.936} \times L \times AADT^{0.658} \times e^{-0.132 \times PZ} \times e^{-0.182 \times SRS} \times e^{0.012 \times AD} \times e^{0.054 \times HCD} \times e^{0.001 \times DCPM}$	*k*= 0.644
District 4		
Total Predicted	$\boldsymbol{N_{total}} = e^{-5.679} \times L \times AADT^{0.718} \times e^{-0.208 \times PZ} \times e^{0.010 \times AD} \times e^{0.018 \times HCD} \times e^{0.002 \times DCPM}$	*k*= 0.413
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-6.358} \times L \times AADT^{0.725} \times e^{-0.134 \times PZ} \times e^{0.011 \times AD} \times e^{0.018 \times HCD} \times e^{0.002 \times DCPM}$	*k*= 0.564
District 5		
Total Predicted	$\boldsymbol{N_{total}} = e^{-5.244} \times L \times AADT^{0.655} \times e^{0.115 \times RHR567} \times e^{-0.140 \times PZ} \times e^{0.011 \times AD} \times e^{0.016 \times HCD} \times e^{0.003 \times DCPM}$	*k*= 0.532
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-5.873} \times L \times AADT^{0.658} \times e^{0.129 \times RHR567} \times e^{-0.144 \times PZ} \times e^{0.012 \times AD} \times e^{0.0161 \times HCD} \times e^{0.003 \times DCPM}$	*k*= 0.598
District 6		
Total Predicted	$\boldsymbol{N_{total}} = e^{-4.826} \times L \times AADT^{0.613} \times e^{0.183 \times RHR45} \times e^{0.288 \times RHR67} \times e^{0.010 \times AD} \times e^{0.048 \times HCD} \times e^{0.001 \times DCPM}$	*k*= 0.533
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-5.144} \times L \times AADT^{0.589} \times e^{0.010 \times AD} \times e^{0.062 \times DCPM}$	*k*= 0.659
District 8		
Total Predicted	$\boldsymbol{N_{total}} = e^{-5.422} \times L \times AADT^{0.711} \times e^{-0.227 \times PZ} \times e^{0.005 \times AD} \times e^{0.034 \times HCD} \times e^{0.002 \times DCPM}$	*k*= 0.529
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-6.112} \times L \times AADT^{0.716} \times e^{-0.247 \times PZ} \times e^{0.005 \times AD} \times e^{0.035 \times HCD} \times e^{0.002 \times DCPM}$	*k*= 0.584

Table 2.2-2 (Continued): Regionalized SPFs for Two-lane Rural Roadway Segments

Regionalized SPF Predictive Equations		Overdispersion Parameter
District 9		
Total Predicted	$\boldsymbol{N_{total}} = e^{-6.039} \times L \times AADT^{0.734} \times e^{0.206\times\mathrm{RHR567}} \times e^{-0.167\times PZ} \times e^{-0.118\times SRS} \times e^{0.007\times AD} \times e^{0.038\times HCD} \times e^{0.002\times DCPM}$	*k*= 0.426
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-6.510} \times L \times AADT^{0.728} \times e^{0.163\times\mathrm{RHR567}} \times e^{-0.212\times PZ} \times e^{-0.182\times SRS} \times e^{0.006\times AD} \times e^{0.041\times HCD} \times e^{0.001\times DCPM}$	*k*= 0.495
District 10		
Total Predicted	$\boldsymbol{N_{total}} = e^{-5.777} \times L \times AADT^{0.702} \times e^{0.132\times\mathrm{RHR4}} \times e^{0.226\times\mathrm{RHR567}} \times e^{-0.147\times PZ} \times e^{-0.123\times SRS} \times e^{0.007\times AD} \times e^{0.026\times HCD} \times e^{0.001\times DCPM}$	*k*= 0.294
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-6.141} \times L \times AADT^{0.681} \times e^{0.106\times\mathrm{RHR4}} \times e^{0.178\times\mathrm{RHR567}} \times e^{-0.143\times PZ} \times e^{-0.125\times SRS} \times e^{0.007\times AD} \times e^{0.023\times HCD} \times e^{0.001\times DCPM}$	*k*= 0.409
District 11		
Total Predicted	$\boldsymbol{N_{total}} = e^{-4.945} \times L \times AADT^{0.571} \times e^{0.293\times\mathrm{RHR5}} \times e^{0.327\times\mathrm{RHR67}} \times e^{0.009\times AD} \times e^{0.029\times HCD} \times e^{0.001\times DCPM}$	*k*= 0.496
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-5.351} \times L \times AADT^{0.552} \times e^{0.265\times\mathrm{RHR5}} \times e^{0.317\times\mathrm{RHR67}} \times e^{0.006\times AD} \times e^{0.043\times HCD} \times e^{0.001\times DCPM}$	*k*= 0.615
District 12		
Total Predicted	$\boldsymbol{N_{total}} = e^{-4.948} \times L \times AADT^{0.630} \times e^{-0.153\times PZ} \times e^{0.015\times AD} \times e^{0.002\times DCPM}$	*k*= 0.342
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-5.427} \times L \times AADT^{0.615} \times e^{-0.216\times PZ} \times e^{0.016\times AD} \times e^{0.002\times DCPM}$	*k*= 0.515

To use the data shown in Table 2.2-3, the District-level SPF from Table 2.2-2 should be calculated and the multiplier shown for the specific county in Table 2.2-3 should be applied to the predicted number of crashes.

Table 2.2-3: County Calibration Factors for Two-lane Rural Road Segments

District	County	County Calibration Factor for Total Crash SPF	County Calibration Factor for Fatal and Injury SPF
1	Crawford, Erie, Mercer	1.00	1.00
	Forest, Venango, Warren	0.78	0.76
2	Cameron, Centre, Clinton, Elk, Juniata, McKean	1.00	1.00
	Clearfield	1.09	1.16
	Mifflin, Potter	0.70	0.70
3	Tioga, Columbia, Northumberland, Snyder	1.00	1.00
	Bradford	1.10	1.00
	Lycoming, Montour	1.09	1.00
	Sullivan, Union	0.86	0.83
4	Lackawanna, Susquehanna, Wayne	1.00	1.00
	Luzerne, Pike, Wyoming	1.20	1.16
5	Schuylkill	1.00	1.00
	Berks, Monroe	1.94	1.71
	Carbon	1.16	1.11
	Lehigh	1.34	1.36
	Northampton	1.48	1.45
6	Bucks, Chester, Delaware, Philadelphia	1.00	1.00
	Montgomery	1.21	1.30
8	Franklin, Cumberland, Lebanon	1.00	1.00
	Adams, Lancaster	1.25	1.28
	Dauphin, Perry	0.92	0.91
	York	1.09	1.10
9	Huntingdon, Somerset	1.00	1.00
	Bedford, Blair, Cambria	1.11	1.10
	Fulton	1.37	1.38
10	Indiana, Jefferson	1.00	1.00
	Armstrong, Clarion	1.10	1.11
	Butler	1.19	1.16
11	Lawrence	1.00	1.00
	Allegheny	1.46	1.33
	Beaver	1.48	1.40
12	Westmoreland, Washington	1.00	1.00
	Fayette	1.15	1.22
	Greene	0.79	0.81

Table 2.2-4 provides a Pennsylvania specific percentage summary of all crashes identified on two-lane rural roadway segments by collision type and severity using the KABCO scale (the police-reported injury coding system). Similarly, Table 2.2-5 provides a summary of all crashes identified by illumination level and severity. The percentages provided in Table 2.2-4 and Table 2.2-5 may be applied as multipliers to the predicted number of crashes to further estimate crash distribution based on severity, collision type, or illumination level. These adjustments are useful when considering countermeasures that apply only to specific crash severities, collision types, or illumination level. Additional detail about applying countermeasures is provided in Chapter 5.

Table 2.2-4: Distribution of Collision Type and Severity for Crashes on Rural Two-lane Highway Segments

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision (lane departure)	0.08%	0.19%	0.55%	1.08%	0.28%	0.06%	1.73%	**3.98%**
Non-collision (lane crash)	0.04%	0.16%	0.50%	0.72%	0.23%	0.02%	1.29%	**2.97%**
Rear-end	0.06%	0.21%	0.98%	3.36%	0.96%	0.16%	4.75%	**10.48%**
Head-on	0.32%	0.42%	0.65%	0.77%	0.31%	0.03%	0.71%	**3.22%**
Rear-to-rear (backing)	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.02%	**0.04%**
Angle	0.27%	0.39%	1.10%	2.14%	0.65%	0.09%	3.35%	**7.99%**
Sideswipe (same direction)	0.01%	0.03%	0.08%	0.25%	0.06%	0.04%	0.58%	**1.05%**
Sideswipe (opposite direction)	0.04%	0.08%	0.25%	0.65%	0.14%	0.06%	0.90%	**2.11%**
Hit fixed object	1.10%	2.10%	6.58%	15.87%	4.03%	1.38%	29.84%	**60.91%**
Hit pedestrian	0.08%	0.13%	0.18%	0.20%	0.07%	0.00%	0.00%	**0.66%**
Other or unknown	0.05%	0.12%	0.46%	0.92%	0.20%	0.04%	4.81%	**6.60%**
Total	**2.06%**	**3.84%**	**11.33%**	**25.98%**	**6.95%**	**1.88%**	**47.97%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.2-5: Distribution of Illumination Level and Severity for Crashes on Rural Two-lane Highway Segments

Illumination	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Daylight	1.08%	2.04%	6.78%	15.70%	4.41%	0.65%	25.95%	**56.61%**
Dark - no streetlights	0.83%	1.49%	3.70%	8.24%	1.95%	1.01%	17.75%	**34.96%**
Dark - streetlights	0.06%	0.13%	0.35%	0.82%	0.28%	0.11%	1.77%	**3.51%**
Dusk	0.05%	0.08%	0.23%	0.49%	0.12%	0.03%	0.85%	**1.84%**
Dawn	0.05%	0.08%	0.23%	0.62%	0.13%	0.03%	1.41%	**2.54%**
Dark - unknown streetlighting	0.00%	0.02%	0.04%	0.09%	0.05%	0.04%	0.20%	**0.44%**
Other	0.00%	0.00%	0.01%	0.02%	0.01%	0.01%	0.05%	**0.11%**
Total	**2.06%**	**3.84%**	**11.33%**	**25.98%**	**6.95%**	**1.88%**	**47.97%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

2.3 Two-lane Rural Roadway Intersection

The regionalization level for SPF equations for Two-lane Rural Roadway Intersections is:

Pennsylvania Statewide level without Regionalized Calibration

The SPF equations for both total and F&I (N_{total} and N_{fatal_inj}) and related overdispersion parameters (k) for intersections on two-lane rural highways are provided in Table 2.3-2. The base condition variables are defined in Table 2.3-1 and vary in the equations for each intersection type. The X's show whether the base condition variable is used in the intersection type SPF.

Statistical analysis during development of the equations determined that there was not enough statistical variation to justify regionalization. The statewide equations for each intersection type apply to all locations and Districts in Pennsylvania.

Table 2.3-1: Base Condition Variables for Two-lane Rural Roadway Intersection

Base Condition Variables		Intersection Type				
		4-leg Signalized	3-leg Signalized	4-leg All-way Stop	4-leg Minor Street Stop	3-leg Minor Street Stop
$AADT_{major}$	major road annual average daily traffic (veh/day)	X	X	X	X	X
$AADT_{minor}$	minor road annual average daily traffic (veh/day)	X	X	X	X	X
PSL_{major}	posted speed limit on the major road (mph)	X	X	X		
PSL_{minor}	posted speed limit on the minor road (mph)	X				
ELT_{major}	exclusive left-turn lane on the major road (1 = present; 0 = not present)					X
ERT_{major}	exclusive right-turn lane on the major road (1 = present; 0 = not present)	X				X
$Walk_{major}$	pedestrian crosswalk on the major road (1 = present; 0 = not present)		X			
$Walk_{minor}$	pedestrian crosswalk on the minor road (1 = present; 0 = not present)		X			
Skew	intersection skew angle (90 – angle) [degrees]				X	

Table 2.3-2: SPF Predictive Equations for Two-lane Rural Roadway Intersection

SPF Predictive Equations		Overdispersion Parameter
3-leg with Minor Street Stop Control[1]		
Total Predicted	$\boldsymbol{N_{total}} = e^{-6.337} \times AADT_{major}^{0.479} \times AADT_{minor}^{0.362} \times e^{-0.330ELT_{major}} \times e^{0.507ERT_{major}}$	*k*= 1.117
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-6.457} \times AADT_{major}^{0.439} \times AADT_{minor}^{0.343} \times e^{-0.267ELT_{major}} \times e^{0.560ERT_{major}}$	*k*= 1.810
4-leg with Minor Street Stop Control		
Total Predicted	$\boldsymbol{N_{total}} = e^{-6.359} \times AADT_{major}^{0.528} \times AADT_{minor}^{0.275} \times e^{0.007Skew}$	*k*= 1.348
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-6.156} \times AADT_{major}^{0.512} \times AADT_{minor}^{0.176} \times e^{0.008Skew}$	*k*= 2.597
4-leg with All-way Stop Control		
Total Predicted	$\boldsymbol{N_{total}} = e^{-6.581} \times AADT_{major}^{0.680} \times AADT_{minor}^{0.064} \times e^{0.028PSL_{major}}$	*k*= 1.283
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-7.541} \times AADT_{major}^{0.639} \times AADT_{minor}^{0.134} \times e^{0.029PSL_{major}}$	*k*= 1.522
3-leg with Signalized Control		
Total Predicted	$\boldsymbol{N_{total}} = e^{-6.813} \times AADT_{major}^{0.451} \times AADT_{minor}^{0.349} \times e^{0.020PSL_{major}} \times e^{-0.433Walk_{major}} \times e^{-0.345Walk_{minor}}$	*k*= 0.982
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-6.981} \times AADT_{major}^{0.452} \times AADT_{minor}^{0.287} \times e^{0.026PSL_{major}} \times e^{-0.605Walk_{major}} \times e^{-0.413Walk_{minor}}$	*k*= 1.114
4-leg with Signalized Control		
Total Predicted	$\boldsymbol{N_{total}} = e^{-5.353} \times AADT_{major}^{0.313} \times AADT_{minor}^{0.250} \times e^{0.025PSL_{major}} \times e^{0.014PSL_{minor}} \times e^{0.216ERT_{major}}$	*k*= 0.579
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-4.960} \times AADT_{major}^{0.202} \times AADT_{minor}^{0.209} \times e^{0.028PSL_{major}} \times e^{0.018PSL_{minor}} \times e^{0.388ERT_{major}}$	*k*= 0.892

[1] – All Estimates of crash frequency on **three-leg minor street stop controlled intersections with 'STOP Except Right Turns' signs** can be performed using the SPF for three-leg minor street stop controlled intersections. However, the estimates from the SPF should be adjusted by a multiplicative calibration factor to obtain the estimate of crash frequency at the three-leg minor street stop controlled intersections with 'STOP Except Right Turns' signs. The calibration factor for total crash frequency is 1.00 and the calibration factor for fatal and injury crash frequency is 0.95.

Table 2.3-3, Table 2.3-5, Table 2.3-7, and Table 2.3-9 provide a Pennsylvania specific percentage summary of all crashes identified for two-lane rural intersections by collision type and severity using the KABCO scale (the police-reported injury coding system). Similarly, Table 2.3-4, Table 2.3-6, Table 2.3-8, and Table 2.3-10 provide a summary of all crashes identified by illumination level and severity. The percentages provided in the following tables may be applied as multipliers to the predicted number of crashes to further estimate crash distribution based on severity, collision type, or illumination level. These adjustments are useful when considering countermeasures that apply only to specific crash severities, collision types, or illumination level. Additional detail about applying countermeasures is provided in Chapter 5.

Table 2.3-3: Distribution of Collision Type and Severity for Crashes on Rural Two-lane Three-leg Intersections with Minor Street Stop Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision	0.09%	0.07%	0.47%	0.74%	0.18%	0.04%	1.10%	**2.69%**
Rear-end	0.02%	0.09%	0.69%	3.15%	0.92%	0.16%	4.16%	**9.19%**
Head-on	0.05%	0.18%	0.89%	1.54%	0.47%	0.02%	1.46%	**4.61%**
Rear-to-rear (backing)	0.00%	0.00%	0.02%	0.00%	0.00%	0.00%	0.04%	**0.05%**
Angle	1.07%	1.93%	7.03%	16.96%	5.23%	0.58%	23.44%	**56.24%**
Sideswipe (same direction)	0.00%	0.02%	0.13%	0.25%	0.02%	0.04%	0.58%	**1.03%**
Sideswipe (opposite direction)	0.00%	0.00%	0.27%	0.52%	0.07%	0.05%	1.08%	**2.01%**
Hit fixed object	0.25%	0.65%	2.62%	5.50%	1.50%	1.01%	11.56%	**23.09%**
Hit pedestrian	0.02%	0.02%	0.09%	0.11%	0.04%	0.00%	0.00%	**0.27%**
Other or unknown	0.00%	0.00%	0.13%	0.13%	0.05%	0.00%	0.51%	**0.81%**
Total	**1.50%**	**2.97%**	**12.33%**	**28.90%**	**8.48%**	**1.90%**	**43.92%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.3-4: Distribution of Illumination Level and Severity for Crashes on Two-lane Three-leg Intersections with Minor Street Stop Control

Illumination	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Daylight	1.08%	1.90%	8.68%	20.20%	6.17%	0.85%	29.24%	**68.12%**
Dark - no streetlights	0.29%	0.76%	2.46%	5.79%	1.56%	0.74%	9.78%	**21.37%**
Dark - streetlights	0.04%	0.16%	0.61%	1.57%	0.56%	0.27%	2.57%	**5.79%**
Dusk	0.04%	0.02%	0.22%	0.60%	0.09%	0.00%	0.89%	**1.84%**
Dawn	0.04%	0.13%	0.27%	0.63%	0.07%	0.04%	1.23%	**2.41%**
Dark - unknown streetlighting	0.02%	0.00%	0.09%	0.11%	0.04%	0.00%	0.18%	**0.43%**
Other	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.04%	**0.04%**
Total	**1.50%**	**2.97%**	**12.33%**	**28.90%**	**8.48%**	**1.90%**	**43.92%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.3-5: Distribution of Collision Type and Severity for Crashes on Rural Two-lane Four-leg Intersections with Minor Street Stop Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision	0.00%	0.03%	0.23%	0.29%	0.08%	0.02%	0.36%	**1.01%**
Rear-end	0.00%	0.05%	0.21%	0.92%	0.34%	0.03%	1.39%	**2.94%**
Head-on	0.02%	0.21%	0.47%	1.11%	0.31%	0.02%	1.05%	**3.19%**
Rear-to-rear (backing)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%	**0.02%**
Angle	1.50%	3.12%	11.18%	24.58%	7.83%	1.18%	35.20%	**84.58%**
Sideswipe (same direction)	0.00%	0.03%	0.00%	0.15%	0.05%	0.00%	0.29%	**0.52%**
Sideswipe (opposite direction)	0.00%	0.07%	0.18%	0.33%	0.21%	0.08%	0.60%	**1.47%**
Hit fixed object	0.05%	0.15%	0.41%	1.13%	0.34%	0.21%	2.92%	**5.21%**
Hit pedestrian	0.03%	0.05%	0.10%	0.08%	0.05%	0.00%	0.00%	**0.31%**
Other or unknown	0.00%	0.03%	0.11%	0.13%	0.16%	0.00%	0.31%	**0.75%**
Total	**1.60%**	**3.74%**	**12.89%**	**28.71%**	**9.38%**	**1.54%**	**42.14%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.3-6: Distribution of Illumination Level and Severity for Crashes on Two-lane Four-leg Intersections with Minor Street Stop Control

Illumination	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Daylight	1.27%	2.76%	10.31%	23.30%	7.60%	0.93%	33.68%	**79.85%**
Dark - no streetlights	0.23%	0.54%	1.73%	3.37%	1.16%	0.31%	4.77%	**12.11%**
Dark - streetlights	0.05%	0.28%	0.49%	1.16%	0.31%	0.18%	2.35%	**4.82%**
Dusk	0.05%	0.13%	0.13%	0.39%	0.18%	0.07%	0.72%	**1.67%**
Dawn	0.00%	0.03%	0.18%	0.41%	0.08%	0.03%	0.46%	**1.19%**
Dark - unknown streetlighting	0.00%	0.00%	0.03%	0.08%	0.05%	0.02%	0.13%	**0.31%**
Other	0.00%	0.00%	0.02%	0.00%	0.00%	0.00%	0.03%	**0.05%**
Total	**1.60%**	**3.74%**	**12.89%**	**28.71%**	**9.38%**	**1.54%**	**42.14%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.3-7: Distribution of Collision Type and Severity for Crashes on Rural Two-lane Three-leg Intersections with Signal Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision	0.00%	0.00%	0.00%	0.48%	0.16%	0.00%	1.43%	**2.07%**
Rear-end	0.16%	0.16%	1.75%	12.10%	5.57%	0.96%	13.38%	**34.08%**
Head-on	0.16%	0.32%	1.43%	2.39%	0.48%	0.00%	1.75%	**6.53%**
Rear-to-rear (backing)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
Angle	0.64%	1.59%	2.71%	11.46%	3.98%	0.64%	20.06%	**41.08%**
Sideswipe (same direction)	0.00%	0.00%	0.16%	0.48%	0.16%	0.00%	0.32%	**1.11%**
Sideswipe (opposite direction)	0.00%	0.00%	0.16%	0.64%	0.16%	0.16%	1.59%	**2.71%**
Hit fixed object	0.16%	0.32%	1.11%	2.23%	1.75%	0.00%	5.89%	**11.46%**
Hit pedestrian	0.00%	0.00%	0.16%	0.32%	0.00%	0.00%	0.00%	**0.48%**
Other or unknown	0.00%	0.00%	0.16%	0.16%	0.00%	0.00%	0.16%	**0.48%**
Total	**1.11%**	**2.39%**	**7.64%**	**30.25%**	**12.26%**	**1.75%**	**44.59%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.3-8: Distribution of Illumination Level and Severity for Crashes on Rural Two-lane Three-leg Intersections with Signal Control

Illumination	Crash Severity Level							
	Fatal (K)	**Suspected Serious Injury (A)**	**Suspected Minor Injury (B)**	**Possible Injury (C)**	**Injury/ Unknown Severity (C)**	**Unknown (U)**	**Not Injured (O)**	**Sum**
Daylight	0.48%	1.43%	4.30%	21.02%	9.55%	1.43%	27.07%	**65.29%**
Dark - no streetlights	0.00%	0.16%	0.80%	3.18%	0.64%	0.16%	5.73%	**10.67%**
Dark - streetlights	0.64%	0.80%	2.23%	4.94%	1.59%	0.16%	9.08%	**19.43%**
Dusk	0.00%	0.00%	0.32%	0.48%	0.32%	0.00%	0.64%	**1.75%**
Dawn	0.00%	0.00%	0.00%	0.32%	0.00%	0.00%	1.75%	**2.07%**
Dark - unknown streetlighting	0.00%	0.00%	0.00%	0.16%	0.16%	0.00%	0.32%	**0.64%**
Other	0.00%	0.00%	0.00%	0.16%	0.00%	0.00%	0.00%	**0.16%**
Total	**1.11%**	**2.39%**	**7.64%**	**30.25%**	**12.26%**	**1.75%**	**44.59%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.3-9: Distribution of Collision Type and Severity for Crashes on Rural Two-lane Four-leg Intersections with Signal Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision	0.00%	0.04%	0.14%	0.50%	0.07%	0.00%	0.50%	**1.24%**
Rear-end	0.14%	0.11%	1.56%	6.79%	3.11%	0.60%	9.16%	**21.48%**
Head-on	0.00%	0.11%	1.34%	1.95%	0.78%	0.04%	2.34%	**6.55%**
Rear-to-rear (backing)	0.00%	0.00%	0.00%	0.04%	0.00%	0.00%	0.00%	**0.04%**
Angle	0.67%	1.80%	7.71%	18.15%	6.40%	1.10%	24.95%	**60.79%**
Sideswipe (same direction)	0.00%	0.00%	0.07%	0.28%	0.14%	0.04%	0.74%	**1.27%**
Sideswipe (opposite direction)	0.00%	0.00%	0.28%	0.53%	0.28%	0.11%	0.92%	**2.12%**
Hit fixed object	0.00%	0.25%	0.28%	0.50%	0.35%	0.32%	2.83%	**4.53%**
Hit pedestrian	0.14%	0.18%	0.35%	0.35%	0.25%	0.00%	0.00%	**1.27%**
Other or unknown	0.00%	0.00%	0.04%	0.32%	0.14%	0.04%	0.18%	**0.71%**
Total	**0.96%**	**2.48%**	**11.78%**	**29.41%**	**11.54%**	**2.23%**	**41.61%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.3-10: Distribution of Illumination Level and Severity for Crashes on Rural Two-lane Four-leg Intersections with Signal Control

Illumination	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Daylight	0.60%	1.42%	8.95%	21.69%	8.74%	1.24%	29.12%	**71.76%**
Dark - no streetlights	0.11%	0.25%	0.57%	1.80%	0.50%	0.18%	3.01%	**6.40%**
Dark - streetlights	0.21%	0.71%	1.88%	5.02%	1.77%	0.74%	7.47%	**17.80%**
Dusk	0.00%	0.07%	0.18%	0.50%	0.14%	0.00%	0.85%	**1.73%**
Dawn	0.00%	0.00%	0.14%	0.32%	0.21%	0.00%	0.85%	**1.52%**
Dark - unknown streetlighting	0.00%	0.04%	0.04%	0.07%	0.14%	0.07%	0.25%	**0.60%**
Other	0.04%	0.00%	0.04%	0.00%	0.04%	0.00%	0.07%	**0.18%**
Total	**0.96%**	**2.48%**	**11.78%**	**29.41%**	**11.54%**	**2.23%**	**41.61%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

2.4 Rural Multi-lane Highway Segments

The regionalization level for SPF equations for rural multi-lane highway segments is:

Pennsylvania Statewide with District Specific Calibration Factors

The District-specific calibration factors are provided for both total and F&I crashes and should be applied to both the $\mathbf{N}_{total}$ and $\mathbf{N}_{fatal\_inj}$ predicted number of crashes respectively to yield an accurate estimate. The basic formula is:

$$N_{predicted} = N_{spf} \times \text{ District Calibration Factor}$$

The SPF equations for both total and F&I ($\mathbf{N}_{total}$ and $\mathbf{N}_{fatal\_inj}$) and related overdispersion parameters (***k***) are provided in Table 2.4-2, and District Calibration Factors are provided in Table 2.4-3. The base condition variables are defined in Table 2.4-1. The X's show that the base condition variables apply for all Districts.

Table 2.4-1: Base Condition Variables for Rural Multi-lane Highway Segments

Base Condition Variables		All Districts
L	Length of segment (miles)	X
AADT	annual average daily traffic on the segment (veh/day)	X
Barrier	presence of a median barrier on the segment (1 = present; 0 otherwise)	X
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)	X
RRHR4	indicator for roadside hazard rating of the right-hand side of the segment is 4 (1 if RRHR = 4; 0 otherwise)	X
RRHR567	indicator for roadside hazard rating on the right-hand side of the segment is 5, 6 or 7 (1 if RRHR = 5, 6, or 7; 0 otherwise)	X
AD	access density along the segment (driveways plus intersections per mile)	X
PSL4550	indicator for posted speed limit of 45 or 50 mph (1 = posted speed limit is 45 or 50 mph on segment; 0 otherwise)	X
PSL55p	indicator for posted speed limit of 55 mph or greater (1 = posted speed limit is 55 mph or greater on segment; 0 otherwise)	X
CRS	indicator for presence of a centerline rumble strip (undivided road) or shoulder rumble strip on the left-hand side (divided road) (1 = centerline or left-hand shoulder rumble strip present; 0 otherwise)	X
SRS	indicator for presence of a right-hand shoulder rumble strip (1 = right-hand shoulder rumble strip present; 0 otherwise)	X

*Appendix A provides guidance on determining RHR and Appendix B provides guidance on using Google Earth to determine DCPM.

Table 2.4-2: Statewide SPFs for Rural Multi-lane Highway Segments

Regionalized SPF Predictive Equations		Overdispersion Parameter
Total Predicted	$N_{Total} = e^{-4.571} \times \mathrm{L} \times AADT^{0.587} \times e^{0.097\times\mathrm{Barrier}} \times e^{0.002\times\mathrm{DCPM}} \times e^{0.188\times\mathrm{RRHR4}} \times e^{0.386\times\mathrm{RRHR567}} \times e^{0.023\times\mathrm{AD}} \times e^{-0.143\times\mathrm{PSL4550}} \times e^{-0.385\times\mathrm{PSL55p}} \times e^{-0.184\times\mathrm{CRS}} \times e^{-0.188\times\mathrm{SRS}}$	*k*= 0.790
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-4.048} \times \mathrm{L} \times AADT^{0.424} \times e^{0.002\times\mathrm{DCPM}} \times e^{0.186\times\mathrm{RRHR4}} \times e^{0.431\times\mathrm{RRHR567}} \times e^{0.029\times\mathrm{AD}} \times e^{-0.281\times\mathrm{PSL55p}} \times e^{-0.259\times\mathrm{CRS}} \times e^{-0.131\times\mathrm{SRS})}$	*k*= 0.929

The District-level modifications to the statewide SPF are shown in Table 2.4-3. To use the District Calibration Factors, it is recommended that the statewide SPF be calculated using the equations shown above, and the multiplicative factors shown in Table 2.4-3 be used to modify the predicted number of crashes from the statewide total and fatal and injury SPFs ($\mathbf{N}_{total}$ and $\mathbf{N}_{fatal\_inj}$).

Table 2.4-3: District Calibration Factors for Multi-lane Rural Highway Segments

District	District Calibration Factor for Total Crash SPF	District Calibration Factor for Fatal and Injury SPF
1	1.00	1.00
2	1.25	1.36
3	0.82	1.00
4	1.00	1.00
5	1.25	1.36
6	1.00	1.00
8	1.00	1.00
9	1.00	1.00
10	1.00	1.00
11	1.21	1.35
12	1.21	1.35

Table 2.4-4 provides a Pennsylvania specific percentage summary of all crashes identified on rural four-lane divided/undivided roadway segments by collision type and severity using the KABCO scale (the police-reported injury coding system). Similarly, Table 2.4-5 provides a summary of all crashes identified by illumination level and severity. The percentages provided in Table 2.4-4 and Table 2.4-5 may be applied as multipliers to predicted number of crashes to further estimate crash distribution based on severity, collision type, or illumination level. These adjustments are useful when considering countermeasures that apply only to specific crash severities, collision types, or illumination level. Additional detail about applying countermeasures is provided in Chapter 5.

Table 2.4-4: Distribution of Collision Type and Severity for Crashes on Rural Four-lane Divided/Undivided Highway Segments

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision (lane departure)	0.09%	0.21%	0.66%	1.81%	0.44%	0.04%	2.52%	**5.77%**
Non-collision (lane crash)	0.04%	0.16%	0.39%	0.76%	0.23%	0.07%	2.64%	**4.27%**
Rear-end	0.19%	0.36%	1.27%	3.86%	1.07%	0.33%	6.11%	**13.19%**
Head-on	0.14%	0.08%	0.12%	0.12%	0.05%	0.00%	0.20%	**0.72%**
Rear-to-rear (backing)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%	**0.03%**
Angle	0.18%	0.30%	0.72%	1.71%	0.46%	0.16%	2.85%	**6.36%**
Sideswipe (same direction)	0.06%	0.13%	0.36%	1.17%	0.23%	0.28%	2.60%	**4.84%**
Sideswipe (opposite direction)	0.02%	0.02%	0.03%	0.10%	0.01%	0.01%	0.14%	**0.34%**
Hit fixed object	0.78%	1.14%	3.92%	11.17%	2.52%	0.51%	27.47%	**47.50%**
Hit pedestrian	0.08%	0.04%	0.03%	0.04%	0.02%	0.00%	0.00%	**0.23%**
Other or unknown	0.02%	0.06%	0.21%	1.35%	0.18%	0.10%	14.83%	**16.74%**
Total	**1.61%**	**2.49%**	**7.72%**	**22.09%**	**5.21%**	**1.49%**	**59.40%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.4-5: Distribution of Illumination Level and Severity for Crashes on Rural Four-lane Divided/Undivided Highway Segments

Illumination	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Daylight	0.78%	1.49%	4.85%	13.39%	3.22%	0.72%	30.37%	**54.83%**
Dark - no streetlights	0.74%	0.84%	2.36%	7.15%	1.61%	0.64%	24.15%	**37.49%**
Dark - streetlights	0.03%	0.05%	0.14%	0.51%	0.13%	0.06%	1.85%	**2.78%**
Dusk	0.02%	0.06%	0.16%	0.40%	0.07%	0.01%	1.03%	**1.75%**
Dawn	0.03%	0.04%	0.19%	0.57%	0.16%	0.05%	1.77%	**2.80%**
Dark - unknown streetlighting	0.00%	0.00%	0.02%	0.05%	0.01%	0.00%	0.17%	**0.26%**
Other	0.00%	0.00%	0.00%	0.02%	0.01%	0.00%	0.05%	**0.09%**
Total	**1.61%**	**2.49%**	**7.72%**	**22.09%**	**5.21%**	**1.49%**	**59.40%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

2.5 Rural Multi-lane Highway Intersections

The regionalization level for SPF equations for rural multi-lane highway intersections is:

Pennsylvania Statewide level without Regionalized Calibration

The SPF equations for both total and F&I ($\mathbf{N}_{total}$ and $\mathbf{N}_{fatal\_inj}$) and related overdispersion parameters (***k***) for intersections on rural multi-lane highways are provided in Table 2.5-2. The base condition variables are defined in Table 2.5-1. The X's show that the base condition variables are used in all three intersection type SPFs.

Table 2.5-1: Base Condition Variables for Rural Multi-lane Highway Intersections

Base Condition Variables		Intersection Type		
		4-leg Signalized	4-leg Minor Street Stop	3-leg Minor Street Stop
$AADT_{Major}$	major road annual average daily traffic (veh/day)	X	X	X
$AADT_{Minor}$	minor road annual average daily traffic (veh/day)	X	X	X

Statistical analysis during development of the equations determined that there was not enough statistical variation to justify regionalization. The statewide equations for each intersection type apply to all locations and PennDOT Engineering Districts.

Table 2.5-2: SPF Predictive Equations for Rural Multi-lane Highway Intersections

SPF Predictive Equations		Overdispersion Parameter
3-leg with Minor Street Stop Control		
Total Predicted	$\boldsymbol{N_{total}} = e^{-8.072} \times AADT_{Major}^{0509} \times AADT_{Minor}^{0.509}$	*k*= 0.187
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-7.830} \times AADT_{Major}^{0.459} \times AADT_{Minor}^{0.459}$	*k*= 0.441
4-leg with Minor Street Stop Control		
Total Predicted	$\boldsymbol{N_{total}} = e^{-4.342} \times AADT_{Major}^{0.334} \times AADT_{Minor}^{0.264}$	*k*= 0.381
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-3.248} \times AADT_{Major}^{0.217} \times AADT_{Minor}^{0.152}$	*k*= 0.413
4-leg with Signalized Control		
Total Predicted	$\boldsymbol{N_{total}} = e^{-3.563} \times AADT_{Major}^{0.389} \times AADT_{Minor}^{0.134}$	*k*= 0.203
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-3.301} \times AADT_{Major}^{0.291} \times AADT_{Minor}^{0.133}$	*k*= 0.227

Table 2.5-3, Table 2.5-5, and Table 2.5-7 provide a Pennsylvania specific percentage summary of all crashes identified for four-lane rural intersections by collision type and severity using the KABCO scale (the police-reported injury coding system). Similarly, Table 2.5-4, Table 2.5-6, and Table 2.5-8 provide a summary of all crashes identified by illumination level and severity. The percentages provided in the following tables may be applied as multipliers to the predicted number of crashes to further estimate crash distribution based on severity, collision type, or illumination level. These adjustments are useful when considering countermeasures that apply only to specific crash severities, collision types, or illumination level. Additional detail about applying countermeasures is provided in Chapter 5.

Table 2.5-3: Distribution of Collision Type and Severity for Crashes on Rural Four-lane Three-leg Intersections with Minor Street Stop Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision	0.00%	0.00%	0.30%	0.30%	0.00%	0.00%	0.61%	**1.22%**
Rear-end	0.00%	0.00%	0.61%	4.57%	1.83%	0.00%	5.79%	**12.80%**
Head-on	0.00%	0.00%	1.22%	1.22%	0.30%	0.30%	0.91%	**3.96%**
Rear-to-rear (backing)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
Angle	2.74%	3.05%	10.06%	21.34%	7.32%	0.91%	26.52%	**71.95%**
Sideswipe (same direction)	0.00%	0.00%	0.00%	0.00%	0.00%	0.30%	1.22%	**1.52%**
Sideswipe (opposite direction)	0.00%	0.00%	0.30%	0.00%	0.00%	0.00%	0.30%	**0.61%**
Hit fixed object	0.00%	0.00%	0.91%	1.22%	0.61%	0.00%	3.96%	**6.71%**
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%	0.30%	0.61%	0.30%	0.00%	0.00%	**1.22%**
Total	**2.74%**	**3.05%**	**13.72%**	**29.27%**	**10.37%**	**1.52%**	**39.33%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.5-4: Distribution of Illumination Level and Severity for Crashes on Rural Four-lane Three-leg Intersections with Minor Street Stop Control

Illumination	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Daylight	2.13%	2.74%	10.37%	22.56%	7.62%	0.61%	29.88%	**75.91%**
Dark - no streetlights	0.30%	0.30%	2.13%	3.96%	1.22%	0.30%	5.49%	**13.72%**
Dark - streetlights	0.30%	0.00%	0.91%	1.22%	0.30%	0.30%	2.74%	**5.79%**
Dusk	0.00%	0.00%	0.00%	0.30%	0.61%	0.30%	0.30%	**1.52%**
Dawn	0.00%	0.00%	0.30%	1.22%	0.61%	0.00%	0.91%	**3.05%**
Dark - unknown streetlighting	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
Other	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
Total	**2.74%**	**3.05%**	**13.72%**	**29.27%**	**10.37%**	**1.52%**	**39.33%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.5-5: Distribution of Collision Type and Severity for Crashes on Rural Four-lane Four-leg Intersections with Minor Street Stop Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision	0.00%	0.00%	0.31%	0.00%	0.00%	0.00%	0.63%	**0.94%**
Rear-end	0.00%	0.31%	0.31%	1.57%	0.63%	0.00%	2.19%	**5.02%**
Head-on	0.00%	0.00%	0.63%	0.94%	0.94%	0.00%	0.31%	**2.82%**
Rear-to-rear (backing)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
Angle	2.82%	5.02%	14.11%	25.39%	8.46%	0.63%	30.41%	**86.83%**
Sideswipe (same direction)	0.00%	0.00%	0.00%	0.63%	0.31%	0.00%	0.00%	**0.94%**
Sideswipe (opposite direction)	0.00%	0.00%	0.00%	0.31%	0.00%	0.00%	0.00%	**0.31%**
Hit fixed object	0.00%	0.00%	0.00%	0.63%	0.31%	0.00%	1.25%	**2.19%**
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%	0.31%	0.00%	0.00%	0.00%	0.63%	**0.94%**
Total	**2.82%**	**5.33%**	**15.67%**	**29.47%**	**10.66%**	**0.63%**	**35.42%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.5-6: Distribution of Illumination Level and Severity for Crashes on Rural Four-lane Four-leg Intersections with Minor Street Stop Control

Illumination	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Daylight	2.51%	4.70%	11.29%	21.94%	9.09%	0.63%	29.15%	**79.31%**
Dark - no streetlights	0.31%	0.00%	3.13%	3.45%	0.94%	0.00%	4.08%	**11.91%**
Dark - streetlights	0.00%	0.63%	0.31%	2.51%	0.63%	0.00%	0.94%	**5.02%**
Dusk	0.00%	0.00%	0.31%	1.25%	0.00%	0.00%	0.31%	**1.88%**
Dawn	0.00%	0.00%	0.63%	0.31%	0.00%	0.00%	0.94%	**1.88%**
Dark - unknown streetlighting	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
Other	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	**0.00%**
Total	**2.82%**	**5.33%**	**15.67%**	**29.47%**	**10.66%**	**0.63%**	**35.42%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.5-7: Distribution of Collision Type and Severity for Crashes on Rural Four-lane Four-leg Intersections with Signal Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision	0.00%	0.14%	0.14%	0.82%	0.14%	0.00%	0.82%	**2.05%**
Rear-end	0.14%	0.41%	3.00%	8.73%	3.82%	0.14%	9.00%	**25.24%**
Head-on	0.00%	0.14%	0.41%	2.05%	0.68%	0.00%	2.73%	**6.00%**
Rear-to-rear (backing)	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.14%	**0.14%**
Angle	0.95%	1.50%	6.14%	17.05%	6.68%	1.09%	24.42%	**57.84%**
Sideswipe (same direction)	0.00%	0.00%	0.00%	0.41%	0.00%	0.00%	0.68%	**1.09%**
Sideswipe (opposite direction)	0.00%	0.00%	0.14%	0.41%	0.55%	0.00%	1.09%	**2.18%**
Hit fixed object	0.00%	0.41%	0.41%	0.82%	0.27%	0.00%	2.86%	**4.77%**
Hit pedestrian	0.00%	0.00%	0.00%	0.14%	0.00%	0.00%	0.00%	**0.14%**
Other or unknown	0.00%	0.00%	0.00%	0.14%	0.27%	0.00%	0.14%	**0.55%**
Total	**1.09%**	**2.59%**	**10.23%**	**30.56%**	**12.41%**	**1.23%**	**41.88%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.5-8: Distribution of Illumination Level and Severity for Crashes on Rural Four-lane Four-leg Intersections with Signal Control

Illumination	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Daylight	0.55%	1.64%	6.96%	21.28%	9.82%	0.55%	29.33%	**70.12%**
Dark - no streetlights	0.27%	0.55%	0.27%	3.00%	0.14%	0.14%	2.05%	**6.41%**
Dark - streetlights	0.27%	0.41%	2.86%	5.73%	1.91%	0.27%	8.05%	**19.51%**
Dusk	0.00%	0.00%	0.00%	0.27%	0.55%	0.00%	0.95%	**1.77%**
Dawn	0.00%	0.00%	0.14%	0.27%	0.00%	0.00%	0.95%	**1.36%**
Dark - unknown streetlighting	0.00%	0.00%	0.00%	0.00%	0.00%	0.27%	0.27%	**0.55%**
Other	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.27%	**0.27%**
Total	**1.09%**	**2.59%**	**10.23%**	**30.56%**	**12.41%**	**1.23%**	**41.88%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

2.6 Urban-suburban Collector Segments – Two-lane Undivided

The regionalization level for SPF equations for urban-suburban collector segments – two-lane undivided is:

District level with County Specific Calibration Factors

The county specific calibration factors are provided for both total and F&I crashes and should be applied to both the $\mathbf{N}_{\boldsymbol{total}}$ and $\mathbf{N}_{\boldsymbol{fatal\_inj}}$ predicted number of crashes respectively to yield an accurate estimate. The basic formula is:

$$N_{predicted} = N_{spf} \text{ x County Calibration Factor}$$

The SPF equations for both total and F&I ($\mathbf{N}_{\boldsymbol{total}}$ and $\mathbf{N}_{\boldsymbol{fatal\_inj}}$) and related overdispersion parameters (*k*) are provided in Table 2.9-2, and County Calibration Factors are provided in Table 2.9-3. The base condition variables are defined in Table 2.6-1 and vary in the equations for each District. The X's show whether the base condition variable is used in the District SPF.

Table 2.6-1: Base Condition Variables for Urban-suburban Collector Segments – Two-lane Undivided

Base Condition Variables		**District**										
		1	**2**	**3**	**4**	**5**	**6**	**8**	**9**	**10**	**11**	**12**
L	length of segment (miles)	X	X	X	X	X	X	X	X	X	X	X
AADT	annual average daily traffic on the segment (veh/day)	X	X	X	X	X	X	X	X	X	X	X
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)		X			X	X		X		X	
Parking Lane	presence of formal parking lane (1 if present, 0 otherwise)		X				X					
curb	presence of a raised curb (1 if present, 0 otherwise)				X		X	X			X	X
PSL45P	posted speed limit set to 45 mph or greater (1 if true, 0 otherwise)	X	X		X	X		X	X			
seg010l	Segment is less than 0.1 mile long (1 if true, 0 otherwise)			X				X				
*seg*025*l*	Segment is less than 0.25 mile long (1 if true, 0 otherwise)		X		X	X	X				X	X
*seg*050*l*	Segment is less than 0.50 mile long (1 if true, 0 otherwise)									X		
*seg*010025	Segment is between 0.1 and 0.25 mile long (1 if true, 0 otherwise)			X				X				
seg025050	Segment is between 0.25 and 0.50 mile long (1 if true, 0 otherwise)			X		X	X	X				
*seg*010050	Segment is between 0.1 and 0.50 mile long (1 if true, 0 otherwise)											

*Appendix B provides guidance on using Google Earth to determine DCPM.

Table 2.6-2: Regionalized SPFs for Urban-suburban Collector Segments – Two-lane Undivided

	Regionalized SPF Predictive Equations	Overdispersion Parameter
District 1		
Total Predicted	$\boldsymbol{N_{total}} = e^{-3.201} \times L \times AADT^{0.448} \times e^{-0.213PSL45P}$	*k*= 0.597
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-4.904} \times L \times AADT^{0.549}$	*k*= 0.918
District 2		
Total Predicted	$\boldsymbol{N_{total}} = e^{-3.836} \times L \times AADT^{0.498} \times e^{0.0016DCPM} \times e^{0.255Parking\_Lane} \times e^{-0.227PSL45P} \times e^{0.442seg025l}$	*k*= 0.236
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-5.026} \times L \times AADT^{0.540} \times e^{0.0033DCPM} \times e^{0.310Parking\_Lane} \times e^{-0.392PSL45P} \times e^{0.267seg025l}$	*k*= 0.533
District 3		
Total Predicted	$\boldsymbol{N_{total}} = e^{-3.699} \times L \times AADT^{0.478} \times e^{1.200seg010l} \times e^{0.411seg010025} \times e^{0.213seg025050}$	*k*= 0.618
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-4.624} \times L \times AADT^{0.490} \times e^{1.047seg010l} \times e^{0.345seg010050}$	*k*= 0.682
District 4		
Total Predicted	$\boldsymbol{N_{total}} = e^{-4.180} \times L \times AADT^{0.602} \times e^{0.330curb} \times e^{-0.541PSL45P} \times e^{0.363seg025l}$	*k*= 0.365
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-5.239} \times L \times AADT^{0.629} \times e^{0.408curb} \times e^{-0.347PSL45P} \times e^{0.523seg025l}$	*k*= 0.445
District 5		
Total Predicted	$\boldsymbol{N_{total}} = e^{-4.679} \times L \times AADT^{0.676} \times e^{0.0026DCPM} \times e^{-0.275PSL45P} \times e^{0.578seg025l} \times e^{0.128seg025050}$	*k*= 0.570
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-5.514} \times L \times AADT^{0.685} \times e^{0.0022DCPM} \times e^{-0.253PSL45P} \times e^{0.562seg025l} \times e^{0.091seg025050}$	*k*= 0.601
District 6		
Total Predicted	$\boldsymbol{N_{total}} = e^{-4.685} \times L \times AADT^{0.620} \times e^{0.0022DCPM} \times e^{0.113Parking\_Lane} \times e^{0.134curb} \times e^{0.503seg025l} \times e^{0.129seg025050}$	*k*= 0.520
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-6.215} \times L \times AADT^{0.695} \times e^{0.0022DCPM} \times e^{0.300Parking\_Lane} \times e^{0.159curb} \times e^{0.519seg025l} \times e^{0.116seg025050}$	*k*= 0.580
District 8		
Total Predicted	$\boldsymbol{N_{total}} = e^{-3.857} \times L \times AADT^{0.560} \times e^{0.108curb} \times e^{-0.199PSL45P} \times e^{1.102seg010l} \times e^{0.423seg010025} \times e^{0.060seg025050}$	*k*= 0.584
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-4.943} \times L \times AADT^{0.583} \times e^{-0.214PSL45P} \times e^{1.103seg010l} \times e^{0.414seg010025} \times e^{0.098seg025050}$	*k*= 0.699

Table 2.6-2 (Continued): Regionalized SPFs for Urban-suburban Collector Segments – Two-lane Undivided

Regionalized SPF Predictive Equations		Overdispersion Parameter
District 9		
Total Predicted	$N_{total} = e^{-4.923} \times L \times AADT^{0.692} \times e^{0.0011DCPM} \times e^{-0.154PSL45P}$	*k*= 0.354
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-5.343} \times L \times AADT^{0.648}$	*k*= 0.430
District 10		
Total Predicted	$N_{total} = e^{-5.057} \times L \times AADT^{0.667} \times e^{0.247seg050l}$	*k*= 0.652
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-5.580} \times L \times AADT^{0.634}$	*k*= 0.529
District 11		
Total Predicted	$N_{total} = e^{-4.918} \times L \times AADT^{0.634} \times e^{0.0011DCPM} \times e^{0.297curb} \times e^{0.590seg025l}$	*k*= 0.755
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-5.511} \times L \times AADT^{0.614} \times e^{0.296curb} \times e^{0.566seg025l}$	*k*= 0.816
District 12		
Total Predicted	$N_{total} = e^{-4.291} \times L \times AADT^{0.582} \times e^{0.331curb} \times e^{0.758seg025l}$	*k*= 0.381
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-5.336} \times L \times AADT^{0.620} \times e^{0.284curb} \times e^{0.674seg025l}$	*k*= 0.238

Table 2.6-3 shows how each District SPF should be modified when considering county-level predicted total and fatal and injury crash frequencies. To calculate the county-specific predicted number of crashes, the County Calibration Factors in Table 2.6-3 are multiplied by the $\mathbf{N}_{total}$ or $\mathbf{N}_{fatal\_inj}$ predicted number of crashes, which are found using the respective District-specific SPF equation in Table 2.6-2.

Table 2.6-3: County Calibration Factors for Urban-suburban Collector Segments Two-lane Undivided

District	County	County Calibration Factor for Total Crash SPF	County Calibration Factor for Fatal and Injury SPF
1	Crawford, Erie, Forest, Venango, Warren	1.000	1.000
	Mercer	1.553	1.778
2	Cameron, Centre, Clearfield, Elk, Juniata, Potter	1.000	1.000
	Clinton	0.665	1.000
	McKean, Mifflin	1.365	1.293
3	Bradford, Columbia, Lycoming, Montour, Snyder, Sullivan, Tioga, Union	1.000	1.000
	Northumberland	0.696	0.682
4	Lackawanna, Luzerne, Pike	1.000	1.000
	Susquehanna, Wayne, Wyoming	0.716	0.685
5	Berks, Lehigh	0.899	0.875
	Carbon, Schuylkill	0.685	0.664
	Monroe	1.392	1.438
	Northampton	1.000	1.000
6	Bucks, Montgomery	1.220	1.344
	Chester	1.000	1.000
	Delaware, Philadelphia	1.455	1.696
8	Adams, Lebanon, Perry	0.745	0.783
	Cumberland	0.808	0.835
	Dauphin, York	1.000	1.000
	Franklin	0.891	1.000
	Lancaster	0.911	1.000
9	Bedford, Cambria, Huntingdon	0.761	0.725
	Blair, Fulton	1.000	1.000
	Somerset	0.799	0.706
10	Armstrong, Jefferson	0.774	1.000
	Butler, Clarion, Indiana	1.000	1.000
11	Allegheny, Beaver, Lawrence	1.000	1.000
12	Fayette, Greene	0.910	1.000
	Washington	0.806	0.814
	Westmoreland	1.000	1.000

Table 2.6-4 provides a Pennsylvania specific percentage summary of all crashes identified on urban-suburban collector two-lane undivided roadway segments by collision type and severity using the KABCO scale (the police-reported injury coding system). The collision type and severity percentages provided in Table 2.6-4 may be applied as multipliers to the predicted number of crashes to further estimate crash distribution based on severity and collision type. These adjustments are useful when considering countermeasures that apply only to specific crash severities or collision types. Additional detail about applying countermeasures is provided in Chapter 5.

Table 2.6-4: Distribution of Collision Type and Severity for Crashes on Urban-suburban Collector Segments Two-lane Undivided

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	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%**	**100.00%**

*Based on 2013-2017 Reportable Crash Data

2.7 Urban-suburban Collector Intersections – Three-leg with Minor Street Stop Control or Signalized Control

The regionalization level for SPF equations for urban-suburban collector intersections – three-leg with minor street stop control or signalized control is:

Pennsylvania Statewide with District Specific Calibration Factors

The District-specific calibration factors are provided for both total and F&I crashes and should be applied to both the $\mathbf{N}_{\mathit{total}}$ and $\mathbf{N}_{\mathit{fatal\_inj}}$ predicted number of crashes respectively to yield an accurate estimate. The basic formula is:

$$N_{predicted} = N_{spf} \text{ x } \text{District Calibration Factor}$$

2.7.1 Urban-suburban Collector Intersection – Three-leg with Minor Street Stop Control

The SPF equations for both total and F&I ($\mathbf{N}_{\mathit{total}}$ and $\mathbf{N}_{\mathit{fatal\_inj}}$) and related overdispersion parameters (***k***) are provided in Table 2.7.1-2, and District Calibration Factors are provided in Table 2.7.1-3. The base condition variables are defined in Table 2.7.1-1. The X's show that the base condition variables apply for all Districts.

Table 2.7.1-1: Base Condition Variables for Urban-suburban Collector Intersections – Three-leg with Minor Street Stop Control

Base Condition Variables		All Districts
$AADT_{Major}$	major road annual average daily traffic (veh/day)	X
$AADT_{Minor}$	minor road annual average daily traffic (veh/day)	X
$Walk_{major}$	pedestrian crosswalk on the major road (1 = present; 0 = not present)	X
Major_PSL40P	posted speed limit set to 40 mph or greater on the major road approach (1 if true, 0 otherwise)	X

Table 2.7.1-2: Statewide SPFs for Urban-suburban Collector Intersections – Three-leg with Minor Street Stop Control

Regionalized SPF Predictive Equations		Overdispersion Parameter
Total Predicted	$N_{Total} = e^{-6.643} \times (AADT_{major})^{0.517} \times (AADT_{minor})^{0.254} \times e^{-0.314Walk_{major}} \times e^{0.158Major\_PSL40P}$	*k*= 0.454
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-7.547} \times (AADT_{major})^{0.513} \times (AADT_{minor})^{0.251} \times e^{0.218Major\_PSL40P}$	*k*= 0.496

The District-level modifications to the statewide SPF are shown in Table 2.7.1-3. To use the District Calibration Factors, it is recommended that the statewide SPF be calculated using the equations shown above, and the multiplicative factors shown in Table 2.7.1-3 be used to modify the predicted number of crashes from the statewide total and fatal and injury SPFs ($\mathbf{N}_{total}$ and $\mathbf{N}_{fatal\_inj}$).

Table 2.7.1-3: District Calibration Factors for Urban-suburban Collector Intersections – Three-leg with Minor Street Stop Control

District	District Calibration Factor for Total Crash SPF	District Calibration Factor for Fatal and Injury SPF
1	0.580	0.661
2	0.434	0.442
3	0.434	0.442
4	0.731	1.000
5	1.000	1.000
6	1.000	1.000
8	0.813	0.844
9	0.727	0.844
10	0.580	0.661
11	0.580	0.661
12	0.727	0.844

Table 2.7.1-4 provides a Pennsylvania specific percentage summary of all crashes identified on urban-suburban collector three-leg minor street stop controlled intersections by collision type and severity using the KABCO scale (the police-reported injury coding system). The collision type and severity percentages provided in Table 2.7.1-4 may be applied as multipliers to the predicted number of crashes to further estimate crash distribution based on severity and collision type. These adjustments are useful when considering countermeasures that apply only to specific crash severities or collision types. Additional detail about applying countermeasures is provided in Chapter 5.

Table 2.7.1-4: Distribution of Collision Type and Severity for Crashes on Urban-suburban Collector Intersections – Three-leg with Minor Street Stop Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	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%**	**100.00%**

*Based on 2013-2017 Reportable Crash Data

2.7.2 Urban-suburban Collector Intersection – Three-leg with Signalized Control

Estimates of crash frequency on three-leg signalized intersections can be performed using the SPF for three-leg minor street stop-controlled intersections. However, the estimates from the SPF should be adjusted by a multiplicative calibration factor to obtain the estimate of crash frequency at the three-leg signalized intersection. The calibration factor for total crash frequency is 1.37 and the calibration factor for fatal and injury crash frequency is 1.46.

2.8 Other Urban-suburban Collector Intersections

The regionalization level for SPF equations for urban-suburban collector intersections (not three-leg with minor street stop control which is described in Section 2.7) is:

Pennsylvania Statewide level without Regionalized Calibration

The SPF equations for both Total and F&I (N_{total} and N_{fatal_inj}) and related overdispersion parameters (*k*) for intersections on two-lane rural highways are provided in Table 2.8-2. The base condition variables are defined in Table 2.8-1 and vary in the equations for each intersection type. The X's show whether the base condition variable is used in the intersection type SPF.

Statistical analysis during development of the equations determined that there was not enough statistical variation to justify regionalization. The statewide equations for each intersection type apply to all locations and Districts in Pennsylvania.

Table 2.8-1: Base Condition Variables for Urban-suburban Collector Intersections

Base Condition Variables		Intersection Type				
		3-leg Signalized	3-leg All-way Stop	4-leg Minor Street Stop	4-leg All-way Stop	4-leg Signalized
$AADT_{major}$	major road annual average daily traffic (veh/day)	X	X	X	X	X
$AADT_{minor}$	minor road annual average daily traffic (veh/day)	X	X	X	X	X

Table 2.8-2: SPF Predictive Equations for Urban-suburban Collector Intersections

SPF Predictive Equations		Overdispersion Parameter
3-leg with All-way Stop Control		
Total Predicted	$\boldsymbol{N_{total}} = e^{-10.160} \times (AADT_{major})^{0.618} \times (AADT_{minor})^{0.534}$	*k*= 0.576
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-12.692} \times (AADT_{major})^{0.867} \times (AADT_{minor})^{0.498}$	*k*= 0.145
4-leg with Minor Street Stop Control		
Total Predicted	$\boldsymbol{N_{total}} = e^{-6.594} \times (AADT_{major})^{0.286} \times (AADT_{minor})^{0.643}$	*k*= 0.442
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-7.309} \times (AADT_{major})^{0.377} \times (AADT_{minor})^{0.526}$	*k*= 0.638
4-leg with All-way Stop Control		
Total Predicted	$\boldsymbol{N_{total}} = e^{-11.032} \times (AADT_{major} + AADT_{minor})^{1.233}$	*k*= 0.306
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-8.297} \times (AADT_{major} + AADT_{minor})^{0.830}$	*k*= 0.084
4-leg with Signalized Control		
Total Predicted	$\boldsymbol{N_{total}} = e^{-6.884} \times (AADT_{major})^{0.542} \times (AADT_{minor})^{0.308}$	*k*= 0.188
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-9.127} \times (AADT_{major})^{0.684} \times (AADT_{minor})^{0.333}$	*k*= 0.243

Table 2.8-3, Table 2.8-4, Table 2.8-5, and Table 2.8-6 Pennsylvania specific percentage summary of all crashes identified for the urban-suburban collector intersections by collision type and severity using the KABCO scale (the police-reported injury coding system). The percentages provided in the following tables may be applied as multipliers to the predicted number of crashes to further estimate crash distribution based on severity and collision type. These adjustments are useful when considering countermeasures that apply only to specific crash severities or collision types. Additional detail about applying countermeasures is provided in Chapter 5.

Table 2.8-3: Distribution of Collision Type and Severity for Crashes on Urban-suburban Collector Intersections – Three-leg with All-way Stop Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	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%**	**100.00%**

*Based on 2013-2017 Reportable Crash Data

Table 2.8-4: Distribution of Collision Type and Severity for Crashes on Urban-suburban Collector Intersections – Four-leg with Minor Street Stop Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	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%**	**100.00%**

*Based on 2013-2017 Reportable Crash Data

Table 2.8-5: Distribution of Collision Type and Severity for Crashes on Urban-suburban Collector Intersections – Four-leg with All-way Stop Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	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%**	**100.00%**

*Based on 2013-2017 Reportable Crash Data

Table 2.8-6: Distribution of Collision Type and Severity for Crashes on Urban-suburban Collector Intersections – Four-leg with Signalized Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	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%**	**100.00%**

*Based on 2013-2017 Reportable Crash Data

2.9 Urban-suburban Arterial Segments – Two-lane Undivided

The regionalization level for SPF equations for urban-suburban arterial segments – two-lane undivided is:

District level with County Specific Calibration Factors

The county specific calibration factors are provided for both total and F&I crashes and should be applied to both the $\mathbf{N}_{total}$ and $\mathbf{N}_{fatal\_inj}$ predicted number of crashes respectively to yield an accurate estimate. The basic formula is:

$$N_{predicted} = N_{spf} \text{ x County Calibration Factor}$$

The SPF equations for both Total and F&I ($\mathbf{N}_{total}$ and $\mathbf{N}_{fatal\_inj}$) and related overdispersion parameters (k) are provided in Table 2.9-2, and County Calibration Factors are provided in Table 2.9-3. The base condition variables are defined in Table 2.9-1 and vary in the equations for each District. The X's show whether the base condition variable is used in the District SPF.

Table 2.9-1: Base Condition Variables for Urban-suburban Arterial Segments – Two-lane Undivided

Base Condition Variables		District										
		1	2	3	4	5	6	8	9	10	11	12
L	length of segment (miles)	X	X	X	X	X	X	X	X	X	X	X
AADT	annual average daily traffic on the segment (veh/day)	X	X	X	X	X	X	X	X	X	X	X
PSL35	indicator variable for speed limits of 35 mph (1 = speed limit of 35 mph; 0 otherwise)	X			X	X	X	X	X		X	X
PSL40	indicator variable for speed limits of 40 mph (1 = speed limit of 40 mph; 0 otherwise)	X				X	X	X			X	
PSL45_65	indicator variable for speed limits of 45 to 65 mph (1 = speed limit of 45 to 65 mph; 0 otherwise)	X				X	X	X			X	
PSL40_65	indicator variable for speed limits of 40 to 65 mph (1 = speed limit of 45 to 65 mph; 0 otherwise)		X	X	X				X	X		X
CTL	indicator variable for presence of center two-way left-turn lane (1 = present; 0 otherwise)		X				X	X				
Parking Lane	indicator variable for presence of formal parking lane (1 = present; 0 otherwise)					X	X	X			X	

Table 2.9-2: Regionalized SPFs for Urban-suburban Arterial Segments – Two-lane Undivided

Regionalized SPF Predictive Equations		Overdispersion Parameter
District 1		
Total Predicted	$N_{total} = e^{-6.000} \times L \times AADT^{0.854} \times e^{-0.230\times \text{PSL35}} \times e^{-0.478\times \text{PSL40}} \times e^{-0.634\times \text{PSL45\_65}}$	*k*= 0.420
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-6.825} \times L \times AADT^{0.883} \times e^{-0.332\times \text{PSL35}} \times e^{-0.545\times \text{PSL40}} \times e^{-0.660\times \text{PSL45\_65}}$	*k*= 0.438
District 2		
Total Predicted	$N_{total} = e^{-5.621} \times L \times AADT^{0.807} \times e^{-0.606\times \text{PSL40\_65}} \times e^{0.230\times \text{CTL}}$	*k*= 0.359
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-7.520} \times L \times AADT^{0.943} \times e^{-0.610\times \text{PSL40\_65}} \times e^{0.115\times \text{CTL}}$	*k*= 0.282
District 3		
Total Predicted	$N_{total} = e^{-6.321} \times L \times AADT^{0.884} \times e^{-0.529\times \text{PSL40\_65}}$	*k*= 0.513
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-7.321} \times L \times AADT^{0.920} \times e^{-0.476\times \text{PSL40\_65}}$	*k*= 0.514
District 4		
Total Predicted	$N_{total} = e^{-7.089} \times L \times AADT^{1.015} \times e^{-0.493\times \text{PSL35}} \times e^{-0.801\times \text{PSL40\_65}}$	*k*= 0.402
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-8.713} \times L \times AADT^{1.124} \times e^{-0.500\times \text{PSL35}} \times e^{-0.823\times \text{PSL40\_65}}$	*k*= 0.440
District 5		
Total Predicted	$N_{total} = e^{-6.162} \times L \times AADT^{0.900} \times e^{-0.407\times \text{PSL35}} \times e^{-0.515\times \text{PSL40}} \times e^{-0.877\times \text{PSL45\_65}} \times e^{0.156\times \text{Parking\_Lane}}$	*k*= 0.340
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-7.170} \times L \times AADT^{0.943} \times e^{-0.403\times \text{PSL35}} \times e^{-0.491\times \text{PSL40}} \times e^{-0.863\times \text{PSL45\_65}} \times e^{0.082\times \text{Parking\_Lane}}$	*k*= 0.393
District 6		
Total Predicted	$N_{total} = e^{-5.004} \times L \times AADT^{0.774} \times e^{-0.247\times \text{PSL35}} \times e^{-0.376\times \text{PSL40}} \times e^{-0.474\times \text{PSL45\_65}} \times e^{0.180\times \text{CTL}} \times e^{0.183\times \text{Parking\_Lane}}$	*k*= 0.364
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-5.773} \times L \times AADT^{0.787} \times e^{-0.261\times \text{PSL35}} \times e^{-0.445\times \text{PSL40}} \times e^{-0.550\times \text{PSL45\_65}} \times e^{0.242\times \text{CTL}} \times e^{0.257\times \text{Parking\_Lane}}$	*k*= 0.393
District 8		
Total Predicted	$N_{total} = e^{-5.872} \times L \times AADT^{0.846} \times e^{-0.140\times \text{PSL35}} \times e^{-0.295\times \text{PSL40}} \times e^{-0.572\times \text{PSL45\_65}} \times e^{0.163\times \text{CTL}} \times e^{0.326\times \text{Parking\_Lane}}$	*k*= 0.369
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-6.902} \times L \times AADT^{0.885} \times e^{-0.169\times \text{PSL35}} \times e^{-0.299\times \text{PSL40}} \times e^{-0.588\times \text{PSL45\_65}} \times e^{0.243\times \text{CTL}} \times e^{0.326\times \text{Parking\_Lane}}$	*k*= 0.435

Table 2.9-2 (Continued): Regionalized SPFs for Urban-suburban Arterial Segments – Two-lane Undivided

Regionalized SPF Predictive Equations		Overdispersion Parameter
District 9		
Total Predicted	$\boldsymbol{N_{total}} = e^{-5.290} \times L \times AADT^{0.791} \times e^{-0.332 \times \text{PSL35}} \times e^{-0.741 \times \text{PSL40\_65}}$	*k*= 0.266
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-6.828} \times L \times AADT^{0.876} \times e^{-0.188 \times \text{PSL35}} \times e^{-0.570 \times \text{PSL40\_65}}$	*k*= 0.349
District 10		
Total Predicted	$\boldsymbol{N_{total}} = e^{-6.679} \times L \times AADT^{0.936} \times e^{-0.328 \times \text{PSL40\_65}}$	*k*= 0.503
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-6.915} \times L \times AADT^{0.889} \times e^{-0.343 \times \text{PSL40\_65}}$	*k*= 0.581
District 11		
Total Predicted	$\boldsymbol{N_{total}} = e^{-6.289} \times L \times AADT^{0.892} \times e^{-0.229 \times \text{PSL35}} \times e^{-0.408 \times \text{PSL40}} \times e^{-0.564 \times \text{PSL45\_65}} \times e^{0.307 \times \text{Parking\_Lane}}$	*k*= 0.562
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-7.343} \times L \times AADT^{0.930} \times e^{-0.249 \times \text{PSL35}} \times e^{-0.415 \times \text{PSL40}} \times e^{-0.557 \times \text{PSL45\_65}} \times e^{0.271 \times \text{Parking\_Lane}}$	*k*= 0.551
District 12		
Total Predicted	$\boldsymbol{N_{total}} = e^{-6.212} \times L \times AADT^{0.886} \times e^{-0.206 \times \text{PSL35}} \times e^{-0.328 \times \text{PSL40\_65}}$	*k*= 0.424
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-6.293} \times L \times AADT^{0.827} \times e^{-0.173 \times \text{PSL35}} \times e^{-0.354 \times \text{PSL40\_65}}$	*k*= 0.444

Table 2.9-2 shows how each District SPF should be modified when considering county-level predicted total and fatal and injury crash frequencies. To use the data shown in Table 2.9-3, the District-level SPF from Table 2.9-2 should be calculated and the multiplier shown for the specific county in Table 2.9-3 should be applied to the predicted number of crashes.

Table 2.9-3: County Calibration Factors for Urban-suburban Arterial Segments Two-lane Undivided

District	County	County Calibration Factor for Total Crash SPF	County Calibration Factor for Fatal and Injury SPF
1	Crawford, Forest, Warren	1.00	1.00
	Erie	1.27	1.22
	Mercer	1.30	1.30
	Venango	1.13	1.00
2	Cameron, Centre, Clinton, Elk, Juniata, McKean, Mifflin, Potter	1.00	1.00
	Clearfield	0.73	0.79
3	Bradford, Montour, Snyder, Sullivan, Tioga, Union	1.00	1.00
	Columbia	1.13	1.00
	Lycoming	1.23	1.15
	Northumberland	0.87	0.84
4	Lackawanna, Luzerne, Pike, Susquehanna, Wayne, Wyoming	1.00	1.00
5	Carbon, Schuylkill	1.00	1.00
	Berks, Northampton	1.43	1.34
	Lehigh	1.59	1.50
	Monroe	1.33	1.30
6	Bucks	0.90	0.86
	Chester	0.84	0.73
	Delaware	1.06	1.13
	Montgomery	1.00	1.00
	Philadelphia	1.36	1.99
8	Dauphin, Franklin, Perry, Lebanon	1.00	1.00
	Adams	0.84	0.78
	Cumberland	1.13	1.00
	Lancaster	1.09	1.07
	York	1.16	1.15
9	Bedford, Cambria, Fulton, Huntingdon, Somerset	1.00	1.00
	Blair	1.12	1.00
10	Butler, Clarion, Indiana, Jefferson	1.00	1.00
	Armstrong	0.70	0.64
11	Allegheny, Lawrence	1.00	1.00
	Beaver	0.84	0.80
12	Fayette, Greene	1.00	1.00
	Washington	0.84	0.76
	Westmoreland	0.90	0.82

Table 2.9-4 provides a Pennsylvania specific percentage summary of all crashes identified on urban-suburban arterial two-lane undivided roadway segments by collision type and severity using the KABCO scale (the police-reported injury coding system). Similarly, Table 2.9-5 provides a summary of all crashes identified by illumination level and severity. The percentages provided in Table 2.9-4 and Table 2.9-5 may be applied as multipliers to the predicted number of crashes to further estimate crash distribution based on severity, collision type, or illumination level. These adjustments are useful when considering countermeasures that apply only to specific crash severities, collision types, or illumination level. Additional detail about applying countermeasures is provided in Chapter 5.

Table 2.9-4: Distribution of Collision Type and Severity for Crashes on Urban-suburban Two-lane Undivided Arterial Segments

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision (lane departure)	0.00%	0.02%	0.04%	0.09%	0.04%	0.01%	0.15%	**0.35%**
Non-collision (lane crash)	0.02%	0.05%	0.21%	0.31%	0.19%	0.02%	0.62%	**1.41%**
Rear-end	0.04%	0.22%	1.81%	8.69%	6.13%	0.62%	13.48%	**30.98%**
Head-on	0.10%	0.25%	0.66%	1.22%	0.91%	0.10%	1.50%	**4.73%**
Rear-to-rear (backing)	0.00%	0.00%	0.00%	0.04%	0.03%	0.00%	0.05%	**0.13%**
Angle	0.19%	0.57%	2.76%	8.62%	5.73%	0.69%	14.54%	**33.10%**
Sideswipe (same direction)	0.01%	0.03%	0.17%	0.61%	0.40%	0.16%	1.61%	**3.00%**
Sideswipe (opposite direction)	0.02%	0.04%	0.19%	0.54%	0.33%	0.08%	1.04%	**2.24%**
Hit fixed object	0.20%	0.50%	1.50%	3.73%	2.29%	0.63%	10.05%	**18.90%**
Hit pedestrian	0.14%	0.29%	0.72%	1.39%	1.11%	0.00%	0.01%	**3.65%**
Other or unknown	0.00%	0.01%	0.07%	0.20%	0.10%	0.02%	1.08%	**1.49%**
Total	**0.72%**	**2.00%**	**8.14%**	**25.43%**	**17.26%**	**2.32%**	**44.12%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.9-5: Distribution of Illumination Level and Severity for Crashes on Urban-suburban Two-lane Undivided Arterial Segments

Illumination	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Daylight	0.37%	1.15%	5.40%	18.24%	12.54%	1.19%	29.36%	**68.26%**
Dark - no streetlights	0.15%	0.26%	0.71%	1.69%	0.89%	0.20%	3.95%	**7.85%**
Dark - streetlights	0.18%	0.50%	1.72%	4.69%	3.24%	0.83%	9.17%	**20.33%**
Dusk	0.01%	0.04%	0.15%	0.47%	0.31%	0.03%	0.80%	**1.81%**
Dawn	0.01%	0.03%	0.10%	0.24%	0.16%	0.03%	0.59%	**1.16%**
Dark - unknown streetlighting	0.00%	0.01%	0.04%	0.09%	0.11%	0.03%	0.20%	**0.48%**
Other	0.00%	0.00%	0.01%	0.02%	0.02%	0.01%	0.04%	**0.11%**
Total	**0.72%**	**2.00%**	**8.14%**	**25.43%**	**17.27%**	**2.32%**	**44.12%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

2.10 Urban-suburban Arterial Segments – Four-lane Undivided

The regionalization level for SPF equations for urban-suburban arterial segments – four-lane undivided is:

Pennsylvania Statewide with District Specific Calibration Factors

The District-specific calibration factors are provided for both total and F&I crashes and should be applied to both the $\mathbf{N}_{total}$ and $\mathbf{N}_{fatal\_inj}$ predicted number of crashes respectively to yield an accurate estimate. The basic formula is:

$$N_{predicted} = N_{spf} \text{ x District Calibration Factor}$$

The SPF equations for both Total and F&I ($\mathbf{N}_{total}$ and $\mathbf{N}_{fatal\_inj}$) and related overdispersion parameters (k) are provided in Table 2.10-2, and District Calibration Factors are provided in Table 2.10-3. The base condition variables are defined in Table 2.10-1. The X's show that the base condition variables apply for all Districts.

Table 2.10-1: Base Condition Variables for Urban-suburban Arterial Segments – Four-lane Undivided

Base Condition Variables		All Districts
L	Length of segment (miles)	X
AADT	annual average daily traffic on the segment (veh/day)	X
PSL35	indicator variable for speed limits of 35 mph (1 = speed limit of 35 mph; 0 otherwise)	X
PSL40	indicator variable for speed limits of 40 mph (1 = speed limit of 40 mph; 0 otherwise)	X
PSL45_65	indicator variable for speed limits of 45 to 65 mph (1 = speed limit of 45 to 65 mph; 0 otherwise)	X
CTL	indicator variable for presence of center two-way left-turn lane (1 = present; 0 otherwise)	X

Table 2.10-2: Statewide SPFs for Urban-suburban Arterial Segment – Four-lane Undivided

	Regionalized SPF Predictive Equations	Overdispersion Parameter
Total Predicted	$\boldsymbol{N_{total}} = e^{-3.487} \times L \times AADT^{0.645} \times e^{-0.262\times \mathrm{PSL35}} \times e^{-0.555\times \mathrm{PSL40}} \times e^{-0.804\times \mathrm{PSL45\_65}} \times e^{0.388\times \mathrm{CTL}}$	*k*= 0.911
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-3.909} \times L \times AADT^{0.651} \times e^{-0.482\times \mathrm{PSL35}} \times e^{-0.826\times \mathrm{PSL40}} \times e^{-1.095\times \mathrm{PSL45\_65}} \times e^{0.440\times \mathrm{CTL}}$	*k*= 0.991

The District-level modifications to the statewide SPF are shown in Table 2.10-2. To use the calibration factors, it is recommended that the statewide SPF be calculated using the equations shown above, and the District Calibration Factors shown in Table 2.10-3 be used to modify the predicted number of crashes from the total and fatal and injury SPFs ($\mathbf{N}_{\boldsymbol{total}}$ and $\mathbf{N}_{\boldsymbol{fatal\_inj}}$).

Table 2.10-3: District Calibration Factors for Urban-suburban Arterial Four-lane Undivided

District	District Calibration Factor for Total Crash SPF	District Calibration Factor for Fatal and Injury SPF
1	0.86	0.90
2	0.73	0.64
3	0.80	0.76
4	1.00	1.00
5	1.42	1.39
6	1.00	1.00
8	1.11	1.07
9	0.73	0.64
10	0.57	0.55
11	1.00	1.00
12	1.00	1.00

Table 2.10-4 provides a summary of all crashes identified on urban-suburban arterial four-lane undivided roadway segments by collision type and severity using the KABCO scale (the police-reported injury coding system). Similarly, Table 2.10-5 provides a summary of all crashes identified by illumination level and severity. The percentages provided in Table 2.10-4 and Table 2.10-5 may be applied as multipliers to the predicted number of crashes to further estimate crash distribution based on severity, collision type, or illumination level. These adjustments are useful when considering countermeasures that apply only to specific crash severities, collision types, or illumination level. Additional detail about applying countermeasures is provided in Chapter 5.

Table 2.10-4: Distribution of Collision Type and Severity for Crashes on Urban-suburban Four-lane Undivided Arterial Segments

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision (lane departure)	0.01%	0.01%	0.01%	0.02%	0.01%	0.00%	0.05%	**0.11%**
Non-collision (lane crash)	0.01%	0.03%	0.16%	0.24%	0.21%	0.03%	0.48%	**1.15%**
Rear-end	0.04%	0.24%	1.77%	8.48%	7.21%	0.69%	11.59%	**30.01%**
Head-on	0.05%	0.17%	0.63%	1.25%	0.94%	0.09%	1.33%	**4.45%**
Rear-to-rear (backing)	0.00%	0.00%	0.01%	0.03%	0.03%	0.01%	0.05%	**0.13%**
Angle	0.23%	0.76%	3.61%	11.09%	8.71%	0.84%	16.69%	**41.93%**
Sideswipe (same direction)	0.00%	0.04%	0.25%	0.98%	0.80%	0.13%	1.80%	**4.00%**
Sideswipe (opposite direction)	0.01%	0.03%	0.14%	0.44%	0.35%	0.06%	0.67%	**1.69%**
Hit fixed object	0.13%	0.28%	0.88%	1.82%	1.43%	0.33%	5.78%	**10.64%**
Hit pedestrian	0.25%	0.40%	0.92%	1.80%	1.63%	0.00%	0.01%	**5.02%**
Other or unknown	0.00%	0.01%	0.05%	0.11%	0.07%	0.03%	0.60%	**0.88%**
Total	**0.72%**	**1.98%**	**8.43%**	**26.24%**	**21.37%**	**2.21%**	**39.05%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.10-5: Distribution of Illumination Level and Severity for Crashes on Urban-suburban Four-lane Undivided Arterial Segments

Illumination	Crash Severity Level							
	Fatal (K)	**Suspected Serious Injury (A)**	**Suspected Minor Injury (B)**	**Possible Injury (C)**	**Injury/ Unknown Severity (C)**	**Unknown (U)**	**Not Injured (O)**	**Sum**
Daylight	0.35%	1.14%	5.59%	18.63%	15.14%	1.22%	26.45%	**68.51%**
Dark - no streetlights	0.08%	0.11%	0.30%	0.68%	0.55%	0.06%	1.56%	**3.34%**
Dark - streetlights	0.26%	0.65%	2.22%	6.09%	4.95%	0.86%	9.74%	**24.78%**
Dusk	0.02%	0.05%	0.17%	0.47%	0.37%	0.03%	0.65%	**1.76%**
Dawn	0.01%	0.03%	0.10%	0.24%	0.20%	0.02%	0.47%	**1.06%**
Dark - unknown streetlighting	0.00%	0.01%	0.04%	0.07%	0.11%	0.01%	0.12%	**0.37%**
Other	0.00%	0.00%	0.00%	0.05%	0.06%	0.00%	0.06%	**0.18%**
Total	**0.72%**	**1.98%**	**8.43%**	**26.24%**	**21.38%**	**2.21%**	**39.05%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

2.11 Urban-suburban Arterial Segments – Four-lane Divided

The regionalization level for SPF equations for urban-suburban arterial segments – four-lane divided is:

Pennsylvania Statewide with District-specific Calibration Factors

The District-specific calibration factors are provided for both total and F&I crashes and should be applied to both the $\mathbf{N}_{\mathbf{\textit{total}}}$ and $\mathbf{N}_{\mathbf{\textit{fatal\_inj}}}$ predicted number of crashes respectively to yield an accurate estimate. The basic formula is:

$$N_{predicted} = N_{spf} \text{ x District Calibration Factor}$$

The SPF equations for both Total and F&I ($\mathbf{N}_{\mathbf{\textit{total}}}$ and $\mathbf{N}_{\mathbf{\textit{fatal\_inj}}}$) and related overdispersion parameters (***k***) are provided in Table 2.11-2, and District Calibration Factors are provided in Table 2.11-3. The base condition variables are defined in Table 2.11-1. The X's show that the base condition variables apply for all Districts.

Table 2.11-1: Base Condition Variables for Urban-suburban Arterial Segments – Four-lane Divided

Base Condition Variables		All Districts
L	Length of segment (miles)	X
AADT	annual average daily traffic on the segment (veh/day)	X
PSL35	indicator variable for speed limits of 35 mph (1 = speed limit of 35 mph; 0 otherwise)	X
PSL40	indicator variable for speed limits of 40 mph (1 = speed limit of 40 mph; 0 otherwise)	X
PSL45	indicator variable for speed limits of 45 mph (1 = speed limit of 45 mph; 0 otherwise)	X
PSL50_65	indicator variable for speed limits of 50 to 65 mph (1 = speed limit of 50 to 65 mph; 0 otherwise)	X
LTL	indicator variable for presence of median left-turn lane (1 = present; 0 otherwise)	X
Barrier	indicator variable for presence of median barrier (1 = present; 0 otherwise)	X

Table 2.11-2: Statewide SPFs for Urban-suburban Arterial Segments – Four-lane Divided

Regionalized SPF Predictive Equations		Overdispersion Parameter
Total Predicted	$N_{total} = e^{-5.044} \times L \times AADT^{0.747} \times e^{-0.126\times PSL35} \times e^{-0.283\times PSL40} \times e^{-0.479\times PSL45} \times e^{-0.912\times PSL50\_65} \times e^{0.155\times barrier} \times e^{0.501\times LTL}$	*k*= 0.994
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-5.344} \times L \times AADT^{0.732} \times e^{-0.275\times PSL35} \times e^{-0.446\times PSL40} \times e^{-0.722\times PSL45} \times e^{-1.172\times PSL50\_65} \times e^{0.129\times barrier} \times e^{0.544\times LTL}$	*k*= 1.120

The District-level modifications to the statewide SPF are shown in Table 2.11-2. To use the calibration factors, it is recommended that the statewide SPF be estimated using the equations shown above, and the District Calibration Factors shown in Table 2.11-3 be used to modify the predicted number of crashes from the total and fatal and injury SPFs ($\mathbf{N}_{total}$ and $\mathbf{N}_{fatal\_inj}$).

Table 2.11-3: District Calibration Factors for Urban-suburban Arterial Segments – Four-lane Divided

District	District Calibration Factor for Total Crash SPF	District Calibration Factor for Fatal and Injury SPF
1	1.00	1.00
2	1.00	1.00
3	0.87	0.81
4	1.29	1.27
5	1.65	1.74
6	1.17	1.25
8	1.33	1.25
9	1.00	1.00
10	1.00	1.00
11	1.05	1.00
12	1.00	1.00

Table 2.11-4 provides a Pennsylvania specific percentage summary of all crashes identified on urban-suburban arterial four-lane divided roadway segments by collision type and severity using the KABCO scale (the police-reported injury coding system). Similarly, Table 2.11-5 provides a summary of all crashes identified by illumination level and severity. The percentages provided in Table 2.11-4 and Table 2.11-5 may be applied as multipliers to the predicted number of crashes to further estimate crash distribution based on severity, collision type, or illumination level. These adjustments are useful when considering countermeasures that apply only to specific crash severities, collision types, or illumination level. Additional detail about applying countermeasures is provided in Chapter 5.

Table 2.11-4: Distribution of Collision Type and Severity for Crashes on Urban-suburban Four-lane Divided Arterial Segments

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision (lane departure)	0.01%	0.01%	0.04%	0.09%	0.03%	0.00%	0.15%	**0.33%**
Non-collision (lane crash)	0.00%	0.04%	0.26%	0.31%	0.18%	0.02%	0.96%	**1.77%**
Rear-end	0.06%	0.31%	2.14%	10.21%	7.56%	0.65%	15.35%	**36.28%**
Head-on	0.06%	0.12%	0.42%	0.84%	0.59%	0.06%	0.88%	**2.97%**
Rear-to-rear (backing)	0.00%	0.01%	0.00%	0.02%	0.02%	0.01%	0.03%	**0.09%**
Angle	0.29%	0.75%	3.27%	9.16%	6.55%	0.49%	13.47%	**33.97%**
Sideswipe (same direction)	0.01%	0.05%	0.23%	0.86%	0.61%	0.15%	1.79%	**3.70%**
Sideswipe (opposite direction)	0.01%	0.02%	0.08%	0.26%	0.21%	0.02%	0.42%	**1.02%**
Hit fixed object	0.18%	0.39%	1.17%	2.78%	1.73%	0.50%	8.69%	**15.43%**
Hit pedestrian	0.16%	0.17%	0.43%	0.65%	0.55%	0.00%	0.01%	**1.97%**
Other or unknown	0.01%	0.01%	0.07%	0.23%	0.11%	0.04%	2.00%	**2.46%**
Total	**0.78%**	**1.87%**	**8.11%**	**25.40%**	**18.15%**	**1.94%**	**43.74%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.11-5: Distribution of Illumination Level and Severity for Crashes on Urban-suburban Four-lane Divided Arterial Segments

Illumination	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Daylight	0.40%	1.02%	5.35%	18.16%	12.87%	1.07%	28.42%	**67.28%**
Dark - no streetlights	0.15%	0.24%	0.72%	1.64%	0.95%	0.16%	4.61%	**8.46%**
Dark - streetlights	0.20%	0.54%	1.75%	4.87%	3.70%	0.64%	9.05%	**20.75%**
Dusk	0.02%	0.03%	0.15%	0.39%	0.30%	0.04%	0.75%	**1.67%**
Dawn	0.02%	0.03%	0.09%	0.24%	0.19%	0.03%	0.71%	**1.30%**
Dark - unknown streetlighting	0.01%	0.01%	0.04%	0.08%	0.11%	0.02%	0.17%	**0.44%**
Other	0.00%	0.00%	0.01%	0.03%	0.04%	0.00%	0.03%	**0.10%**
Total	**0.78%**	**1.87%**	**8.11%**	**25.40%**	**18.15%**	**1.94%**	**43.74%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

2.12 Urban-suburban Arterial Intersections – Three-leg with Minor Street Stop Control

The regionalization level for SPF equations for urban-suburban arterial intersections – three-leg with minor street stop control is:

District level with County Specific Calibration Factors

The county-specific calibration factors are provided for both total and F&I crashes and should be applied to both the $\mathbf{N}_{total}$ and $\mathbf{N}_{fatal\_inj}$ predicted number of crashes respectively to yield an accurate estimate. The basic formula is:

$$N_{predicted} = N_{spf} \ \text{x} \ \text{County Calibration Factor}$$

The SPF equations for both Total and F&I ($\mathbf{N}_{total}$ and $\mathbf{N}_{fatal\_inj}$) and related overdispersion parameters (*k*) are provided in Table 2.12-2, and County Calibration Factors are provided in Table 2.12-3. The base condition variables are defined in Table 2.12-1 and vary in the equations for each District. The X's show whether the base condition variable is used in the District SPF.

Table 2.12-1: Base Condition Variables for Urban-suburban Arterial Segments: Three-leg with Minor Street Stop Control

Base Condition Variables		District										
		1	2	3	4	5	6	8	9	10	11	12
$AADT_{Major}$	major road annual average daily traffic (veh/day)	X	X	X	X	X	X	X	X	X	X	X
$AADT_{Minor}$	minor road annual average daily traffic (veh/day)	X	X	X	X	X	X	X	X	X	X	X
MajPSL40p	indicator for posted speed limit of 40 mph or greater on major road (1 = present; 0 otherwise)	X	X	X		X	X				X	X
MinPSL40p	indicator for posted speed limit of 40 mph or greater on minor road (1 = present; 0 otherwise)	X	X	X				X			X	

Table 2.12-2: Regionalized SPFs for Urban-suburban Arterial Segment: Three-leg with Minor Street Stop Control

Regionalized SPF Predictive Equations		Overdispersion Parameter
District 1		
Total Predicted	$N_{total} = e^{-6.758} \times AADT_{Major}^{0.538} \times AADT_{Minor}^{0.188} \times e^{0.210 \times \text{MajPSL40p}} \times e^{0.356 \times \text{MinPSL40p}}$	*k*= 0.286
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-7.447} \times AADT_{Major}^{0.557} \times AADT_{Minor}^{0.150} \times e^{0.551 \times \text{MajPSL40p}}$	*k*= 0.0000057
District 2		
Total Predicted	$N_{total} = e^{-6.758} \times AADT_{Major}^{0.538} \times AADT_{Minor}^{0.188} \times e^{0.210 \times \text{MajPSL40p}} \times e^{0.356 \times \text{MinPSL40p}}$	*k*= 0.286
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-7.447} \times AADT_{Major}^{0.557} \times AADT_{Minor}^{0.150} \times e^{0.551 \times \text{MajPSL40p}}$	*k*= 0.0000057
District 3		
Total Predicted	$N_{total} = e^{-8.382} \times AADT_{Major}^{0.532} \times AADT_{Minor}^{0.931} \times e^{0.344 \times \text{MajPSL40p}} \times e^{0.327 \times \text{MinPSL40p}}$	*k*= 0.193
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-10.660} \times AADT_{Major}^{0.638} \times AADT_{Minor}^{0.451} \times e^{0.522 \times \text{MajPSL40p}} \times e^{0.486 \times \text{MinPSL40p}}$	*k*= 0.119
District 4		
Total Predicted	$N_{total} = e^{-8.655} \times AADT_{Major}^{0.662} \times AADT_{Minor}^{0.362}$	*k*= 0.166
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-10.980} \times AADT_{Major}^{0.884} \times AADT_{Minor}^{0.323}$	*k*= 0.049
District 5		
Total Predicted	$N_{total} = e^{-6.255} \times AADT_{Major}^{0.403} \times AADT_{Minor}^{0.350} \times e^{0.293 \times \text{MajPSL40p}}$	*k*= 0.342
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-8.088} \times AADT_{Major}^{0.549} \times AADT_{Minor}^{0.321} \times e^{0.392 \times \text{MajPSL40p}}$	*k*= 0.406
District 6		
Total Predicted	$N_{total} = e^{-6.729} \times AADT_{Major}^{0.423} \times AADT_{Minor}^{0.373} \times e^{0.131 \times \text{MajPSL40p}}$	*k*= 0.397
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-9.186} \times AADT_{Major}^{0.575} \times AADT_{Minor}^{0.432}$	*k*= 0.449
District 8		
Total Predicted	$N_{total} = e^{-8.417} \times AADT_{Major}^{0.623} \times AADT_{Minor}^{0.334} \times e^{0.236 \times \text{MinPSL40p}}$	*k*= 0.272
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-10.217} \times AADT_{Major}^{0.722} \times AADT_{Minor}^{0.357} \times e^{0.267 \times \text{MinPSL40p}}$	*k*= 0.263

Table 2.12-2 (Continued): Regionalized SPFs for Urban-suburban Arterial Segment: Three-leg with Minor Street Stop Control

Regionalized SPF Predictive Equations		Overdispersion Parameter
District 9		
Total Predicted	$\boldsymbol{N_{total}} = e^{-7.090} \times AADT_{Major}^{0.550} \times AADT_{Minor}^{0.244}$	*k*= 0.482
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-8.011} \times AADT_{Major}^{0.642} \times AADT_{Minor}^{0.162}$	*k*= 0.456
District 10		
Total Predicted	$\boldsymbol{N_{total}} = e^{-7.090} \times AADT_{Major}^{0.550} \times AADT_{Minor}^{0.244}$	*k*= 0.482
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-8.011} \times AADT_{Major}^{0.642} \times AADT_{Minor}^{0.162}$	*k*= 0.456
District 11		
Total Predicted	$\boldsymbol{N_{total}} = e^{-9.485} \times AADT_{Major}^{0.787} \times AADT_{Minor}^{0.288} \times e^{0.153 \times \text{MajPSL40p}} \times e^{0.139 \times \text{MinPSL40p}}$	*k*= 0.407
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-10.899} \times AADT_{Major}^{0.913} \times AADT_{Minor}^{0.229} \times e^{0.309 \times \text{MajPSL40p}}$	*k*= 0.452
District 12		
Total Predicted	$\boldsymbol{N_{total}} = e^{-9.022} \times AADT_{Major}^{0.826} \times AADT_{Minor}^{0.169} \times e^{0.245 \times \text{MajPSL40p}}$	*k*= 0.440
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-10.305} \times AADT_{Major}^{0.870} \times AADT_{Minor}^{0.193} \times e^{0.351 \times \text{MajPSL40p}}$	*k*= 0.364

To apply the County Calibration Factors for total and fatal and injury crashes, multiply the predicted number of crashes calculated from the appropriate District-level SPF in Table 2.12-2 by the corresponding (either total or fatal and injury) county specific calibration factor in Table 2.12-3.

Table 2.12-3: County Calibration Factors for Urban-suburban Arterial Segment: Three-leg with Minor Street Stop Control

District	County	County Calibration Factor for Total Crash SPF[1]	County Calibration Factor for Fatal and Injury SPF[1]
1	All Counties	1.00	1.00
2	All Counties	1.00	1.00
3	All Counties	1.00	1.00
4	All Counties	1.00	1.00
5	All Counties	1.00	1.00
6	All Counties	1.00	1.00
8	All Counties	1.00	1.00
9	All Counties	1.00	1.00
10	All Counties	1.00	1.00
11	Allegheny, Lawrence	1.00	1.00
	Beaver	1.46	1.56
12	All Counties	1.00	1.00

[1] – All Estimates of crash frequency on **three-leg minor street stop controlled intersections with 'STOP Except Right Turns' signs** can be performed using the county-level SPF for three-leg minor street stop controlled intersections. However, the estimates from the county-level SPF should be adjusted by a multiplicative calibration factor to obtain the estimate of crash frequency at the three-leg minor street stop controlled intersections with 'STOP Except Right Turns' signs. The calibration factor for total crash frequency is 0.68 and the calibration factor for fatal and injury crash frequency is 0.54.

Table 2.12-4 provides a Pennsylvania specific percentage summary of all crashes identified on urban-suburban three-leg arterial intersections with stop control by collision type and severity using the KABCO scale (the police-reported injury coding system). Similarly, Table 2.12-5 provides a summary of all crashes identified by illumination level and severity. The percentages provided in Table 2.12-4 and Table 2.12-5 may be applied as multipliers to the predicted number of crashes to further estimate crash distribution based on severity, collision type, or illumination level. These adjustments are useful when considering countermeasures that apply only to specific crash severities, collision types, or illumination level. Additional detail about applying countermeasures is provided in Chapter 5.

Table 2.12-4: Distribution of Collision Type and Severity for Crashes on Urban-suburban Three-leg Arterial Intersection with Minor Street Stop Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision	0.03%	0.03%	0.19%	0.31%	0.28%	0.02%	0.42%	**1.27%**
Rear-end	0.02%	0.08%	0.87%	4.58%	3.44%	0.31%	6.20%	**15.49%**
Head-on	0.03%	0.10%	0.50%	1.09%	0.86%	0.07%	1.51%	**4.14%**
Rear-to-rear (backing)	0.00%	0.00%	0.01%	0.03%	0.04%	0.00%	0.05%	**0.13%**
Angle	0.60%	1.18%	5.38%	16.18%	10.29%	1.11%	28.03%	**62.76%**
Sideswipe (same direction)	0.01%	0.01%	0.20%	0.36%	0.24%	0.10%	0.87%	**1.79%**
Sideswipe (opposite direction)	0.00%	0.04%	0.13%	0.34%	0.25%	0.04%	0.92%	**1.73%**
Hit fixed object	0.08%	0.19%	0.73%	1.79%	0.87%	0.43%	5.27%	**9.36%**
Hit pedestrian	0.11%	0.10%	0.45%	1.07%	0.99%	0.00%	0.00%	**2.72%**
Other or unknown	0.00%	0.01%	0.03%	0.10%	0.15%	0.02%	0.29%	**0.61%**
Total	**0.86%**	**1.75%**	**8.49%**	**25.84%**	**17.41%**	**2.09%**	**43.56%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.12-5: Distribution of Illumination Level and Severity for Crashes on Urban-suburban Three-leg Arterial Intersection with Minor Street Stop Control

Illumination	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Daylight	0.61%	1.25%	6.19%	20.15%	13.64%	1.36%	31.80%	**75.00%**
Dark - no streetlights	0.13%	0.19%	0.58%	1.27%	0.82%	0.13%	3.02%	**6.13%**
Dark - streetlights	0.12%	0.28%	1.38%	3.59%	2.30%	0.54%	6.88%	**15.09%**
Dusk	0.01%	0.02%	0.18%	0.48%	0.37%	0.03%	0.98%	**2.06%**
Dawn	0.00%	0.00%	0.11%	0.28%	0.17%	0.00%	0.62%	**1.18%**
Dark - unknown streetlighting	0.00%	0.00%	0.03%	0.05%	0.11%	0.03%	0.24%	**0.46%**
Other	0.00%	0.01%	0.02%	0.02%	0.01%	0.00%	0.03%	**0.08%**
Total	**0.86%**	**1.75%**	**8.49%**	**25.84%**	**17.41%**	**2.09%**	**43.56%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

2.13 Other Urban-suburban Arterial Intersections

The regionalization level for SPF equations for all other urban-suburban arterial intersections (not three-leg with minor street stop control which is described in Section 2.12) is:

Pennsylvania Statewide with District-Specific Calibration Factors

The District-specific calibration factors are provided for both total and F&I crashes and should be applied to both the $\mathbf{N}_{\boldsymbol{total}}$ and $\mathbf{N}_{\boldsymbol{fatal\_inj}}$ predicted number of crashes respectively to yield an accurate estimate. The basic formula is:

$$N_{predicted} = N_{spf} \text{ x } \text{District Calibration Factor}$$

The SPF equations for both Total and F&I ($\mathbf{N}_{\boldsymbol{total}}$ and $\mathbf{N}_{\boldsymbol{fatal\_inj}}$) and related overdispersion parameters ($\boldsymbol{k}$) are provided in the first table provided for each intersection type, and District Calibration Factors are provided in the second table. The base condition variables are defined in Table 2.13.1-1, Table 2.13.2-1, Table 2.13.3-1. The X's show that the base condition variables apply for all Districts.

2.13.1 Four-leg with Minor Street Stop Control

A statewide SPF with District-level calibration factors is recommended for four-leg minor stop-controlled intersections. The total and fatal and injury crash SPFs are shown in Table 2.13.1-2, and the District Calibration Factors are shown in Table 2.13.1-3. To apply the District-specific calibration factors, the statewide SPF should be estimated first and the result multiplied by the District-level calibration factor.

Table 2.13.1-1: Base Condition Variables for Urban-suburban Arterial – Four-leg Minor-Stop Control

Base Condition Variables		All Districts
$AADT_{Major}$	major road annual average daily traffic (veh/day)	X
$AADT_{Minor}$	minor road annual average daily traffic (veh/day)	X
MajPSL40_45	indicator for posted speed limit of 40 or 45 mph on major road (1 = present; 0 otherwise)	X
MajPSL50_55	indicator for posted speed limit of 50 or 55 mph on major road (1 = present; 0 otherwise)	X
MinPSL40p	indicator for posted speed limit of 40 mph or more on minor road (1 = present; 0 otherwise)	X

Table 2.13.1-2: Statewide SPFs for Urban-suburban Arterial – Four-leg Minor-Stop Control

Regionalized SPF Predictive Equations		Overdispersion Parameter
Total Predicted	$N_{total} = e^{-6.909} \times AADT_{Major}^{0.530} \times AADT_{Minor}^{0.279} \times e^{0.183 \times \text{MajPSL40\_45}} \times e^{0.356 \times \text{MajPSL50\_55}} \times e^{0.131 \times \text{MinPSL40p}}$	*k*= 0.387
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-8.223} \times AADT_{Major}^{0.585} \times AADT_{Minor}^{0.296} \times e^{0.132 \times \text{MajPSL40\_45}} \times e^{0.396 \times \text{MajPSL50\_55}} \times e^{0.169 \times \text{MinPSL40p}}$	*k*= 0.368

Table 2.13.1-3: District Calibration Factors for Urban-suburban Arterial – Four-leg Minor-Stop Control

District	District Calibration Factor for Total Crash SPF	District Calibration Factor for Fatal and Injury SPF
1	1.00	1.00
2	1.00	1.00
3	1.00	1.00
4	1.00	1.00
5	1.44	1.44
6	1.16	1.14
8	1.44	1.44
9	1.00	1.00
10	1.00	1.00
11	1.00	1.00
12	1.00	1.00

Table 2.13.1-4 provides a Pennsylvania specific percentage summary of all crashes identified on urban-suburban four-leg arterial intersections with stop control by collision type and severity using the KABCO scale (the police-reported injury coding system). Similarly, Table 2.13.1-5 provides a summary of all crashes identified by illumination level and severity. The percentages provided in Table 2.13.1-4 and Table 2.13.1-5 may be applied as multipliers to the predicted number of crashes to further estimate crash distribution based on severity, collision type, or illumination level. These adjustments are useful when considering countermeasures that apply only to specific crash severities, collision types, or illumination level. Additional detail about applying countermeasures is provided in Chapter 5.

Table 2.13.1-4: Distribution of Collision Type and Severity for Crashes on Urban-suburban Four-leg Arterial Intersection with Minor Street Stop Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision	0.00%	0.04%	0.15%	0.24%	0.14%	0.00%	0.20%	**0.78%**
Rear-end	0.01%	0.04%	0.39%	1.60%	1.40%	0.11%	2.29%	**5.84%**
Head-on	0.02%	0.06%	0.38%	0.92%	0.59%	0.07%	1.24%	**3.29%**
Rear-to-rear (backing)	0.00%	0.00%	0.01%	0.04%	0.03%	0.00%	0.04%	**0.12%**
Angle	0.40%	1.43%	6.66%	21.09%	14.15%	1.56%	35.24%	**80.53%**
Sideswipe (same direction)	0.01%	0.03%	0.06%	0.35%	0.11%	0.04%	0.51%	**1.11%**
Sideswipe (opposite direction)	0.00%	0.03%	0.19%	0.46%	0.34%	0.08%	0.86%	**1.96%**
Hit fixed object	0.01%	0.07%	0.25%	0.66%	0.42%	0.10%	1.75%	**3.27%**
Hit pedestrian	0.07%	0.11%	0.43%	1.24%	0.83%	0.00%	0.02%	**2.71%**
Other or unknown	0.00%	0.00%	0.02%	0.13%	0.07%	0.02%	0.15%	**0.39%**
Total	**0.53%**	**1.81%**	**8.57%**	**26.73%**	**18.08%**	**1.98%**	**42.30%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.13.1-5: Distribution of Illumination Level and Severity for Crashes on Urban-suburban Four-leg Arterial Intersection with Minor Street Stop Control

Illumination	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Daylight	0.38%	1.16%	6.56%	20.93%	14.19%	1.27%	33.09%	**77.60%**
Dark - no streetlights	0.03%	0.18%	0.36%	1.02%	0.67%	0.07%	1.86%	**4.20%**
Dark - streetlights	0.09%	0.38%	1.40%	4.00%	2.66%	0.57%	6.15%	**15.25%**
Dusk	0.01%	0.05%	0.14%	0.55%	0.41%	0.03%	0.80%	**1.99%**
Dawn	0.01%	0.02%	0.05%	0.16%	0.08%	0.01%	0.29%	**0.63%**
Dark - unknown streetlighting	0.00%	0.00%	0.03%	0.05%	0.06%	0.03%	0.08%	**0.25%**
Other	0.00%	0.01%	0.02%	0.01%	0.01%	0.00%	0.03%	**0.08%**
Total	**0.53%**	**1.81%**	**8.57%**	**26.73%**	**18.08%**	**1.98%**	**42.30%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

2.13.2 Three-leg with Signalized Control

A statewide SPF with District-level calibration factors is recommended for three-leg signalized intersections. The **total** and **fatal and injury** crash SPFs are shown in Table 2.13.2-2, and the District Calibration Factors are shown in Table 2.13.2-3. To apply the District-specific calibration factors, the statewide SPF should be estimated first and the result multiplied by the District-level calibration factor.

Table 2.13.2-1: Base Condition Variables for Urban-suburban Arterial – Three-leg with Signalized Control

Base Condition Variables		All Districts
$AADT_{Major}$	major road annual average daily traffic (veh/day)	X
$AADT_{Minor}$	minor road annual average daily traffic (veh/day)	X
ELTMaj	indicator variable for exclusive left-turn lane on the major street approach (1 = present; 0 otherwise)	X
ELTMin	indicator variable for exclusive left-turn lane on the minor street approach (1 = present; 0 otherwise)	X
MajPSL30_35	indicator for posted speed limit of 30 or 35 mph on major road (1 = present; 0 otherwise)	X
MajPSL40p	indicator for posted speed limit of 40 mph or more on major road (1 = present; 0 otherwise)	X

Table 2.13.2-2: Statewide SPFs for Urban-suburban Arterial – Three-leg with Signalized Control

Regionalized SPF Predictive Equations		Overdispersion Parameter
Total Predicted	$\boldsymbol{N_{total}} = e^{-5.113} \times AADT_{Major}^{0.393} \times AADT_{Minor}^{0.219} \times e^{0.097\times \text{ELTMaj}} \times e^{0.110\times \text{ELTMin}} \times e^{0.131\times \text{MajPSL30\_35}} \times e^{0.346\times \text{MajPSL40p}}$	*k*= 0.385
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-5.677} \times AADT_{Major}^{0.381} \times AADT_{Minor}^{0.247} \times e^{0.115\times \text{ELTMaj}} \times e^{0.181\times \text{MajPSL40p}}$	*k*= 0.458

Table 2.13.2-3: District Calibration Factors for Urban-suburban Arterial – Three-leg with Signalized Control

District	District Calibration Factor for Total Crash SPF	District Calibration Factor for Fatal and Injury SPF
1	1.00	1.00
2	1.00	1.00
3	0.87	0.81
4	1.00	1.00
5	1.18	1.12
6	1.00	1.00
8	0.87	0.81
9	0.87	0.81
10	1.00	1.00
11	1.18	1.12
12	1.00	1.00

Table 2.13.2-4 provides a Pennsylvania specific percentage summary of all crashes identified on urban-suburban three-leg arterial intersections with signalized control by collision type and severity using the KABCO scale (the police-reported injury coding system). Similarly, Table 2.13.2-5 provides a summary of all crashes identified by illumination level and severity. The percentages provided in Table 2.13.2-4 and Table 2.13.2-5 may be applied as multipliers to the predicted number of crashes to further estimate crash distribution based on severity, collision type, or illumination level. These adjustments are useful when considering countermeasures that apply only to specific crash severities, collision types, or illumination level. Additional detail about applying countermeasures is provided in Chapter 5.

Table 2.13.2-4: Distribution of Collision Type and Severity for Crashes on Urban-suburban Three-leg Arterial Intersection with Signalized Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision	0.00%	0.01%	0.22%	0.18%	0.16%	0.03%	0.48%	**1.08%**
Rear-end	0.07%	0.27%	2.16%	10.29%	8.24%	0.74%	13.82%	**35.58%**
Head-on	0.02%	0.09%	0.55%	1.36%	1.20%	0.14%	1.77%	**5.11%**
Rear-to-rear (backing)	0.00%	0.01%	0.01%	0.05%	0.01%	0.00%	0.02%	**0.10%**
Angle	0.32%	0.65%	3.40%	11.29%	7.69%	0.67%	16.64%	**40.66%**
Sideswipe (same direction)	0.02%	0.04%	0.15%	0.64%	0.51%	0.08%	1.28%	**2.72%**
Sideswipe (opposite direction)	0.01%	0.01%	0.12%	0.32%	0.31%	0.03%	0.80%	**1.61%**
Hit fixed object	0.04%	0.16%	0.60%	1.52%	1.29%	0.36%	4.94%	**8.92%**
Hit pedestrian	0.10%	0.31%	0.62%	1.59%	1.26%	0.00%	0.01%	**3.88%**
Other or unknown	0.00%	0.01%	0.02%	0.06%	0.05%	0.01%	0.20%	**0.34%**
Total	**0.57%**	**1.55%**	**7.85%**	**27.30%**	**20.72%**	**2.05%**	**39.95%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.13.2-5: Distribution of Illumination Level and Severity for Crashes on Urban-suburban Three-leg Arterial Intersection with Signalized Control

Illumination	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Daylight	0.29%	0.93%	5.04%	19.07%	14.59%	1.07%	26.86%	**67.85%**
Dark - no streetlights	0.04%	0.07%	0.27%	0.72%	0.53%	0.06%	1.22%	**2.91%**
Dark - streetlights	0.24%	0.47%	2.24%	6.80%	4.98%	0.83%	10.60%	**26.17%**
Dusk	0.00%	0.01%	0.16%	0.45%	0.32%	0.04%	0.55%	**1.54%**
Dawn	0.01%	0.04%	0.07%	0.21%	0.17%	0.02%	0.57%	**1.09%**
Dark - unknown streetlighting	0.00%	0.03%	0.06%	0.03%	0.11%	0.02%	0.12%	**0.37%**
Other	0.00%	0.00%	0.00%	0.03%	0.02%	0.01%	0.02%	**0.08%**
Total	**0.57%**	**1.55%**	**7.85%**	**27.30%**	**20.72%**	**2.05%**	**39.95%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

2.13.3 Four-leg with Signalized Control

A statewide SPF with District-level calibration factors is recommended for four-leg signalized intersections. The **total** and **fatal and injury** crash SPFs are shown in Table 2.13.3-2, and the District Calibration Factors are shown in Table 2.13.3-3. To apply the District-specific calibration factors, the statewide SPF should be estimated first and the result multiplied by the District-level calibration factor.

Table 2.13.3-1: Base Condition Variables for Urban-suburban Arterial – Four-leg with Signalized Control

Base Condition Variables		All Districts
$AADT_{Major}$	major road annual average daily traffic (veh/day)	X
$AADT_{Minor}$	minor road annual average daily traffic (veh/day)	X
ELTMaj	indicator variable for exclusive left-turn lane on the major street approach (1 = present; 0 otherwise)	X
ERTMaj	indicator variable for exclusive right-turn lane on the major street approach (1 = present; 0 otherwise)	X
ELTMin	indicator variable for exclusive left-turn lane on the minor street approach (1 = present; 0 otherwise)	X
ERTMin	indicator variable for exclusive right-turn lane on the minor street approach (1 = present; 0 otherwise)	X
MajPSL40_45	indicator for posted speed limit of 40 or 45 mph on major road (1 = present; 0 otherwise)	X
MajPSL50_55	indicator for posted speed limit of 50 or 55 mph on major road (1 = present; 0 otherwise)	X
MinPSL35p	indicator for posted speed limit of 35 mph or more on minor road (1 = present; 0 otherwise)	X

Table 2.13.3-2: Statewide SPFs for Urban-suburban Arterial – Four-leg with Signalized Control

Regionalized SPF Predictive Equations		Overdispersion Parameter
Total Predicted	$\boldsymbol{N_{total}} = e^{-5.501} \times AADT_{Major}^{0.403} \times AADT_{Minor}^{0.316} \times e^{0.053 \times \mathrm{ELTMaj}} \times e^{0.126 \times \mathrm{ERTMaj}} \times e^{0.056 \times \mathrm{ELTMin}} \times e^{0.045 \times \mathrm{ERTMin}} \times e^{0.101 \times \mathrm{MajPSL40\_45}} \times e^{0.290 \times \mathrm{MajPSL50\_55}} \times e^{0.075 \times \mathrm{MinPSL35p}}$	*k*= 0.356
Fatal Inj Predicted	$\boldsymbol{N_{fatal\_inj}} = e^{-6.374} \times AADT_{Major}^{0.411} \times AADT_{Minor}^{0.363} \times e^{0.130 \times \mathrm{ELTMaj}} \times e^{0.053 \times \mathrm{ELTMin}} \times e^{0.226 \times \mathrm{MajPSL50\_55}}$	*k*= 0.432

Table 2.13.3-3: District Calibration Factors for Urban-suburban Arterial – Four-leg with Signalized Control

District	District Calibration Factor for Total Crash SPF	District Calibration Factor for Fatal and Injury SPF
1	0.78	0.74
2	0.78	0.74
3	0.71	0.64
4	1.11	1.09
5	1.00	1.00
6	1.00	1.00
8	0.88	0.79
9	0.88	0.79
10	0.71	0.64
11	0.96	0.83
12	0.78	0.74

Table 2.13.3-4 provides a Pennsylvania specific percentage summary of all crashes identified on urban-suburban four-leg arterial intersections with signalized control by collision type and severity using the KABCO scale (the police-reported injury coding system). Similarly, Table 2.13.3-5 provides a summary of all crashes identified by illumination level and severity. The percentages provided in Table 2.13.3-4 and Table 2.13.3-5 may be applied as multipliers to the predicted number of crashes to further estimate crash distribution based on severity, collision type, or illumination level. These adjustments are useful when considering countermeasures that apply only to specific crash severities, collision types, or illumination level. Additional detail about applying countermeasures is provided in Chapter 5.

Table 2.13.3-4: Distribution of Collision Type and Severity for Crashes on Urban-suburban Four-leg Arterial Intersection with Signalized Control

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision	0.01%	0.02%	0.14%	0.17%	0.09%	0.01%	0.31%	**0.75%**
Rear-end	0.02%	0.19%	1.44%	7.63%	6.21%	0.49%	8.76%	**24.73%**
Head-on	0.01%	0.12%	0.67%	1.55%	1.01%	0.10%	1.76%	**5.22%**
Rear-to-rear (backing)	0.00%	0.00%	0.01%	0.03%	0.03%	0.00%	0.05%	**0.12%**
Angle	0.20%	0.87%	4.94%	14.71%	10.49%	1.07%	20.86%	**53.15%**
Sideswipe (same direction)	0.00%	0.02%	0.17%	0.66%	0.48%	0.11%	0.98%	**2.43%**
Sideswipe (opposite direction)	0.00%	0.02%	0.18%	0.54%	0.33%	0.07%	0.79%	**1.93%**
Hit fixed object	0.03%	0.09%	0.37%	0.84%	0.58%	0.18%	2.83%	**4.93%**
Hit pedestrian	0.12%	0.34%	1.17%	2.67%	2.15%	0.00%	0.01%	**6.45%**
Other or unknown	0.00%	0.01%	0.03%	0.06%	0.05%	0.01%	0.13%	**0.29%**
Total	**0.39%**	**1.67%**	**9.13%**	**28.86%**	**21.42%**	**2.04%**	**36.48%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Table 2.13.3-5: Distribution of Illumination Level and Severity for Crashes on Urban-suburban Four-leg Arterial Intersection with Signalized Control

Illumination	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Daylight	0.21%	0.97%	6.01%	20.22%	15.05%	1.11%	24.46%	**68.03%**
Dark - no streetlights	0.02%	0.06%	0.26%	0.60%	0.39%	0.05%	1.08%	**2.45%**
Dark - streetlights	0.14%	0.57%	2.54%	7.17%	5.17%	0.81%	9.76%	**26.15%**
Dusk	0.01%	0.03%	0.16%	0.50%	0.41%	0.02%	0.64%	**1.77%**
Dawn	0.01%	0.03%	0.09%	0.25%	0.20%	0.03%	0.42%	**1.04%**
Dark - unknown streetlighting	0.00%	0.01%	0.05%	0.08%	0.16%	0.01%	0.11%	**0.43%**
Other	0.00%	0.01%	0.02%	0.04%	0.05%	0.00%	0.02%	**0.12%**
Total	**0.39%**	**1.67%**	**9.13%**	**28.86%**	**21.42%**	**2.04%**	**36.48%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

2.13.4 Four-leg with All Way Stop Control

Estimates of crash frequency on four-leg all-way stop-controlled intersections can be performed using the SPF for four-leg minor stop-controlled intersections. However, the estimates from the SPF should be adjusted by a multiplicative calibration factor to obtain the estimate of crash frequency at the four-leg all-way stop-controlled intersection. The calibration factor for total crash frequency is 0.96 and the calibration factor for fatal and injury crash frequency is 0.85.

2.13.5 Five-leg with Signalized Control

Estimates of crash frequency on five-leg signalized intersections can be performed using the SPF for four-leg signalized intersections. However, the estimates from the SPF should be adjusted by a multiplicative calibration factor to obtain the estimate of crash frequency at the five-leg signalized intersection. The calibration factor for total crash frequency is 1.05 and the calibration factor for fatal and injury crash frequency is 0.98.

Chapter 3 — Utilizing Pennsylvania Calibration Factors for the HSM Predictive Method for Freeways and Ramps

3.1 General

In 2014, AASHTO released a supplement to the 2010 HSM. This supplement added Chapter 18 – Freeways and Chapter 19 – Ramps. Rather than create Pennsylvania-specific SPFs for freeways and ramps, PennDOT calibrated the HSM Supplement SPFs. Table 3.1-1 lists categories of freeway and ramp SPFs and indicates which have been calibrated for Pennsylvania. The 2014 HSM Supplement defines the site types in Table 3.1-1 and provides depictions. Notably, Figure 18-10 illustrates freeway segments and speed change lanes, Figure 19-1 illustrates ramp terminal intersection types, and Figure 19-10 illustrates ramps and collector-distributor roads.

Table 3.1-1: HSM Freeway and Ramp Predictive Models and Pennsylvania Calibration Status

Site Type	SPF	Applicable Predictive Model Equation from 2014 Supplement to HSM	Calibrated for Pennsylvania?
Freeway Segment	Multi-vehicle fatal-and-injury crashes, all cross sections	18-3	Yes
Freeway Segment	Multiple-vehicle property-damage-only crashes, all cross sections	18-5	Yes
Freeway Segment	Single-vehicle fatal-and-injury crashes, all cross sections	18-4	Yes
Freeway Segment	Single-vehicle property-damage-only crashes, all cross sections	18-6	Yes
Ramp Segment	Entrance ramp, multiple-vehicle fatal-and-injury crashes, all lanes	19-3	Yes
Ramp Segment	Entrance ramp, multiple-vehicle property-damage-only crashes, all lanes	19-5	Yes
Ramp Segment	Entrance ramp, single-vehicle fatal-and-injury crashes, all lanes	19-4	Yes
Ramp Segment	Entrance ramp, single-vehicle property-damage-only crashes, all lanes	19-6	Yes
Ramp Segment	Exit ramp, multiple-vehicle fatal-and-injury crashes, all lanes	19-3	Yes
Ramp Segment	Exit ramp, multiple-vehicle property-damage-only crashes, all lanes	19-5	Yes
Ramp Segment	Exit ramp, single-vehicle fatal-and-injury crashes, all lanes	19-4	Yes
Ramp Segment	Exit ramp, single-vehicle property-damage-only crashes, all lanes	19-6	Yes
C-D Road Segment	C-D road, multiple-vehicle fatal-and-injury crashes, all cross sections	19-8	No
C-D Road Segment	C-D road, multiple-vehicle property-damage-only crashes, all cross sections	19-10	No
C-D Road Segment	C-D road, single-vehicle fatal-and-injury crashes, all cross sections	19-9	No
C-D Road Segment	C-D road, single-vehicle property-damage-only crashes, all cross sections	19-11	No
Speed-Change Lane	Ramp entrance speed-change lane, fatal-and-injury crashes of all types	18-8	No
Speed-Change Lane	Ramp entrance speed-change lane, property-damage-only crashes of all types	18-9	No
Speed-Change Lane	Ramp exit speed-change lane, fatal-and-injury crashes of all types	18-11	No
Speed-Change Lane	Ramp exit speed-change lane, property-damage-only crashes of all types	18-12	No
Ramp Terminal	One-way stop control ramp terminal, fatal-and-injury crashes of all types	19-13	Yes
Ramp Terminal	One-way stop control ramp terminal, property-damage-only crashes of all types	19-14	Yes
Ramp Terminal	Signal control ramp terminal, fatal-and-injury crashes of all types	19-16	Yes
Ramp Terminal	Signal control ramp terminal, property-damage-only crashes of all types	19-17	Yes

Rows of Table 3.1-1 have multiple SPFs associated with them. For example, the first row, multi-vehicle fatal-and-injury crashes on freeway segments, encompasses SPFs for rural 4-lane freeway segments, rural 6-lane freeway segments, rural 8-lane freeway segments, urban 4-lane freeway segments, urban 6-lane freeway segments, urban 8-lane freeway segments, and urban 10-lane freeway segments. Freeway rows of Table 3.1-1 generally encompass SPFs for urban and rural freeways with different numbers of lanes. Ramp rows of Table 3.1-1 generally encompass SPFs or urban and rural area types, one-lane and two-lane ramps in urban areas, and different ramp terminal configurations in the case of ramp terminal SPFs. Recognizing the challenges of calibrating such a large number of SPFs, the HSM presents a streamlined calibration process that groups some related SPFs together to lessen data and analysis needs for calibration.

Calibration factors were not developed for collector-distributor roads or speed-change lanes. At the time calibration factors were developed, there was not a means of readily identifying collector-distributor roads statewide. The calibration process was begun for speed-change lanes, but significant variability in the crash data and calibration results was found. The computed calibration factors were not more statistically reliable than an uncalibrated model, therefore calibration factors for speed-change lanes in Pennsylvania are not recommended for use and are not presented in this Publication. Given the lack of calibration factors, collector-distributor road and speed-change lane crash prediction models can be used uncalibrated (i.e. with a calibration factor of 1.00), recognizing there is less reliability with these models than the calibrated models for other site types.

Calibration factors were developed from PennDOT-owned roadway sites statewide and are applicable statewide; there is no regionalization of the calibration factors. Crash data from years 2013-2017 was used for the calibration.

3.2 Applying Freeway and Ramp Models in Pennsylvania

The 2014 HSM Supplement, available for purchase from AASHTO, fully describes the SPFs and defines all variables used in those equations. This section describes Pennsylvania-specific issues associated with using the SPFs and assigning crashes to sites for the purpose of Empirical Bayes analysis. Following the guidance in this section will result in HSM analysis consistent with the analysis used to develop the calibration factors.

3.2.1 Ramp Curvature

Ramp SPFs are highly sensitive to curvature and accurate measurement of curves is essential. Users should manually collect curve data for ramps or utilize PennDOT’s Video Log curve data (which is under development at the time this Publication is being written). Options for manual collection include acquiring design plans, importing aerial photographs into CADD software and measuring curve data in CADD, or measuring curve data using an online mapping/navigation aid. Appendix B describes one means of measuring curve data with Google Earth.

3.2.2 Average Traffic Speed on Freeway

Ramp SPFs are highly sensitive to the value of the ‘average traffic speed on freeway’ variable. The SPFs use this variable and ramp curve data to compute the speed vehicles are travelling through curves under the assumption that traffic enters and exits the freeway at the speed of average freeway traffic. However, the geometry of many loop ramps in Pennsylvania does not permit this and drivers enter or exit the freeway at speeds lower than the average travel speed. When analyzing a loop ramp, the ‘average traffic speed on freeway’ value should be set as the average of the posted speed limit on the freeway and the posted advisory speed of the ramp or the first curve of the ramp (whichever advisory speed is posted first along the ramp). For example, if a freeway is posted at 65 MPH and a loop ramp has an advisory speed of 35 MPH, the value of ‘average traffic speed on freeway’ should be set at 50 MPH because (65+35)/2 = 50. This results in predicted crash frequencies that are more consistent with observed crash frequencies.

3.2.3 Loop Ramp Classification

The 2014 HSM supplement classifies ramps as entrance ramps, exit ramps, or connector ramps. Connector ramps are generally between two freeways. Loop connector ramps are relatively common in Pennsylvania but relatively rare in the states used to develop the HSM ramp models. Loop connector ramps should be analyzed as exit ramps – not connectors. This results in predicted crash frequencies that are more consistent with observed crash frequencies.

3.2.4 Bifurcated Ramps

Ramps are sometimes bifurcated (or split), and different portions of the ramp serve different vehicular movements. For example, an exit ramp may fork, with the left portion of the ramp serving traffic turning left at the crossroad and the right portion of the ramp serving traffic turning right at the crossroad. Sometimes the bifurcation occurs near the ramp terminal intersection and forms what is effectively a short channelized turn lane.

If the gore point of the bifurcation is within 250 feet of the ramp terminal, the resulting ramp created by the bifurcation is considered a channelized turn lane and not analyzed as a separate ramp (i.e. crashes along it are accounted for in the SPF of the ‘first’ ramp or the ramp terminal intersection, and separate analysis of the ‘second’ ramp and ramp speed-change lane connecting it with the ‘first’ ramp is unnecessary). Table 3.1-1 shows examples of channelized turn lanes that begin/end within 250 feet of the crossroad and are not analyzed as separate ramps.

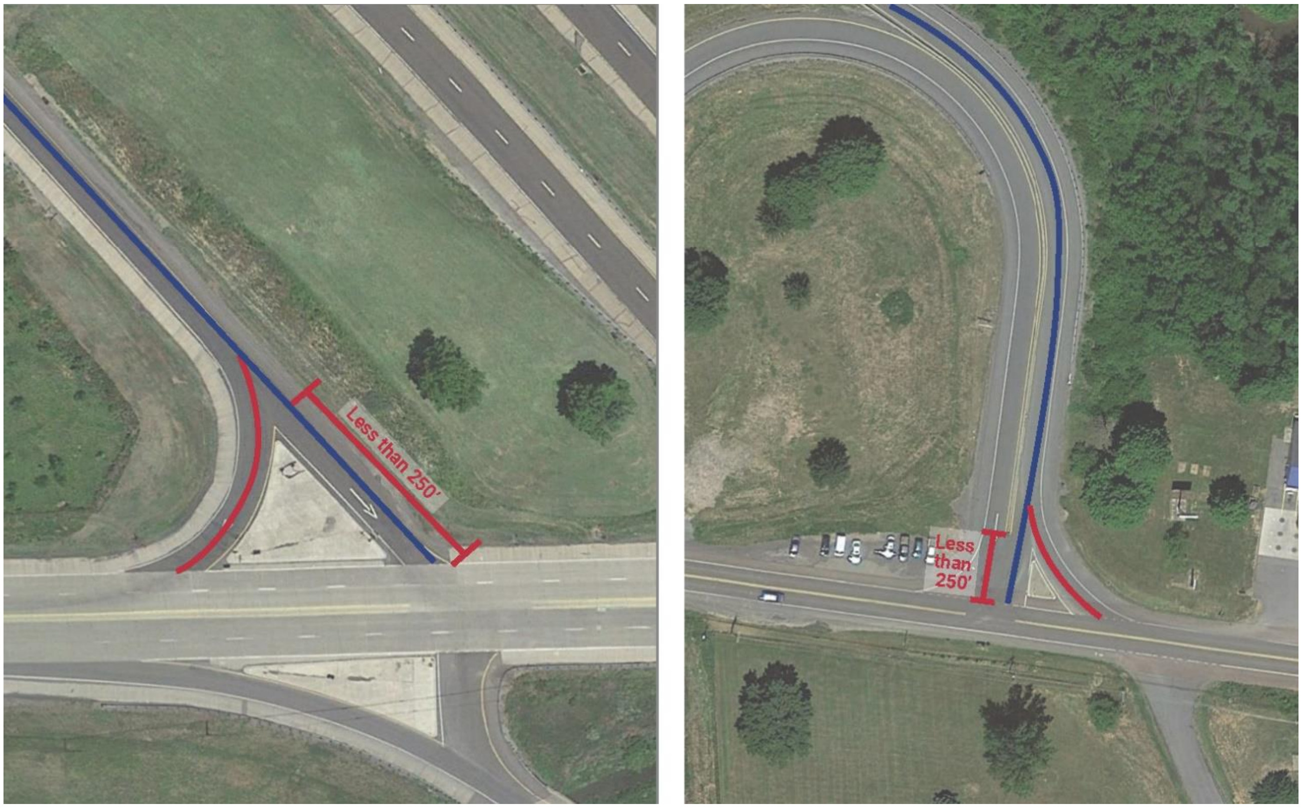

Figure 3-1: Channelized Turn Lanes Not Considered to be Bifurcated Ramps

In Figure 3-1, the blue portion of the ramp is analyzed with a ramp SPF. The red portion of the ramp is considered to be a channelized turn lane and should not be analyzed as a separate ramp. Crashes occurring along the red portion are accounted for with the ramp SPF used to analyze the blue portion of the ramp or the ramp terminal intersection SPF.

If the gore point of the bifurcation is more than 250 feet from the ramp terminal, both forks of the ramp should be analyzed as separate ramps. Figure 3-2 shows examples of this.

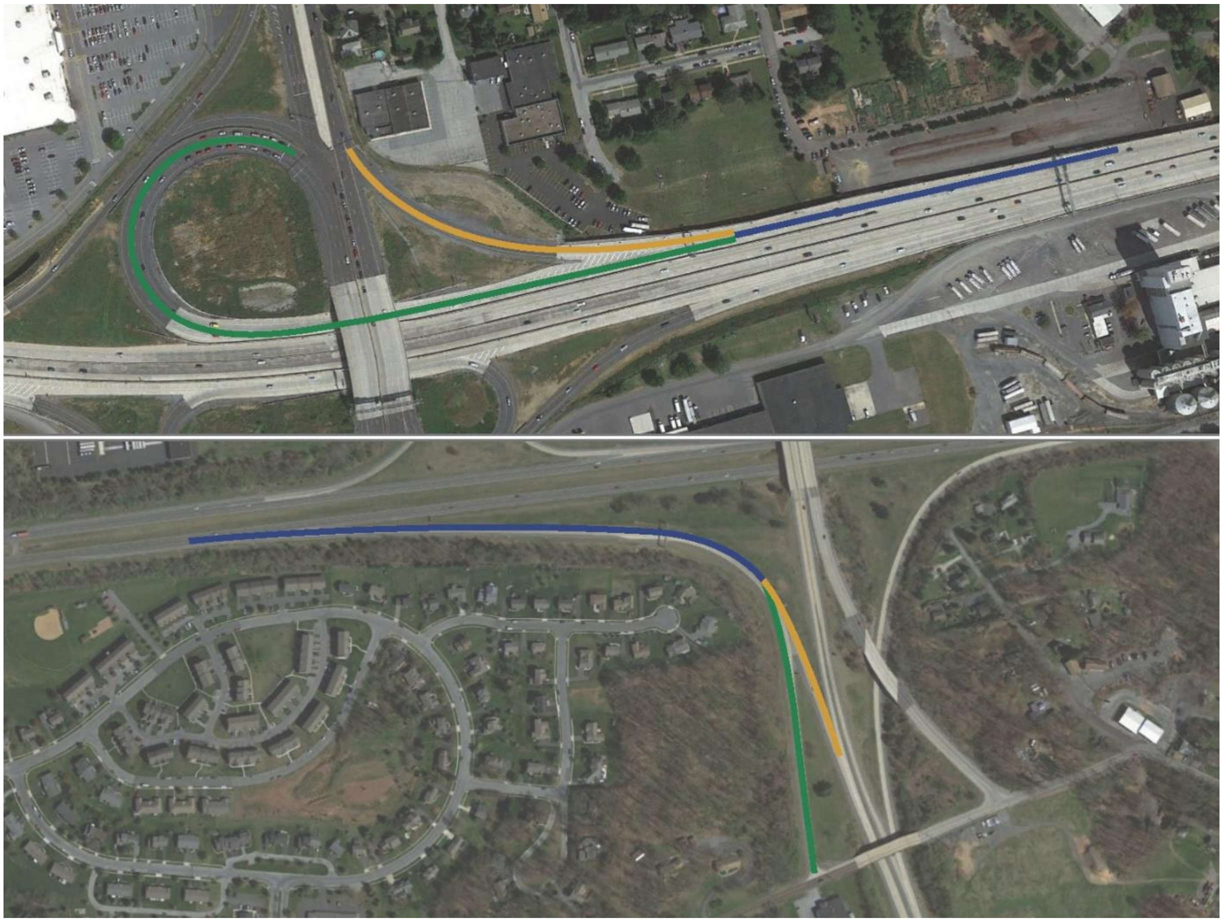

Figure 3-2: Bifurcated Ramps

In Figure 3-2, the blue, green, and orange portions of the ramps should be analyzed with ramp SPFs. There are two means of doing this:

- Analyze as three ramps (blue, green, and orange) by applying a ramp SPF three times.
- Analyze as two ramps by applying a ramp SPF two times
    - The blue ramp and the higher-volume of the green and orange ramps. The length of this ramp is the sum of the lengths of 1) the blue ramp and 2) the green or orange ramp.
    - The lower-volume of the green and orange ramps.

Ramp SPFs have an adjustment factor for speed-change lanes on a ramp; the speed-change lane is where the blue ramp meets/bifurcates into the orange and green ramps. The adjustment factor for this speed-change lane must be used in only one of the ramp SPFs.

Crash data may not distinguish the portion of the ramp (blue, green, or orange) on which a crash occurred. In order to perform Empirical Bayes analysis with such data and determine the expected number of crashes, it may be necessary to compare the predicted crash frequency for all portions of the ramp (i.e. sum the ramp SPFs described in the prior paragraph) to the observed crash frequency for all portions of the ramp.

3.2.5 Ramp and Ramp Terminal Crash Data

Ramps in Pennsylvania are designed as state routes with route numbers in the 8000s or 9000s. All ramps at a given interchange generally have the same state route number and each ramp is a unique segment, as shown in Figure 3-3. The narratives of crashes assigned to ramp state routes should be reviewed to determine the HSM site type on which the crash occurred – the speed-change lane, the ramp terminal intersection, or the ramp proper. Additionally, the review of the narrative should confirm the crash was assigned to the correct ramp (i.e. segment) at a given interchange.

Figure 3-3: Example Segmentation of Ramps at an Interchange with SR 8024 Designation

3.2.6 Ramp Terminal Intersection Crash Assignment

During the development of calibration factors, the following crashes were assigned to ramp terminal intersections rather than the ramp proper: crashes on the last 250 feet of an exit ramp where the terminal had signal or stop control, and crashes on the first 250 feet of an entrance ramp where the terminal had signal control. Crashes within 250 feet of the ramp terminal on entrance ramps where the terminal had stop control or on any ramp where the terminal had yield control or no control remained assigned to the ramp proper and were not assigned to the ramp terminal. Crashes should be assigned in this same manner when the calibration factors presented in the following section are used. A recommendation is to review crash narratives to obtain this location information.

3.3 Pennsylvania Calibration Factors for Freeways and Ramps

Pennsylvania calibration factors are shown in Table 3.3-1.

Table 3.3-1: Pennsylvania Calibration Factors for Freeway Site Types

Site Type	Fatal and Injury		Property Damage Only (PDO)	
	Multi-Vehicle	Single-Vehicle	Multi-Vehicle	Single-Vehicle
Basic Freeway Segment	1.07	0.93	0.43	0.66
Signalized Ramp Terminal	0.67		0.49	
Stop-Controlled Ramp Terminal	1.37		1.04	
Ramps (Entrance, Exit, and Connector)	1.00	1.00	0.49	0.49
Speed-Change Lanes and Collector Distributor Roads	1.00[1]			

[1] – Not calibrated

The calibration factor for ramp fatal and injury crashes (multi-vehicle and single-vehicle) represents a value obtained through the calibration process and computed to be 1.00, not merely a default value of 1.00.

With the exception of stop-controlled ramp terminals, fatal and injury calibration factors are closer to 1.00 than PDO calibration factors. The percentage of PDO crashes that are police-reported may be lower in Pennsylvania than in the states used to develop the 2014 HSM Supplement SPFs, and uncalibrated fatal and injury SPFs for speed-change lanes and collector-distributor roads may be more reliable in Pennsylvania than uncalibrated PDO SPFs for speed-change lanes and collector-distributor roads.

3.4 Use of Calibration Factors in Software

The 2014 HSM Supplement SPFs are most frequently applied with the Enhanced Interchange Safety Analysis Tool (ISATe) or the Interactive Highway Safety Design Module (IHSDM). ISATe is a macro-powered Microsoft Excel spreadsheet tool. A Pennsylvania version of ISATe has been developed and is available on the PennDOT Safety Infrastructure Improvement Program Website at https://www.penndot.gov/TravelInPA/Safety/Pages/Safety-Infrastructure-Improvement-Programs.aspx

The Pennsylvania version of ISATe has the calibration factors in Table 3.3-1 pre-loaded. The PA version also allows users to enter the ‘average traffic speed on freeway’ variable for ramp analysis as low as 30 MPH, for reasons described in Section 3.2.2.

Chapter 4 — PennDOT Network Screening

4.1 General

Prior to 2017, PennDOT utilized number of crash clusters, fatal and serious injury crashes, and crash rates in order to develop high crash lists. These lists then served as part of the basis to justify highway safety projects. These high crash lists did not use the HSM predictive method. Accordingly, the high crash lists inherently emphasized highway facilities with high traffic volume (typically in urban areas), while neglecting highway facilities with low traffic volumes (typically within rural areas). Additionally, the high crash lists did not account for traffic control or geometric data.

The HSM defines network screening as “a process for reviewing a transportation network to identify and rank sites from most likely to least likely to realize a reduction in crash frequency with implementation of a countermeasure.” In 2017, PennDOT completed a network screening of non-freeway roadways and intersections using HSM methods. This network screening analysis accounted for traffic volumes, traffic control parameters, and geometric data. By accounting for this additional data, the network screening analysis represents an evolution from the previous high crash lists by providing an apples-to-apples comparison between all analyzed highway facilities.

4.2 Network Screening Methodology

4.2.1 Focus

The focus of PennDOT’s network screening analysis is to identify and rank sites where improvements may have the most potential to reduce the number of crashes. PennDOT’s 2017 network screening accounts for sites across the entire state of Pennsylvania. Due to resource constraints, the focus of the 2017 network screening was limited to a targeted number of sites within each county, based on the following methodology:

- For roadway segments, rural and urban crash clusters of a varying minimum threshold were included.
- For intersections, rural and urban total number of crashes per intersection of a varying minimum threshold were included.

In certain counties, the targeted number of sites were not analyzed. This was due to limited rural or urban locations and / or a minimal number of sites about the minimum crash thresholds.

4.2.2 Network Elements

The 2017 network screening completed by PennDOT includes intersections and roadway segments. Basic freeway segments, speed change lanes (freeway acceleration and deceleration lanes), ramps, and ramp terminals are not included in the 2017 PennDOT network screening. However, these additional network elements will be analyzed during future iterations of the network screening analysis.

4.2.3 Identification of Network Screening Area and Facility Type (Reference Populations)

When undertaking network screening, the limits of the network screening area and the roadway facility subtypes within that area must be identified. In the 2010 HSM, this is described as reference populations. Reference populations refer to the specific types of facilities that are to be included in the network screening analysis based on certain characteristics. Reference populations are used in order to define the elements to be screened and organize these elements within groups. For intersections, reference populations can be defined by traffic control, number of approaches, cross-section, functional classification, area type, traffic volume ranges, and terrain. For segments, reference populations can be defined by number of lanes per direction, access density, traffic volume ranges, median type or width, speed, adjacent land use, and functional classification.

For the Pennsylvania 2017 network screening, reference populations were applied. However, site types without a relevant SPF were either excluded from the network screening or included in the best fit SPF. For example, there are no SPFs available to calculate the predicted number of crashes for a roundabout and thus roundabouts were excluded from network screening. However, though there are no SPFs specifically for one-way roadways, due to the high-level nature of network screening and the similar reference population characteristics, one-way roadways were analyzed based on the SPF equations for two-way roadways.

4.2.4 Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment

The HSM defines various network screening performance measures, which can be utilized to evaluate the potential to reduce the number of crashes or crash severity at a particular site. Pennsylvania's network screening utilizes the Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment (this is the predictive method as described in Chapter 1 of this manual). This method is also referred to as Potential for Safety Improvement (PSI).

For each individual site, the Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment method involves:

- Calculation of predicted crashes via SPF equations.
- Calculation of observed crashes per year. The 2017 Pennsylvania network screening accounts for the five years of available crash data prior to the 2017 screening.
- Predicted crashes and observed crashes are then utilized to calculate expected crashes.
- The difference between the expected crashes and predicted crashes is then calculated and is referred to as the excess crash frequency. A negative excess crash frequency is indicative of a site operating better than expected. A positive excess crash frequency is indicative of a site operating worse than expected and is indicative of PSI. High excess crash frequencies are indicative of the greatest PSI.

4.2.5 Crash Cost Weighting

Weighted crash costs are estimates of crash unit costs that are averaged or blended across two or more crash types or severity levels. For example, a weighted average fatal and serious injury cost averages the fatality cost and serious injury cost by the proportion of respective crashes to develop one weighted cost for all fatal and serious injuries. This process is described in FHWA Publication SA-17-071, *Crash Costs for Highway Safety Analysis.*

Based on the FHWA Publication SA-17-071 process, the cost of a fatal and injury crash using Pennsylvania crash costs is approximately $421,521 (in 2018 dollars). The cost of a property damage only crash is approximately $12,110 (in 2018 dollars). These costs can be multiplied by the corresponding excess crash frequencies and then combined in order to obtain an overall excess cost for each site. The 2017 network screening analysis calculates excess crash frequencies based on total crashes. Succeeding network screening analyses will include calculations for total crashes and for fatal and injury crashes. By subtracting the fatal and injury excess crash frequencies from the total excess crash frequencies, property damage only excess crash frequencies are able to be obtained. Subsequent Pennsylvania network screening analyses will rank individual sites from the highest yearly excess cost to the lowest yearly excess cost.

4.2.6 Pennsylvania Network Screening Evaluation

All data, calculations, and results for each site are recorded within Excel spreadsheets. Each County within Pennsylvania has a spreadsheet dedicated to intersections and a separate spreadsheet dedicated to segments. Within each spreadsheet, there is a tab for rural facilities and a separate tab for urban facilities. Within each tab, one individual site is summarized per row and the sites / rows are ranked from the highest excess crash frequency to the lowest excess crash frequency.

4.3 PennDOT Highway Safety Network Screening Maps

The results of the 2017 network screening analysis have been input to GIS and are available via PennDOT's CDART, PCIT credential user access, and PennShare website (which are available only to registered users). Intersections that were analyzed are shown graphically with circles and segments are shown graphically with line segments. The circles and line segments are color coded by excess crash frequency in order to depict the potential safety benefits and are as follows:

- Green – The facility is operating better than expected.
- Yellow – The facility is operating close to expected.
- Orange – The facility has a relatively moderate PSI.
- Red – The facility has a relatively high PSI.

4.4 Using Network Screening to Select Project Sites for Further Investigation

A particular facility (intersection or segment) can be referenced on the network screening spreadsheets or maps. If the facility is not included on these sources, this simply means that the number of crashes at that facility did not meet the minimum threshold for analysis. In this case, the user could utilize the network screening tools described in Section 4.5 in order to perform an analysis utilizing Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment and Crash Cost Weighting.

If the particular facility is present on the network screening spreadsheets or network screening maps, the excess cost represents the dollar amount associated with potential safety improvement. A relatively large positive dollar amount would be indicative of a high potential safety improvement. In this case, additional analysis should be completed in order to determine underlying safety issues and potential safety improvements to mitigate the issues. Note that the network screening results are ordered by excess yearly cost, but this does not mean the solution is a higher cost option. Oftentimes, facilities with high excess costs have seemingly obvious safety issues that can be mitigated with low cost solutions.

4.5 Network Screening Tools

PennDOT has developed Excel based tools to streamline the network screening analysis of additional sites that have not already been analyzed. These tools consist of a spreadsheet for segments and a separate spreadsheet for intersections. The spreadsheets are located at the PennDOT Safety Infrastructure Improvement Program website at the following link: https://www.penndot.gov/TravelInPA/Safety/Pages/Safety-Infrastructure-Improvement-Programs.aspx within the section titled 'Pennsylvania Highway Safety Manual (HSM) Tools & Data' and within the subsection titled 'Highway Safety Screening Tool (Existing Condition Analysis)'.

Within each spreadsheet, there are separate tabs for rural and urban facilities. Selecting the correct tab is crucial, because this will determine which SPF equations are applied and which base condition variables (independent variables) are required. Each row in both of the spreadsheets is indicative of a separate site. To analyze a new site, the user can begin inputting data beginning at the left (Column A) and working towards the right. Not all independent variables are required for each SPF equation. Accordingly, 'N/A' will appear within some of the columns based on parameters input by the user (i.e. two-lane roadways do not account for Presence of Median Barrier, Speed Limit, or Centerline Rumble Strips). Inputs for the independent variables are determined as described in Chapter 2 for each SPF equation and demonstrated in Appendix C — Example Calculations.

When all required independent variable data has been input by the user, the predicted crashes will automatically be calculated. Likewise, when the Observed Crash section has been input by the user, the remaining calculations associated with the EB method, excess crash frequencies, and excess cost will automatically be calculated.

Chapter 5 — Countermeasure Evaluation and CMF Combination Methods

5.1 General

As described in Section 1.8, common countermeasure treatments have been the subject of many safety studies, and the anticipated effect of those countermeasures has been quantified in the form of CRFs and CMFs. Once the predictive method (2010 HSM Part C) has been used to estimate the predicted and/or expected number of crashes for a particular location, CMFs can be used to estimate the change in predicted or expected number of crashes when specific safety countermeasures or treatments are implemented.

Applying a single countermeasure at a location has a different mathematical level of predictability than applying several countermeasures at once. Because of this, the method for estimating the effects of countermeasure treatments varies based on whether there is a single treatment or multiple treatments. The sections below provide detail on applying single CMFs (Section 5.3) and the methods for applying multiple CMFs (Section 5.4). Additionally, Section 5.2 provides resources on where to find CMF values.

Understanding the difference and relationship between crash reduction factors (CRFs) and crash modification factors (CMFs) is the first step toward implementing 2010 HSM Part D countermeasure evaluations correctly.

5.1.1 Crash Modification Factors

As defined by the 2010 *Highway Safety Manual*, a CMF is "an index of how much crash experience is expected to change following a modification in design or traffic control" at a particular location. Each CMF is a numerical value that provides the ratio of the expected number of crashes over some unit of time after a change is made to the expected number of crashes for the same time period had the change not been made. The equation below shows how the ratio is applied to develop a CMF for a particular countermeasure i:

$$CMF_i = \frac{Expected\ number\ of\ crashes\ if\ change\ i\ is\ made}{Expected\ number\ of\ crashes\ if\ change\ i\ is\ not\ made}$$

CMF values are greater than or equal to 0. As shown in Figure 5-1, a CMF value less than 1.0 indicates that the change should reduce crash frequency, while CMF values greater than 1.0 indicate that the change should increase crash frequency. CMF values equal to 1.0 indicate that the change is expected to have no impact on crash frequency.

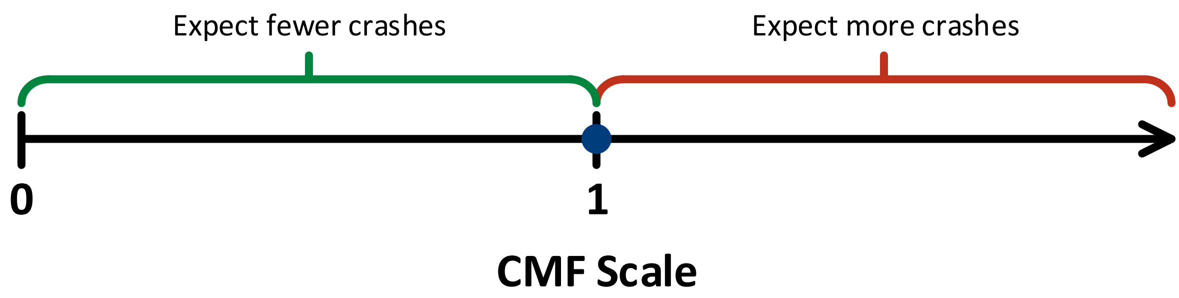

Figure 5-1: CMF Value Related to Crash Frequency

Each CMF is provided for a specific set of conditions (e.g., traffic volumes, roadway types, crash types, and severity). These CMFs are only applicable to these specific conditions and should not be applied directly to other situations. There are several reasons for this. Many countermeasures only influence a subset of crash types and/or severities (e.g., shoulder rumble strips will likely reduce run-off-the-road crashes but should not significantly influence rear-end crashes). Therefore, the CMFs for these countermeasures are typically limited in their application to the set of crashes associated with that specific countermeasure. Other countermeasures may have different impacts in different driving environments (e.g., the effectiveness of intersection treatments often varies with the type of control and configuration of the intersection). In addition, CMFs are often only estimated with a subset of crash data (e.g., only using crash records that involve a fatality or injury) and are therefore only useful to describe the influence of a countermeasure for these crash types and severities. Nevertheless, in this case, CMF values can still serve as a guide that, along with engineering judgment, provides some indication of the expected change in crash frequency under alternative conditions, even if no CMFs are available for the specific alternative conditions.

5.1.2 Crash Reduction Factors

CRFs are another way to describe numerical values of the percentage of crash reduction that may be experienced by implementing a particular crash countermeasure. For example, if the estimated percentage crash reduction for a particular countermeasure is calculated to be 21%, then the CRF is 21. Note that some countermeasures may actually increase the anticipated number of total crashes (but may be beneficial because they reduce the severity or change the type of crash). In such cases, the value will be a negative number, which would have the effect of increasing the number of anticipated crashes. CRF values are based on studies that have been conducted that take into account roadway conditions and traffic volumes. Depending on the studies from which the CRFs are derived, the CRFs have differing levels of reliability.

5.1.3 Relationship between Countermeasures, CRFs and CMFs

CMFs and CRFs simply represent the same information about a particular countermeasure in different ways. The relationship between a CMF and CRF is as follows:

$$CRF = (1 - CMF) \times 100.$$

For example, a countermeasure with a CMF of 0.81 would be associated with a CRF of 19 and both of these values represent a 19% reduction in crash frequency associated with the countermeasure. CMFs, CRFs, and the relationship between them is discussed in more detail on the FHWA CMF Clearinghouse website http://www.cmfclearinghouse.org/.

5.2 CMF Resources

- The primary CMF resource is the FHWA CMF Clearinghouse. CMFs and CRFs based on empirical studies can be found at the CMF Clearinghouse website at http://www.cmfclearinghouse.org/. The CMF Clearinghouse rating criteria was updated in February 2021. The updated rating system provides scores for different factors including sample size, study design, methodology, and statistical significance. The 5-star rating system has been retained but modified to correspond to the updated rating system. CMFs with a higher star rating (and score) are more reliable than those with a lower rating. When multiple CMFs exist for a given countermeasure, the higher-rated CMFs should be used when possible.
- Some Pennsylvania recommended CRFs are provided in PennDOT Publication 638, Section 5.4.4–Systematic Studies and Process for Low-Cost Improvements for many common countermeasures.
- Volume 3 (Part D) of the 2010 HSM provides many common CMFs. These CMFs are also included in the CMF Clearinghouse.
- FHWA also provides CRFs for Roadway Departure Countermeasures. The FHWA Roadway Departure Countermeasure Toolbox website is located at https://safety.fhwa.dot.gov/tools/crf/resources/briefs/rdwydepartissue.cfm.

5.3 How to Apply a Single CMF

The application of a single countermeasure usually falls under one of two relationships to the SPF equations:

- **Condition 1:** The countermeasure treatment is **not** included as a base condition variable in the SPF equation (considered a 'typical' countermeasure application).
- **Condition 2:** The countermeasure treatment changes or modifies a base condition variable used in the SPF equation.

Determining the effect of these countermeasure treatments on the predicted or expected number of crashes is computed differently in each case and described in more detail below. Basically, if the countermeasure treatment modifies a base condition then the SPF equation is recalculated; if it does not then the CMF is utilized.

5.3.1 Condition 1: Typical Countermeasure Applications (Countermeasure does not affect a base condition variable)

To estimate the difference in crashes that may result from implementing a safety countermeasure, the analyst should obtain the most appropriate corresponding CMF (either from the CMF Clearinghouse, HSM, or a similar source (see also the section below regarding implementing countermeasures that change a base condition feature)). The predicted or expected number of crashes generated using the predictive method 2010 HSM Part C process will then be multiplied by the CMF to obtain the new predicted or expected number of crashes. The difference between the original predicted number and the CMF modified number will demonstrate the anticipated reduction in crashes associated with implementing the countermeasure. The more reliable the study that generated the CMF, the more reliable the estimate will be.

When more than one countermeasure treatment is being implemented at the same time, a multiple CMF method must be determined and applied. The methods to apply multiple CMF are described in more detail in Section 5.4.

Single countermeasure analysis usually takes the following general form:

$$N_{treatment} = N_{spf} \text{ x CMF}$$

- $\mathbf{N}_{treatment}$ is the number of crashes predicted after implementing the countermeasure treatment
- $\mathbf{N}_{spf}$ is the number of crashes predicted or expected at the location prior to implementing the countermeasure (determined from the 2010 HSM Part C analysis) and
- CMF is the crash modification factor for the countermeasure

5.3.2 Condition 2: Countermeasures that Revise an SPF Base Condition Feature

To estimate the difference in crashes that may result from changing a base condition feature, rather than applying a CMF, the SPF equation should be recalculated with the treatment associated adjustment factor revised to reflect the change being considered. For example, the PA regionalized SPF equation for total number of crashes (as opposed to fatal and injury only) at a three-leg signalized intersection is:

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

Note that the equation includes the presence (or absence) of exclusive left-turn lanes (ELT_{Maj} and ELT_{Min}) as part of the base condition assumptions. Therefore, if a proposed countermeasure is to add an exclusive left-turn lane, then the expected modification to the crash rate should be recalculated with the SPF equation to reflect a change in the left-turn lane adjustment factor. The difference in the outcomes of the SPF equation with and without the left-turn lane will be the expected crash reduction from implementing the left-turn lane.

Countermeasure calculations that involve modifying a base condition feature usually take the following form:

$$N_{treatment} = N_{spf'} \text{(recomputed using base condition modified by the countermeasure treatment)}$$

- $N_{treatment}$ is the number of crashes predicted or expected after implementing the countermeasure treatment
- $N_{spf'}$ is the number of crashes predicted or expected at the location assuming a base condition has been modified. This is computed by modifying the base condition variable that represents the countermeasure treatment to assume the countermeasure has already been implemented.

5.4 How to Apply Multiple CMFs

Often, multiple countermeasures might be considered for application at the same time and the analyst needs to consider how to estimate the combined impact of these countermeasures when applied together. Ideally, the analyst would identify and use a single CMF that represents the combined application of the specific countermeasures, if such a CMF exists. However, CMFs for multiple treatments in combination are rare as CMFs generally only exist for individual countermeasures applied in isolation. Instead, the analyst will need to consider how the CMFs for each individual countermeasure can be combined to estimate their combined effects when applied together. Several methods are available to do this. The remainder of this section will describe how to apply multiple CMFs when two countermeasures are considered. Note that these methods can be extended to the application of three or more countermeasures with care, but doing so is generally not recommended. Thus, the methods described will focus on the application of two CMFs.

5.4.1 Countermeasure Applicability and Targeted Crash Types

The analyst must carefully consider both the crash and severity type(s) of CMFs that are available for each of the countermeasures, as well as the crash and severity type(s) that the countermeasures are targeted toward. CMF applicability refers to the range of crash and severity types for which the CMF may be applied. For example, CMFs for total crash frequency may be applied to determine the expected change in total crash frequency when a countermeasure is implemented. A CMF for right-angle fatal and injury crashes are only applicable to that specific crash and severity type combination. In addition to crash and severity type, other factors that might be considered in a CMF's applicability include time of day (e.g., daytime vs. nighttime) and location (e.g., specific points vs. entire roadway segment).

However, even though it may influence many crash and severity types, countermeasures are targeted to influence just a subset of these. For example, while CMFs for shoulder rumble strips might exist for total crash frequency or for all fatal and injury crashes, shoulder rumble strips are typically targeted towards reducing lane departure crashes to the right. As another example, implementing lighting on a roadway segment is targeted towards reducing crashes that occur during the night. CMFs for this countermeasure are generally only applicable to nighttime crashes.

5.4.2 Countermeasure Overlap

Next, the analyst must consider if there is any overlap in the set of crash and severity type combinations that the multiple countermeasures target. The potential for overlapping effects for targeted crash and severity types generally falls within one of three categories:

- **No overlap –** The countermeasures are targeted towards completely different sets of crashes and severity types and thus are not likely to have interactive effects. An example of this would be the installation of median barrier and a shared-use bicycle path. The median barrier is targeted towards roadway departure crashes to the left (specifically those resulting in head-on collisions with opposing traffic) and the shared-use bicycle path is targeted toward reducing crashes involving pedestrians or bicyclists. In cases with no overlap, the analyst is likely to expect the complete benefit of both countermeasures.
- **Complete overlap –** The countermeasures are targeted towards the same set of crash types and severities and thus are likely to have interactive effects. An example of this would be the installation of shoulder rumble strips and increasing the paved shoulder width on a two-lane rural roadway segment. Both of these countermeasures are targeted toward reducing roadway departure crashes to the right. In cases with complete overlap, the analyst will need to consider if one countermeasure is likely to enhance the effects of the other (and vice versa).
- **Some overlap** – The countermeasures do not completely overlap in terms of the crash and severity types that they target, but some overlap exists. In this case, some interactive effects will have to be considered. An example is the installation of lighting along a roadway segment and a pedestrian hybrid beacon at a mid-block crossing on the segment. Lighting is targeted toward reducing crashes that occur at night, while the pedestrian hybrid beacon is targeted toward reducing vehicle-pedestrian crashes at the mid-block crossing. The lighting may provide a supplemental safety benefit that reduces crashes at the mid-block crossing, but only for those crashes that would occur at night. In cases with some overlap, the analyst will also need to consider if one countermeasure is likely to enhance the effects of the other (and vice versa).

5.4.3 Effect Magnitude

The analyst must also consider the magnitude of how much the countermeasure(s) may change expected crash frequency for the applicable crash and severity type(s) when deciding how to combine the individual CMFs. This can be measured using the expected change in crash frequency provided by the countermeasure CMF. Three categories of effectiveness are considered:

- **Small impact** – The countermeasure is expected to change crash frequency by less than 10 percent. Countermeasures in this category would have a CMF between 0.90 and 1.10 or a CRF between -10 and 10.
- **Medium impact** – The countermeasure is expected to change crash frequency by between 10 and 25 percent. Countermeasures in this category would have a CMF between 0.75 and 0.90 or between 1.10 and 1.25. This is associated with CRFs between 10 and 25 or -25 and -10.
- **Large impact** – The countermeasure is expected to change crash frequency by greater than 25 percent. Countermeasures in this category would have a CMF less than 0.75 or greater than 1.25. This is associated with CRFs less than -25 or greater than 25.

The effect magnitude does not influence the final selection of method to combine multiple CMFs. However, it should be noted that the importance of selecting the most appropriate method is much greater when combining CMFs with different effect magnitudes than when combining CMFs with similar magnitudes. For example, when combining CMFs for two treatments with small impacts, the results will generally be the same across the different CMF combination methods. However, when combining CMFs for one treatment with a large impact and one treatment with a small impact, the selection of the method becomes more important as the methods may provide vastly different results.

5.4.4 Effect Direction

Lastly, the analyst must consider the direction of the countermeasure effect on the applicable crash and severity type(s) when deciding how to combine individual CMFs. This direction is relative to a CMF value of 1.0, which represents no change in expected crash frequency due to the countermeasure. Countermeasures are classified based on if the associated CMF is greater than or less than 1.0. Recall, that a CMF greater than 1.0 represents an expected increase in crash frequency associated with the countermeasure, while a CMF less than 1.0 represents an expected decrease in crash frequency associated with the countermeasure.

5.4.5 Methods to Combine CMFs

With the above factors in mind, the analyst must then decide which method would be used to combine the two CMFs. As described in the CMF Clearinghouse website (http://www.cmfclearinghouse.org/using_cmfs.cfm), there are four methods that might be used to combine individual CMFs. These are:

- **Multiplicative method** – This method is included in the first edition of the *Highway Safety Manual*. The combined CMF using the multiplicative method is computed as follows:

$$CMF_{combined} = CMF_1 \times CMF_2$$

where CMF_1 and CMF_2 are the CMF values for countermeasure 1 and countermeasure 2, respectively, and $CMF_{combined}$ is the combined CMF estimate.

- **Additive method** – This method considers the full effects of both countermeasures. The combined CMF using the additive method is computed as follows:

$$CMF_{combined} = 1 - [(1 - CMF_1) + (1 - CMF_2)]$$

where CMF_1 and CMF_2 are the CMF values for countermeasure 1 and countermeasure 2, respectively, and $CMF_{combined}$ is the combined CMF estimate.

- **Dominant effect method** – This method only considers the impact of the countermeasure with the smallest CMF (i.e., the one that is the most effective at reducing crash frequency) as follows:

$$CMF_{combined} = \begin{cases} CMF_1 & CMF_1 < CMF_2 \\ CMF_2 & CMF_2 < CMF_1 \end{cases}$$

where CMF_1 and CMF_2 are the CMF values for countermeasure 1 and countermeasure 2, respectively, and $CMF_{combined}$ is the combined CMF estimate that represents the dominant effect.

- **Dominant common residuals method** – This method considers the effect of both countermeasures but reduces the effect of the more effective countermeasure. The combined CMF estimate is computed as follows:

$$CMF_{combined} = \begin{cases} (CMF_1 \times CMF_2)^{CMF_1} & CMF_1 < CMF_2 \\ (CMF_1 \times CMF_2)^{CMF_2} & CMF_2 < CMF_1 \end{cases}$$

where CMF_1 and CMF_2 are the CMF values for countermeasure 1 and countermeasure 2, respectively, and $CMF_{combined}$ is the combined CMF estimate.

Table 5.4-1 provides an overview of which method should be chosen based on the magnitude of the CMF and amount of overlapping countermeasure effects.

Table 5.4-1: CMF Method Based on Magnitude and Overlap

Effect Direction	Amount of Overlap	CMF Combination Method
One or more CMFs > 1.0	Not applicable	Multiplicative
All CMFs <= 1.0	Zero overlap or enhancing effects	Additive
	Some overlap	[1]Consider both dominant effect AND dominant common residuals; select method that provides smallest CMF
	Complete overlap	Dominant effect

1 – The dominant effect method tends to work well when the individual effects of each countermeasure are large in magnitude while the dominant common residuals method tends to work well when the individual effects of each countermeasure are not large. However, both should always be computed and the result compared.

The combined CMFs estimated using the methods above are only applied to crash and severity type combinations with common CMFs across the two countermeasures. If one crash and severity type combination is only influenced by a single countermeasure (i.e., only one of the two countermeasures has a CMF that is applicable to that crash and severity combination), the impact of the combined treatment on that crash and severity type combination is estimated using only that countermeasure's CMF.

5.4.6 Example Applications

This section provides several examples to demonstrate the principles described in this chapter. Note that these examples are for illustrative purposes and the CMF values provided should not be used for any real analyses.

Example 1: Consider a two-lane rural roadway segment in which two treatments are being considered for combined application: shoulder rumble strips and paved shoulders. CMFs for total crash frequency are available for both countermeasures: the CMF for shoulder rumble strips is 0.84 and the CMF for paved shoulders is 0.82. **What would be the combined safety impact of these two treatments at this location?**

Solution 1: In this case, both treatments are targeted towards the same crash type: roadway departure crashes to the right. Since the treatments target the same crash types, we would expect that there would be complete overlap in their effects. The CMFs for both treatments suggest they would both have medium impact on crash frequency and both would reduce crash frequency. Thus, we would apply the dominant effect method to combine the two CMFs to estimate the combined application of both treatments. In this method, the most effective CMF is applied, which is the CMF for paved shoulders. Thus, the combined CMF would be equal to 0.82.

Example 2: Consider a two-lane rural roadway segment in which two treatments are being considered for combined application: shoulder rumble strips and centerline rumble strips. CMFs are available for run-off-road head-on and sideswipe crashes. The CMF for shoulder rumble strips is 0.84 and the CMF for centerline rumble strips is 0.90. **What would be the combined safety impact of these two treatments at this location?**

Solution 2: In this case, the two treatments target some similar crash types. The shoulder rumble strips targets roadway departure crashes to the right but might induce sideswipe or head-on crashes in the opposing lane. The centerline rumble strips target head-on crashes in the opposing lane but might induce roadway departure crashes to the right. Thus, there is some overlap in the targeted crash types. The CMFs for both treatments suggest they would both have medium impact on crash frequency, and both would reduce crash frequency. Thus, we would estimate the combined effect using both the dominant effect and the dominant common residuals methods and select the value that provides the smallest CMF. The most effective CMF for the dominant effect method is the CMF for shoulder rumble strips and is equal to 0.84. For the dominant common residuals method, the combined CMF estimate is $(0.84 \times 0.90)^{0.84} = 0.79$. The combined CMF would be the smaller of these two values, which is 0.79.

Appendix A — Roadside Hazard Rating Determination

The Roadside Hazard Rating Determination description below is derived from the Pennsylvania Department of Transportation, 2016 PSU Report. The complete version of the Roadside Hazard Rating process is in Appendix A of the original report.

The roadside hazard rating (RHR) is a qualitative characterization of the crash potential for roadside designs on rural highways. These estimates are made by visually inspecting a segment of roadway and assigning it a value based on the guidelines provided in Zegeer et. al. (1986). In this system, a seven-point categorical scale is used to describe the potential hazards, ranging from 1 (least hazardous) to 7 (most hazardous). The analyst may utilize the PennDOT online video log system or other online mapping sites with images of the roadway to estimate the RHR on roadway segments. If images are not available, a field visit may be required. A detailed description of roadside design features that 'map' to each of the seven RHR categories are shown below, as are example graphics illustrating each rating category (Torbic et al, 2009). This information is summarized in Table A-1.

Table A-1: Roadside Hazard Rating (RHR) Parameters

RHR #	Clear Zone[1]	Side Slope	Cliff or Vertical Rock	Guiderail	Rigid Obstacles	Recoverable
1	≥ 30 ft	Flatter than 1:4	None	None	None	Yes
2	20-25 ft	1:4	None	None	None	Yes
3	10 ft	1:3 or 1:4	None	None	Rough roadside surface	Marginally
4	5-10 ft	1:3 or 1:4	None	Allowable 5-6.5 ft	About 10 ft	Marginally forgiving
5	5-10 ft	1:3	None	Allowable 0-5 ft	6.5-10 ft	Virtually non-recoverable
6	≤ 5 ft	1:2	None	None	0-6.5 ft	No
7	≤ 5 ft	1:2 or steeper	Yes	None	N/A	No (high likelihood of injury)

[1] – The clear zone is measured from the painted edgeline. If there is no painted edgeline, the edge of the paved surface is considered to be the edgeline.

Rating = 1

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

Figure A-1: Typical Roadway with Roadside Hazard Rating Equal to 1

Rating = 2

- Clear zone between 20 and 25 ft from pavement edgeline.[1]
- Side slope about 1V:4H.
- Recoverable.

Figure A-2: Typical Roadway with Roadside Hazard Rating Equal to 2

[1] The clear zone is measured from the painted edgeline. If there is no painted edgeline, the edge of the paved surface is considered to be the edgeline.

Rating = 3

- Clear zone about 10 ft from the pavement edgeline.[1]
- Side slope about 1V:3H or 1V:4H.
- Rough roadside surface.
- Marginally recoverable.

Figure A-3: Typical Roadway with Roadside Hazard Rating Equal to 3

Rating = 4

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

Figure A-4: Typical Roadway with Roadside Hazard Rating Equal to 4

[1] The clear zone is measured from the painted edgeline. If there is no painted edgeline, the edge of the paved surface is considered to be the edgeline.

Rating = 5

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

Figure A-5: Typical Roadway with Roadside Hazard Rating Equal to 5

Rating = 6

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

Figure A-6: Typical Roadway with Roadside Hazard Rating Equal to 6

[1] The clear zone is measured from the painted edgeline. If there is no painted edgeline, the edge of the paved surface is considered to be the edgeline.

Rating = 7

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

Figure A-7: Roadway with Roadside Hazard Rating Equal to 7

Example:

Consider State Route 3009 in Bedford County as an example. In this example, as in most segments, the RHR will be different for the two directions of travel within the segment limits. As such, data collectors should estimate the average of the RHR within the segment (i.e., produce only a single RHR measure per segment). Figure A-8, Figure A-9 and Table A-2 show the process used to determine that SR 3009, Segment 0010 is category 6.

Figure A-8: Video Log for SR 3009, Segment 0010

Figure A-9: Video Log for SR 3009 Segment 0010

Table A-2: The checklist of RHR for SR 3009 Segment 0010

SR 3009 seg. 0010 RHR						
	Clear Zone	Side Slope	Cliff or Vertical Rock	Guiderail	Rigid Obstacles	Recoverable
Rating 1	>= 30 ft	Flatter than 1:4	No	No	No	Yes
Rating 2	20 - 25 ft	1:4				
Rating 3	10 ft	1:3 or 1:4			Rough roadside surface	Marginally
Rating 4	5 - 10 ft			Allowable (5 - 6.5 ft)	About 10 ft	Marginally forgiving
Rating 5		1:3		Allowable (0 - 5 ft)	6.5 - 10 ft	Virtually non-recoverable
Rating 6	<=5 ft	1:2		N/A	0 - 6.5 ft	No
Rating 7		1:2 or steeper	Yes		N/A	No (high likelihood of injury)

SR 3009 segment 0010 is an example of a ‘severe’ roadside. An example of a more forgiving roadside is shown in Figure A-10 through Figure A-12, which is SR 3009, Segment 0090 in Bedford County. This example also illustrates how the RHR can change within the limits of a segment. Figure A-10 shows how the RHR from both sides of the segment are averaged, while Figure A-11 and Figure A-12 show how the RHR is averaged over the length of the segment. This process resulted in Segment 0090 being assigned a RHR of 3.

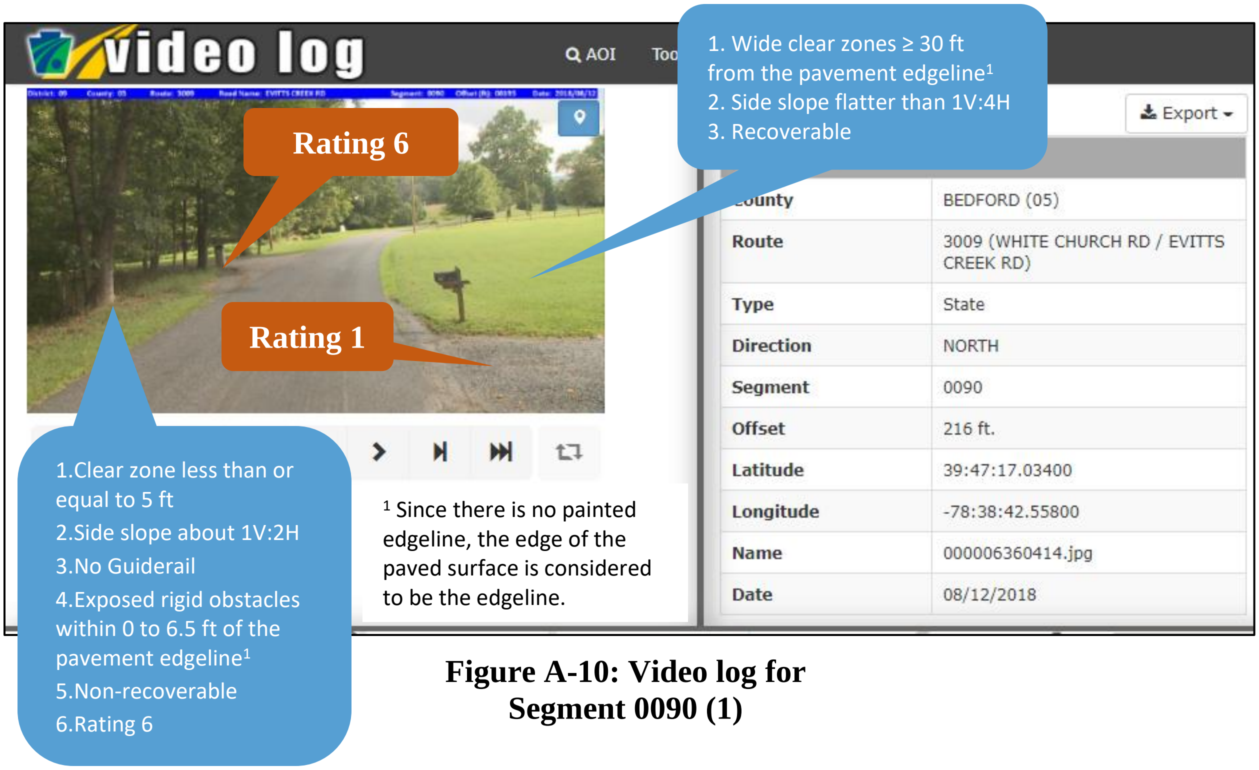

Figure A-10: Video log for Segment 0090 (1)

Figure A-11: Video log for Segment 0090 (2)

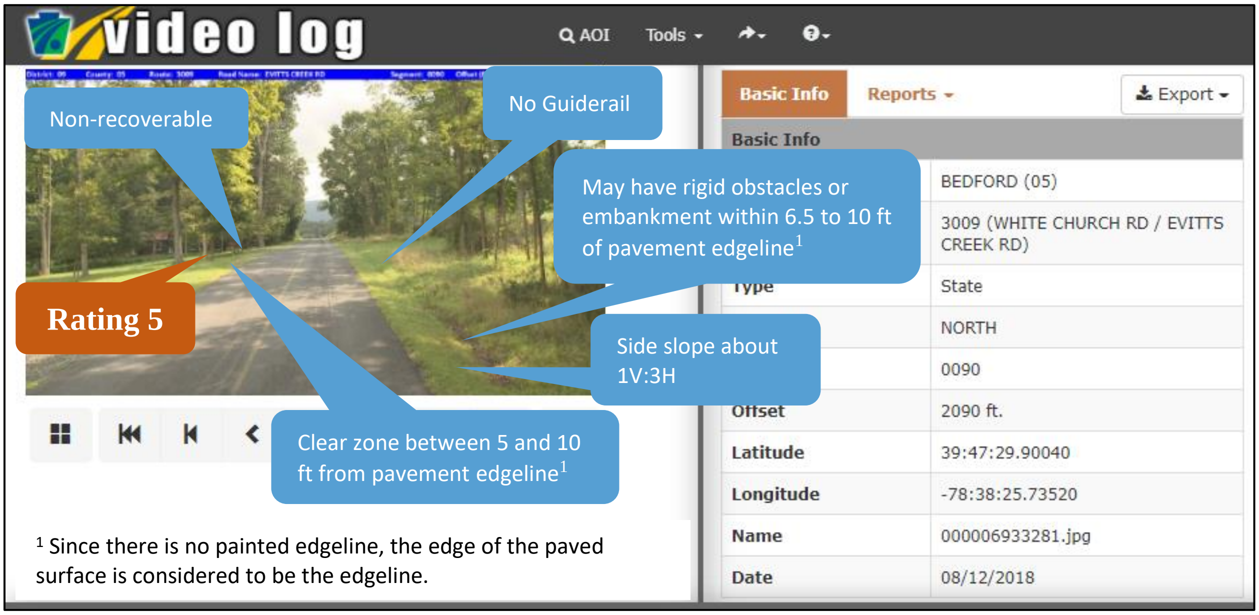

Figure A-12: Video log for Segment 0090 (3)

Appendix B — Degree of Curvature per Mile Determination

A number of options exist for determining the Degree of Curvature per Mile (DCPM). Two methods are described in PennDOT Publication 46, *Traffic Engineering Manual*, on pages 2-20 and 2-21. DCPM data is also available on the State Road Horizontal Curve Inventory (2017) database, online at https://www.penndot.gov/TravelInPA/Safety/Pages/Safety-Infrastructure-Improvement-Programs.aspx.

The Degree of Curvature per Mile Determination description (Google Earth Data Collection Instructional Guide) below is derived from the 2016 PSU Report. If additional information is desired, the complete version of the Google Earth Data Collection Instructional Guide can be found in Appendix B of the original report.

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. Google Earth provides a useful and straightforward way to collect the geometric parameters describing horizontal curves. The Google Earth tool is freely available online at: http://www.google.com/earth/index.html.

Horizontal Curve Data Collection

The geometric data that must be determined for each horizontal curve includes: 1) the length of the curve (i.e., its arc length); and, 2) the radius of the curve. Once the radius (R) of the curve is determined, the degree of curvature (D) can be derived using the equation:

$$D = \frac{5729.578}{R}$$

The following sections describe the specific processes used to collect this horizontal curve data.

Step 1: Drawing the route path in Google Earth

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 B-1) . A window will appear to create a new path (see Figure B-2). 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 B-1: ‘Add Path’ Icon

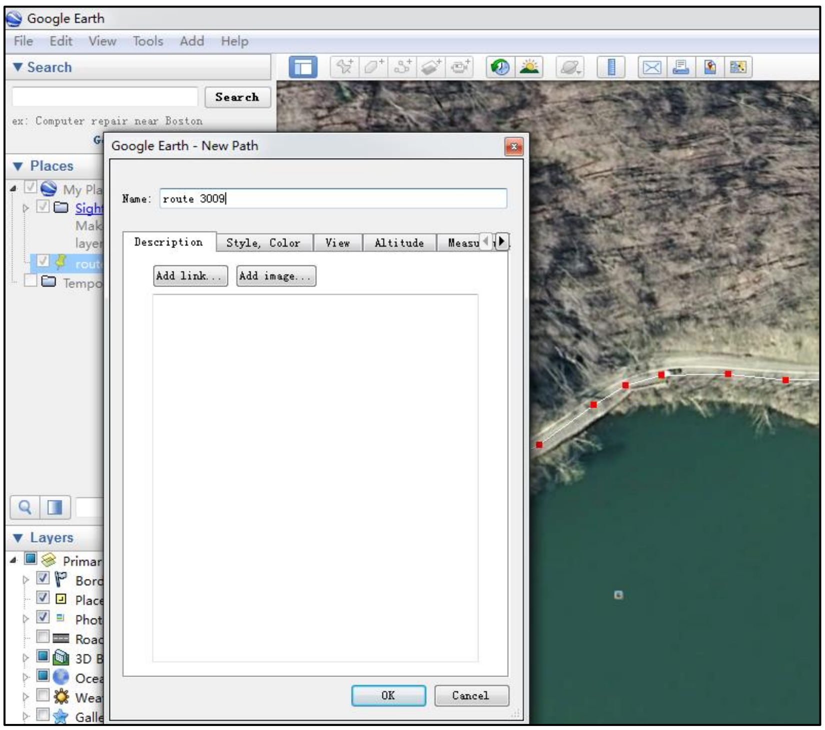

Figure B-2: Screenshot for Adding Path

<u>Step 2</u>: Locating the starting and ending point for each segment

We must now determine the starting and ending point of each segment using the PennDOT roadway database. In Table B-1, there are 18 contiguous segments on SR 3009 in Bedford County. The first segment is 0010 while the last is 0180. The segment length in feet is provided in the fourth column, while a mileage-based segment length is shown in the fifth column. The cumulative length column is a measure of the roadway length within the county beginning at the western- or southern-most starting point. Adjacent cumulative length values represent the beginning and ending mileposts for each segment along the 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 B-3), and change the unit of length to ‘Feet’, as shown in Figure B-4.

Table B-1: Length of Segments in PennDOT Profile

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

Figure B-3: The 'Show Ruler' Icon

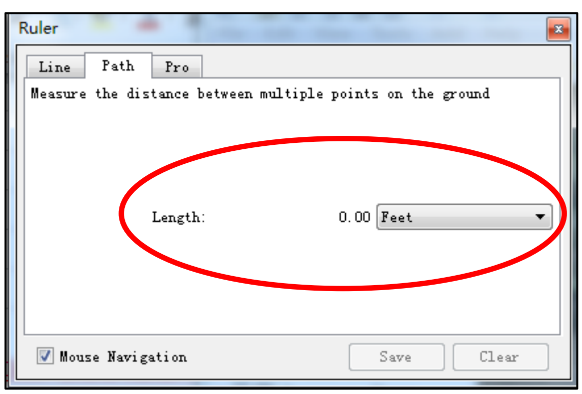

Figure B-4: Screenshot for 'Show Ruler' in the Starting Location

Using the ruler, measure a distance from the first point on the path to the end of the segment. This location represents the end point of the segment and the beginning point of the next/adjacent segment. Using the distance, save this location on the map. To do this, click ‘Save’ and then click ‘Add Placemark’  (see Figure B-5 and Figure B-6). This will create a placemark that denotes the starting/ending point (see Figure B-7 and Figure B-8).

Figure B-5: The ‘Add Placemark’ Icon

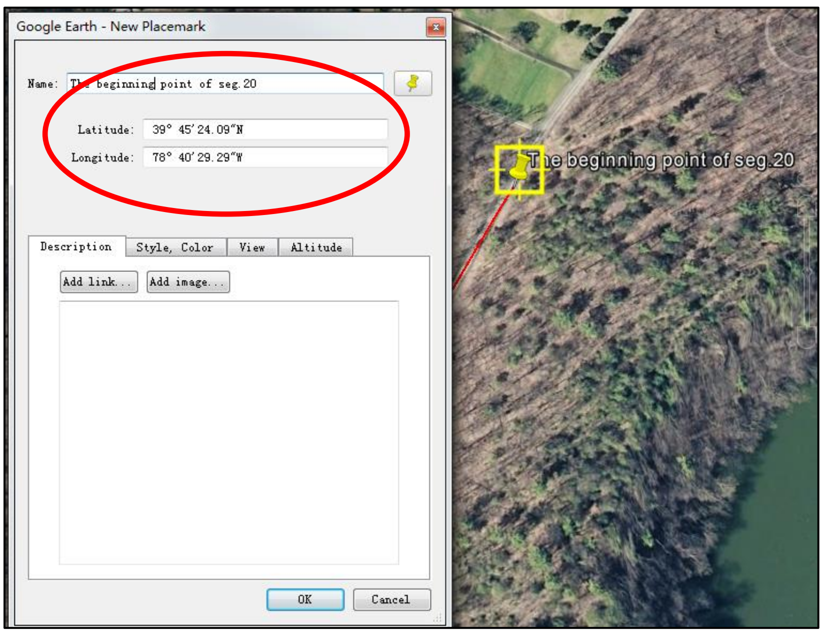

Figure B-6: Screenshot for ‘Add Placemark’

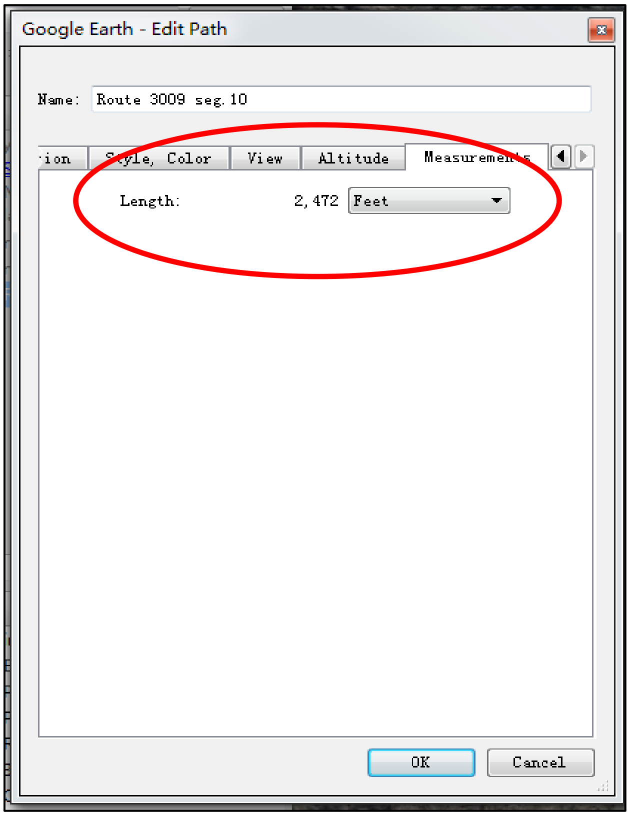

Figure B-7: Locating the ending points

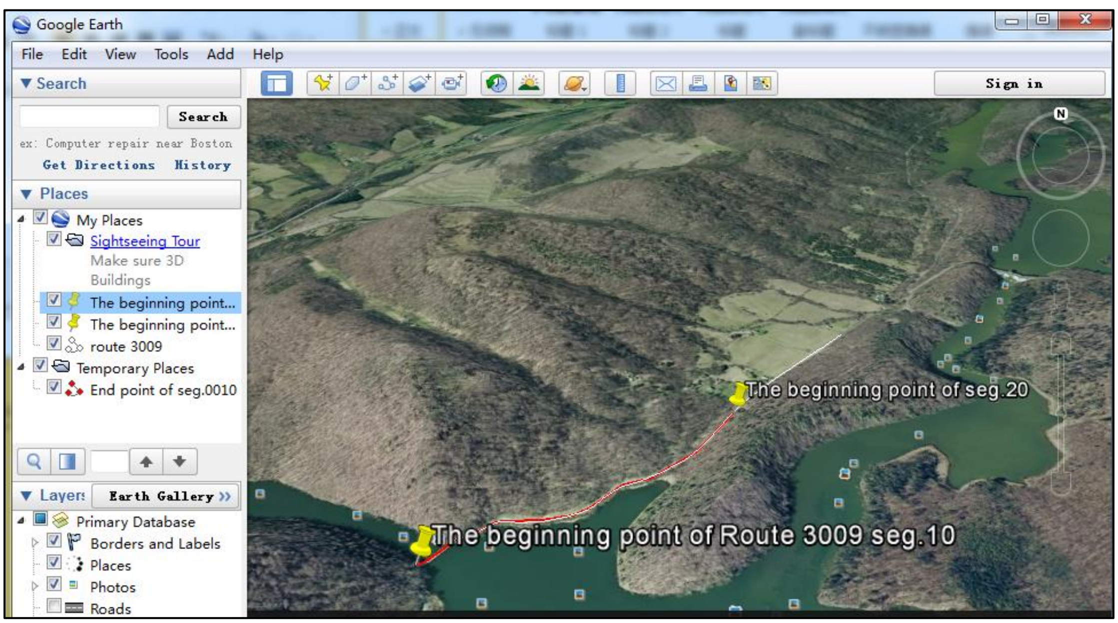

Figure B-8: The Starting and Ending Points for Segments

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

<u>Step 3</u>: Measuring Curves in Google Earth

Visually inspect each segment to identify any horizontal curves that exist. Measure the curve's properties. Figure B-9 shows the various components of a simple horizontal curve (AASHTO, 2011). Figure B-10 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.'

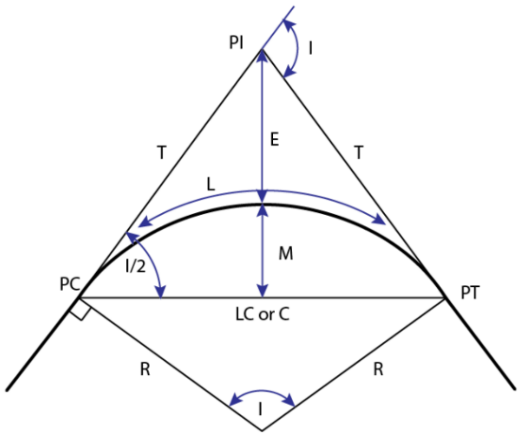

Figure B-9: Measuring the length of arc and radius of the curve.

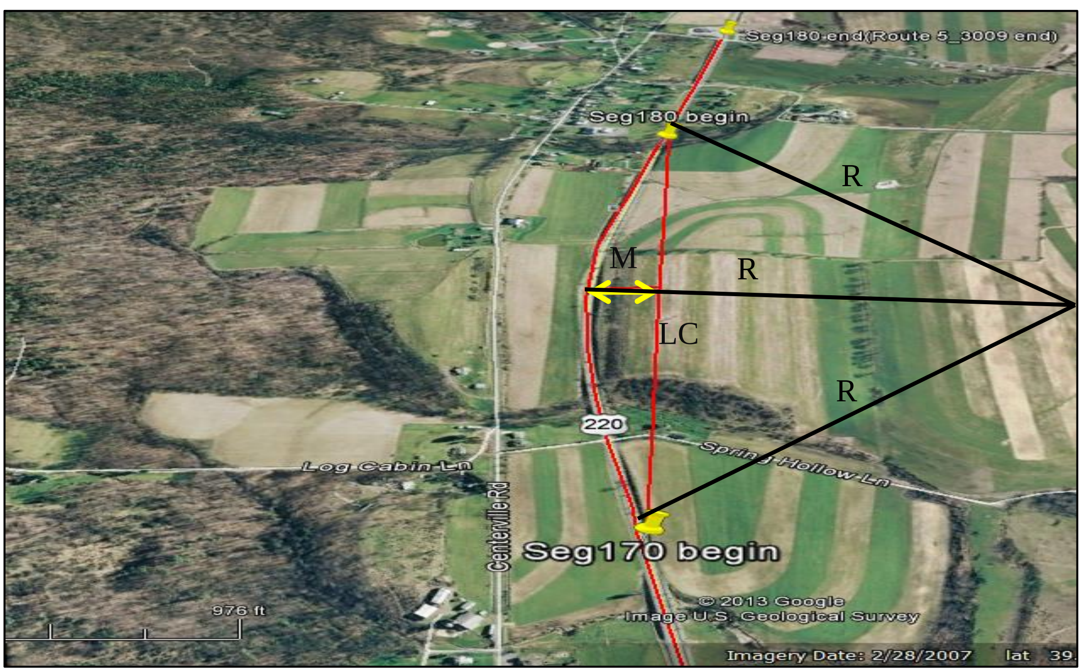

Figure B-10: The Relationship between LC, M, and R

Based on the geometry of Figure B-9 and Figure B-10, the relationship between LC, M, and radius R is as follows:

Equation B1: $(LC/2)^2 + (R-M)^2 = R^2$
Equation B2: $R = LC^2/8M + M/2$

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 B-9). This is done by clicking 'Add Placemark'  so you can move the yellow pin  to mark these points. The second procedure to measure the curve is to draw a chord (line LC or C in Figure B-10) to connect the PC and PT. This is also illustrated in Figure B-11. Then, draw a perpendicular line from the chord to the mid-point of the arc (line M in Figure B-10). This is also illustrated in Figure B-12. Table B-2 and Table B-3 illustrate how the analyst can populate the length of chord and mid-line length data into the respective cells of a tracking spreadsheet.

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.

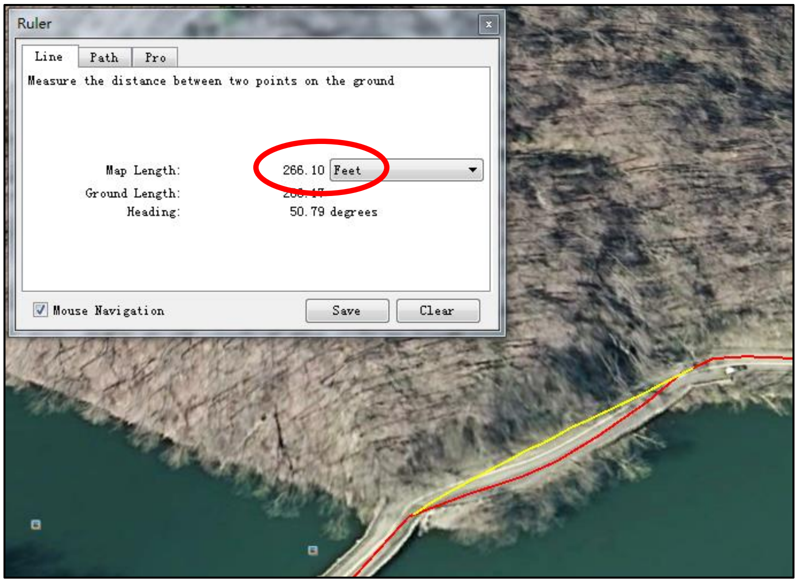

Figure B-11: Example of Drawing the Chord

Table B-2: Filling in Length of Chord Data

CNTY	SR	SEG	LENGTH (ft)	Length of chord (1) (LC,ft)	Mid-line length (1) (M,ft)	Radius in map (1) (ft)
5	3009	10	2472	266.10	27.09	340.28

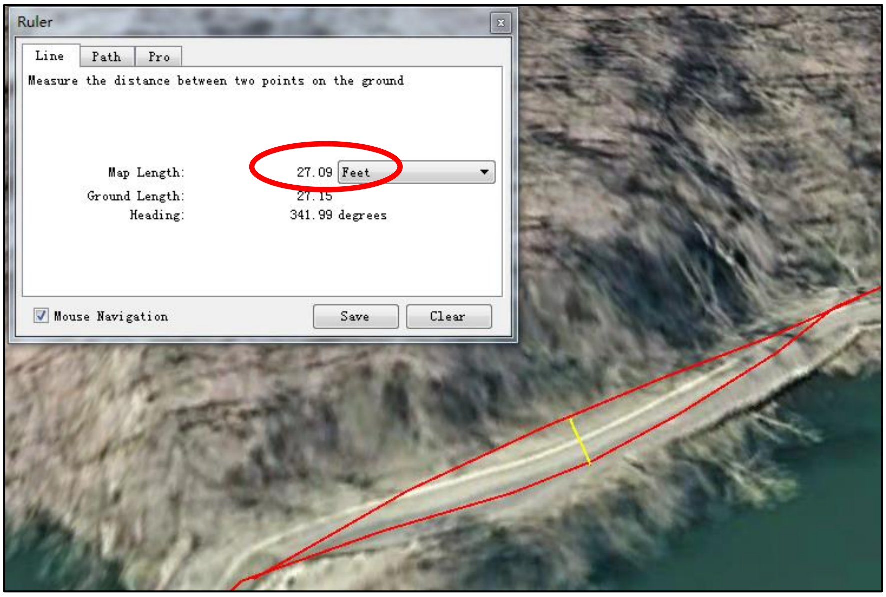

Figure B-12: Example of Drawing the Mid-line

Table B-3: Filling in Mid-line Data

CNTY	SR	SEG	LENGTH (ft)	Length of chord (1) (LC,ft)	Mid-line length (1) (M,ft)	Radius in map (1) (ft)
5	3009	10	2472	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 B-4. 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 B-4: PT Coordinates, Length of chord, Mid-line Length and Radius of Curve

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

Appendix C — Example Calculations

The following provides sample problems with example calculations demonstrating the application of the HSM predictive method using Pennsylvania SPF equations for an intersection and for a roadway segment. The PennDOT HSM Tool A could be used to automate the predictive method calculations. The tool is found at the PennDOT Safety Infrastructure Improvement Program website (https://www.penndot.gov/TravelInPA/Safety/Pages/Safety-Infrastructure-Improvement-Programs.aspx).

This appendix demonstrates the use of the HSM predictive method using Pennsylvania SPF equations in the following applications:

- Sample Problem 1 – Intersection Analysis
- Sample Problem 2 – Roadway Segment Analysis
- Sample Problem 2 – Countermeasure Evaluation

Sample Problem 1 – Intersection Analysis

Utilize the HSM predictive method with the Pennsylvania SPF equations to analyze crashes at the intersection of PA Route 5 (12th Street) / PA Route 290 (12th Street) and Cherry Street in Erie, PA as depicted in Figure C-1.

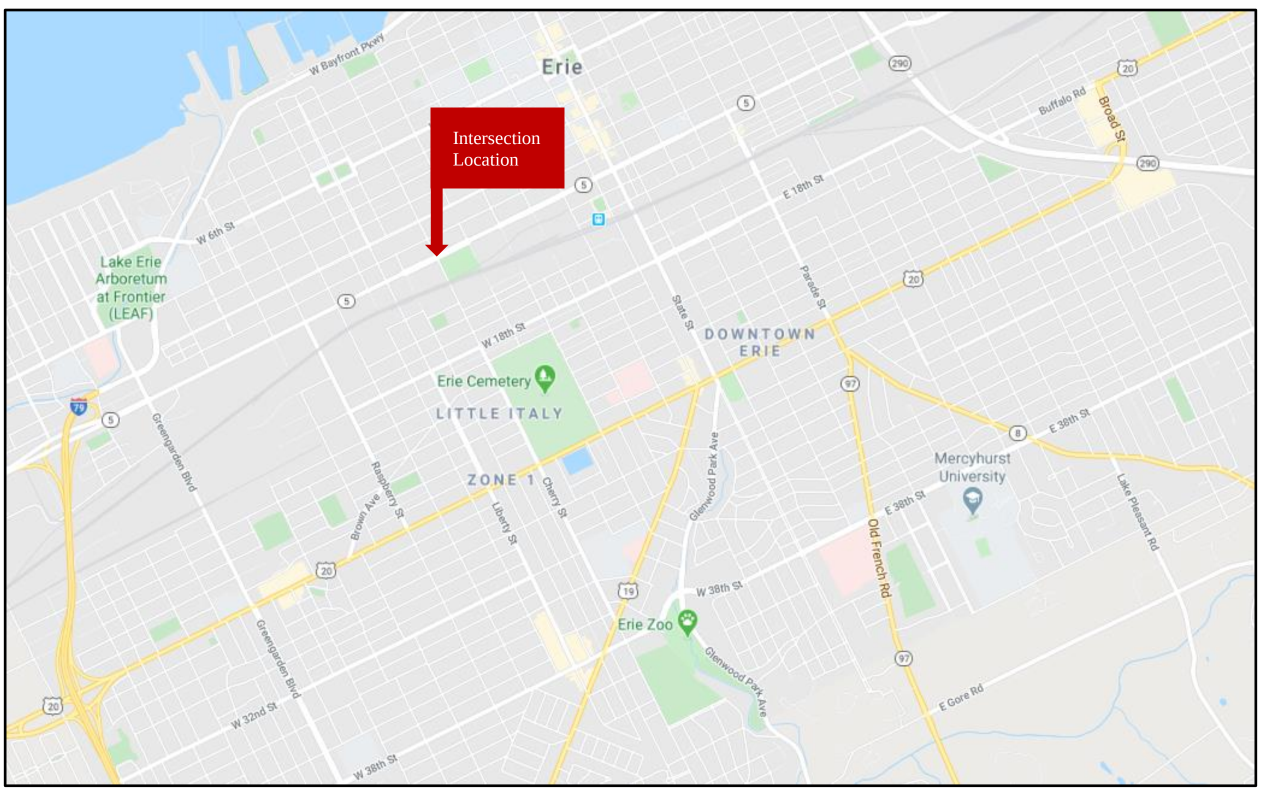

Figure C-1: Location of Analysis Intersection

Solution:

Follow the problem steps outlined in Section 2.1.1 and summarized in Figure C-2.

2.1.1 Pennsylvania Highway Safety Predictive Analysis Method

To implement the 2010 HSM Part C predictive method utilizing the Pennsylvania Regionalized Safety Performance Functions the following steps should be followed:

1. Determine the location to be analyzed and identify District and county.
2. Categorize the analysis location into one of the roadway facility types from Table 2.1-1.

   Note: For roadway types not included in Table 1.5-1 (i.e., freeways, ramps, and ramp terminals) refer to the 2010 HSM Part C Supplement and use the nationwide SPF equations (with Pennsylvania calibration factors as described in Chapter 3 of this document) following the HSM predictive method.
3. Gather historical crash data and calculate $\mathbf{N}_{observed}$ (historical crash data) for the location being analyzed, ensuring only the applicable crash data is included (i.e., If $\mathbf{N}_{total}$ then include all crashes, if $\mathbf{N}_{f\&i}$ then only include fatal and injury crashes).
4. Determine the SPF equation, base condition variables, and calibration factors (if applicable).
5. Gather all base condition data for the variables identified based on the location being analyzed (the base conditions are listed in the corresponding sections below for each SPF).
6. Calculate $\mathbf{N}_{predicted}$ (Number of predicted crashes) using the corresponding SPF equation and location specific base condition adjustments (using data gathered in Step 5 and Step 6), and location specific calibration factors. Note that SPF equations are given to calculate $\mathbf{N}_{predicted}$ for either total predicted crashes ($\mathbf{N}_{total}$) or fatal and injury predicted crashes ($\mathbf{N}_{f\&i}$).
7. Apply the Empirical Bayes method (EB Method) described in Sections 1.4 and 1.5 to obtain the number of expected crashes, $\mathbf{N}_{expected}$, using the equations:

$$N_{expected} = w \text{ x } N_{predicted} + (1.00 - w) \text{ x } N_{observed}$$

   Where *w* for segment SPF equations equals:

$$w = \frac{1}{1 + \frac{k}{L} \times \left(\sum_{\text{all study years}} N_{predicted} \right)}$$

   And *w* for intersection SPF equations equals:

$$w = \frac{1}{1 + k \times \left(\sum_{\text{all study years}} N_{predicted} \right)}$$

8. Compare $\mathbf{N}_{observed}$, $\mathbf{N}_{predicted}$, and $\mathbf{N}_{expected}$ for the location being analyzed.

Figure C-2: Problem Steps outlined in Section 2.1.1 for Analysis Intersection

<u>Step 1:</u> Determine the location to be analyzed and identify the District and County:

The location can be determined by utilizing PennDOT District Maps, PennDOT OneMap, and/or other online navigation aids such as Google Maps. In this example, PennDOT OneMap was utilized to determine the county and District of the analysis intersection. This location is in Erie County in PennDOT District 1-0.

To load the appropriate layers in PennDOT OneMap, select the Layers Catalog on the top right of the web page (Step 1). Once the Layers Catalog is open you can search for the 'Boundaries' layers (Step 2). Selecting the 'Counties' and 'Engineering Districts' boxes will populate OneMap with the necessary information as illustrated below in Figure C-3 (Step 3).

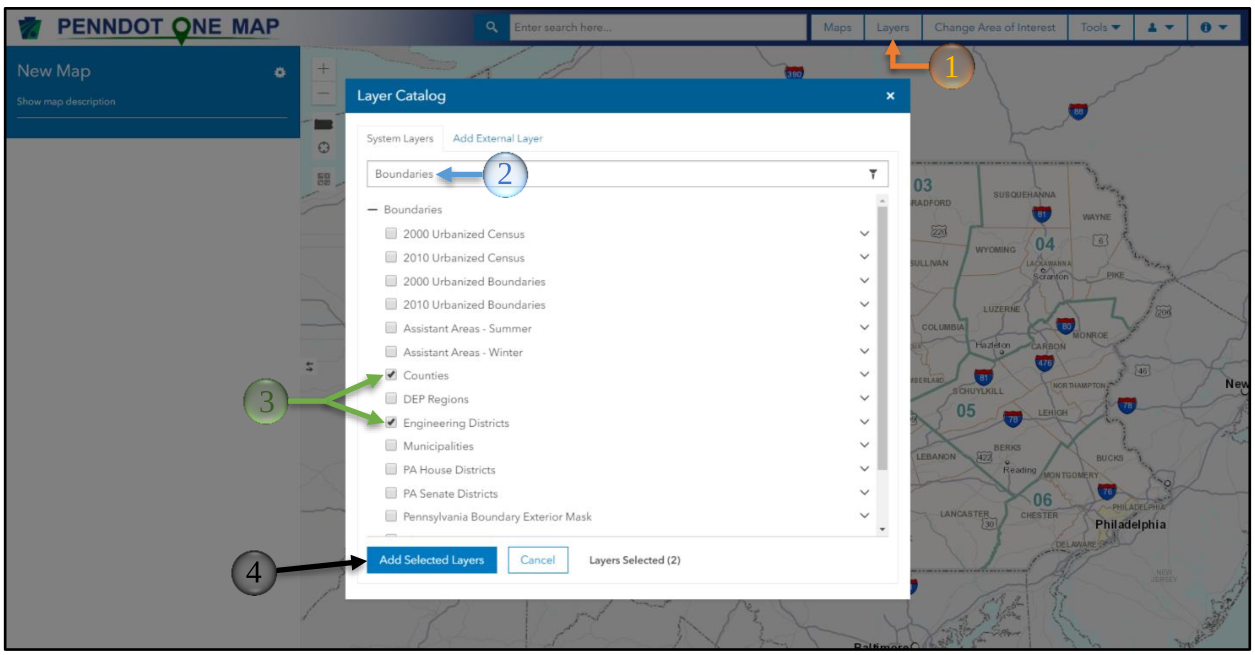

Figure C-3: Navigating PennDOT One Map

Step 2: Categorize the study location into one of the roadway facility types:

Use online navigation aids and PennDOT TIRe to determine number of lanes and functional character of the analysis intersection. If information regarding the specific analysis intersection is rather limited, then a site visit may be necessary. Use number of lanes and other roadway characteristics to categorize the intersection. In this case, the analysis intersection is an urban-suburban arterial intersection with four-leg signalized control. An aerial view of the analysis intersection has been taken using Google Maps and can be seen in Figure C-4.

Figure C-4: Geometric Configuration of Analysis Intersection

Step 3: Gather historical crash data and calculate $N_{observed}$:

The analyst should collect historical crash data, if available, to compare the predicted number of crashes with the expected number of crashes (as described in Step 8). Historical crash data can be obtained from the Custom Query Tool located on the Pennsylvania Crash Information Tool (PCIT) website at https://crashinfo.penndot.gov/PCIT/queryTool.html.

As shown in Figure C-5, a point map was generated from PCIT to depict the crashes at the analysis intersection. It is typical to include crashes that are within a 250-FT buffer distance on each leg of the intersection.

A Crash History Report can be exported from PCIT to see the crash severity level by year for the analysis intersection (Figure C-6).

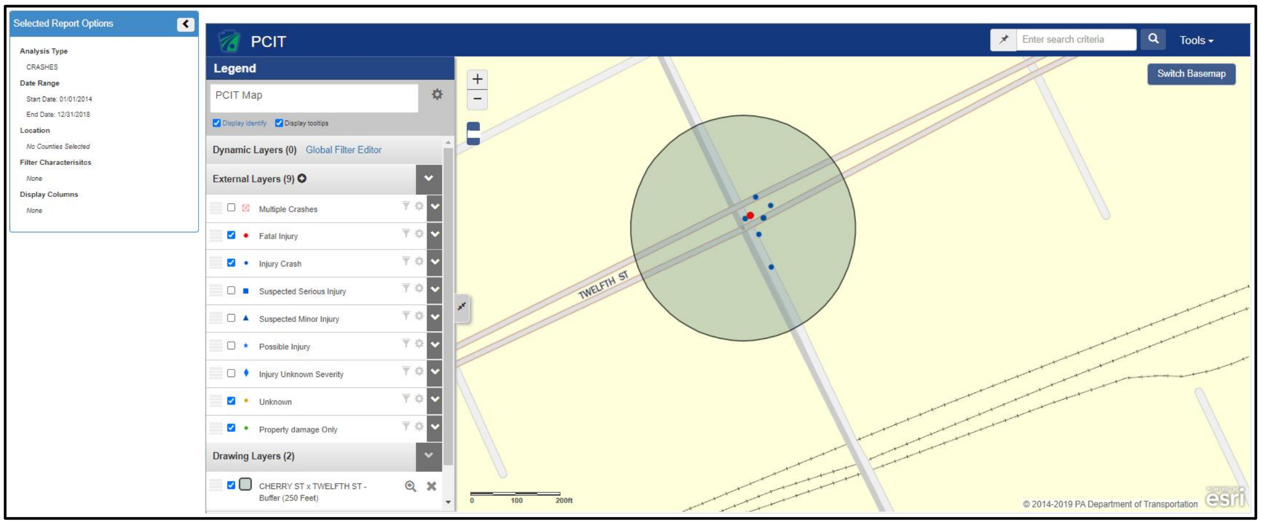

Figure C-5: PCIT Point Map Results for Analysis Intersection

Date Range: 01/01/2014 to 12/31/2018*

CRASH SEVERITY LEVEL BY YEAR

	2014 CRASHES	2015 CRASHES	2016 CRASHES	2017 CRASHES	2018 CRASHES	ALL YEARS CRASHES
FATAL INJURY	1	0	0	1	0	2
SUSPECTED SERIOUS INJURY	0	2	0	0	1	3
SUSPECTED MINOR INJURY	0	1	2	0	2	5
POSSIBLE INJURY	0	2	1	0	2	5
UNKNOWN SEVERITY	0	3	1	1	1	6
UNKNOWN IF INJURED	0	0	0	1	1	2
PROPERTY DMG ONLY	2	1	3	4	4	14
TOTAL	3	9	7	7	11	37

Figure C-6: PCIT Crash History Report Summary for Analysis Intersection

From the PCIT Crash History Report, shown in Figure C-6, the five-year crash data (January 2014 – December 2018) showed that there were a total of 37 reportable crashes observed at the analysis intersection yielding an average of 7.4 crashes per year. The 7.4 crashes per year will be used as $\mathbf{N}_{observed(total)}$ during analysis in Step 8.

$$\mathbf{N}_{observed(total)} = \frac{37\ crashes}{5\ years} = 7.4\ crashes\ per\ year$$

The data also showed there were two fatal crashes and 21 injury crashes (three suspected serious injury, five suspected minor injury, five possible injury, six unknown severity, and two unknown if injured) during the same time frame, yielding an average of 4.6 fatal and injury crashes observed per year. The 4.6 fatal and injury crashes per year will be used as $\mathbf{N}_{observed(f\&i)}$ during future analysis in Step 8.

$$\mathbf{N}_{observed(f\&i)} = \frac{2\ fatal\ crash + 21\ injury\ crashes}{5\ years} = 4.6\ f\&i\ crashes\ per\ year$$

<u>Step 4:</u> Determine the SPF Equation, base condition variables, and calibration factors:

For this step, the SPF equation, base condition variables, and calibration factors for $\mathbf{N}_{predicted}$ total crashes and F&I crashes using the District, county, and roadway facility type for the intersection. The SPF equations applicable for this analysis are identified in Table 2.13.3-2 (also shown in Figure C-7). Table 2.1-1 can be used to quickly identify the section of Chapter 2 with the required SPF equation and its regionalization level.

Table 2.13.3-2: Statewide SPFs for Urban-suburban Arterial – Four-leg with Signalized Control

	Regionalized SPF Predictive Equations	Overdispersion Parameter
Total Predicted	$N_{total} = e^{-5.501} \times AADT_{Major}^{0.403} \times AADT_{Minor}^{0.316} \times e^{0.053 \times ELTMaj} \times e^{0.126 \times ERTMaj} \times e^{0.056 \times ELTMin} \times e^{0.045 \times ERTMin} \times e^{0.101 \times MajPSL40\_45} \times e^{0.290 \times MajPSL50\_55} \times e^{0.075 \times MinPSL35p}$	k= 0.356
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-6.374} \times AADT_{Major}^{0.411} \times AADT_{Minor}^{0.363} \times e^{0.130 \times ELTMaj} \times e^{0.053 \times ELTMin} \times e^{0.226 \times MajPSL50\_55}$	k= 0.432

Figure C-7: Markup of Table 2.13.3-2 for Analysis Intersection

As identified in Section 2.2, a calibration factor is required to modify the Statewide-level SPF to be applied to a specific county. The District 1-0 calibration factor can be identified in Table 2.13.3-3, District 1-0 (also shown in Figure C-8).

Table 2.13.3-3: District Calibration Factors for Urban-suburban Arterial – Four-leg with Signalized Control

District	District Calibration Factor for Total Crash SPF	District Calibration Factor for Fatal and Injury SPF
1	0.78	0.74

Figure C-8: Markup of Table 2.13.3-3 for Analysis Intersection

In Table 2.13.3-1, in Section 2.2 (SPFs for Other Urban-Suburban Arterial Intersections) the base condition variables for the SPF equation are listed (also shown in Figure C-9). For an urban-suburban arterial intersection with four-leg signalized control, all of the base condition variables are used for all of the Districts.

Table 2.13.3-1: Base Condition Variables for Urban-Suburban Arterial – Four-leg with Signalized Control

Base Condition Variables		All Districts
$AADT_{Major}$	major road annual average daily traffic (veh/day)	X
$AADT_{Minor}$	minor road annual average daily traffic (veh/day)	X
ELTMaj	indicator variable for exclusive left-turn lane on the major street approach (1 = present; 0 otherwise)	X
ERTMaj	indicator variable for exclusive right-turn lane on the major street approach (1 = present; 0 otherwise)	X
ELTMin	indicator variable for exclusive left-turn lane on the minor street approach (1 = present; 0 otherwise)	X
ERTMin	indicator variable for exclusive right-turn lane on the minor street approach (1 = present; 0 otherwise)	X
MajPSL40_45	indicator for posted speed limit of 40 or 45 mph on major road (1 = present; 0 otherwise)	X
MajPSL50_55	indicator for posted speed limit of 50 or 55 mph on major road (1 = present; 0 otherwise)	X
MinPSL35p	indicator for posted speed limit of 35 mph or more on minor road (1 = present; 0 otherwise)	X

Figure C-9: Markup of Table 2.13.3-1 for Analysis Intersection

Based on Table 2.13.3-1 (Figure C-9), the variables for which data must be collected are:

- $\mathbf{AADT_{Major}}$ – Major road annual average daily traffic (veh/day)
- $\mathbf{AADT_{Minor}}$ – Minor road annual average daily traffic (veh/day)
- **ELTMaj** – Indicator variable for exclusive left-turn lane on the major street approach
- **ERTMaj** – Indicator variable for exclusive right-turn lane on the major street approach
- **ELTMin** – Indicator variable for exclusive left-turn lane on the minor street approach
- **ERTMin** – Indicator variable for exclusive right-turn lane on the minor street approach
- **MajPSL40_45** – Indicator variable for posted speed limit of 40 or 45 mph on major road
- **MajPSL50_55** – Indicator variable for posted speed limit of 50 or 55 mph on major road
- **MinPSL35p** – Indicator variable for posted speed limit of 35 mph or more on minor road

Step 5: Gather all base condition data for the variables identified based on the location being analyzed:

As determined from Step 4, the base condition variables needed for the urban-suburban arterial intersection with four-leg signalized control SPF equation were gathered and summarized below in Table C-1.

Google Maps or PennDOT VideoLog can be used to identify most of the required SPF variables. PennDOT TIRe can be utilized to find the AADT of the major and minor legs of the intersection for state roads. If data is unavailable in PennDOT TIRe, local road traffic counts may be available on the Safety Infrastructure Improvement Programs page from the PennDOT Website. If no data is available, traffic counts must be obtained prior to computation.

Table C-1: SPF Equation Base Condition Variables for Analysis Intersection

Base Condition Variables		Value	Data Source
$AADT_{Major}$	major road annual average daily traffic (veh/day)	**11,615 veh/day**	PennDOT TIRe[1]
$AADT_{Minor}$	minor road annual average daily traffic (veh/day)	**4,790 veh/day**	PennDOT TIRe[1]
ELTMaj	indicator variable for exclusive left-turn lane on the major street approach (1 = present; 0 otherwise)	**Present (Equation Input = 1)**	Google Maps[2] PennDOT VideoLog[3]
ERTMaj	indicator variable for exclusive right-turn lane on the major street approach (1 = present; 0 otherwise)	**Not Present (Equation Input = 0)**	Google Maps[2] PennDOT VideoLog[3]
ELTMin	indicator variable for exclusive left-turn lane on the minor street approach (1 = present; 0 otherwise)	**Present (Equation Input = 1)**	Google Maps[2] PennDOT VideoLog[3]
ERTMin	indicator variable for exclusive right-turn lane on the minor street approach (1 = present; 0 otherwise)	**Not Present (Equation Input = 0)**	Google Maps[2] PennDOT VideoLog[3]
MajPSL40_45	indicator for posted speed limit of 40 or 45 mph on major road (1 = present; 0 otherwise)	**Speed Limit = 40 (Equation Input = 1)**	ArcGIS[4] Google Maps[2] PennDOT VideoLog[3]
MajPSL50_55	indicator for posted speed limit of 50 or 55 mph on major road (1 = present; 0 otherwise)	**Speed Limit = 40 (Equation Input = 0)**	ArcGIS[4] Google Maps[2] PennDOT VideoLog[3]
MinPSL35p	indicator for posted speed limit of 35 mph or more on minor road (1 = present; 0 otherwise)	**Speed Limit = 25 (Equation Input = 0)**	ArcGIS[4] Google Maps[2] PennDOT VideoLog[3]

1 – See Figure C-10 to learn how to navigate PennDOT TIRe to determine traffic volume for the analysis location. If data is unavailable on PennDOT TIRe, local road traffic counts are available on the Safety Infrastructure Improvement Programs page from the PennDOT Website.
2 – Google Maps street view can be used to identify field condition of the analysis intersection. If street view is unavailable or outdated, a field observation may be required.
3 – In addition to Google Maps, PennDOT VideoLog can be used to identify field condition of the analysis intersection.
4 – The PA Speed Limits map can be found on ArcGIS.

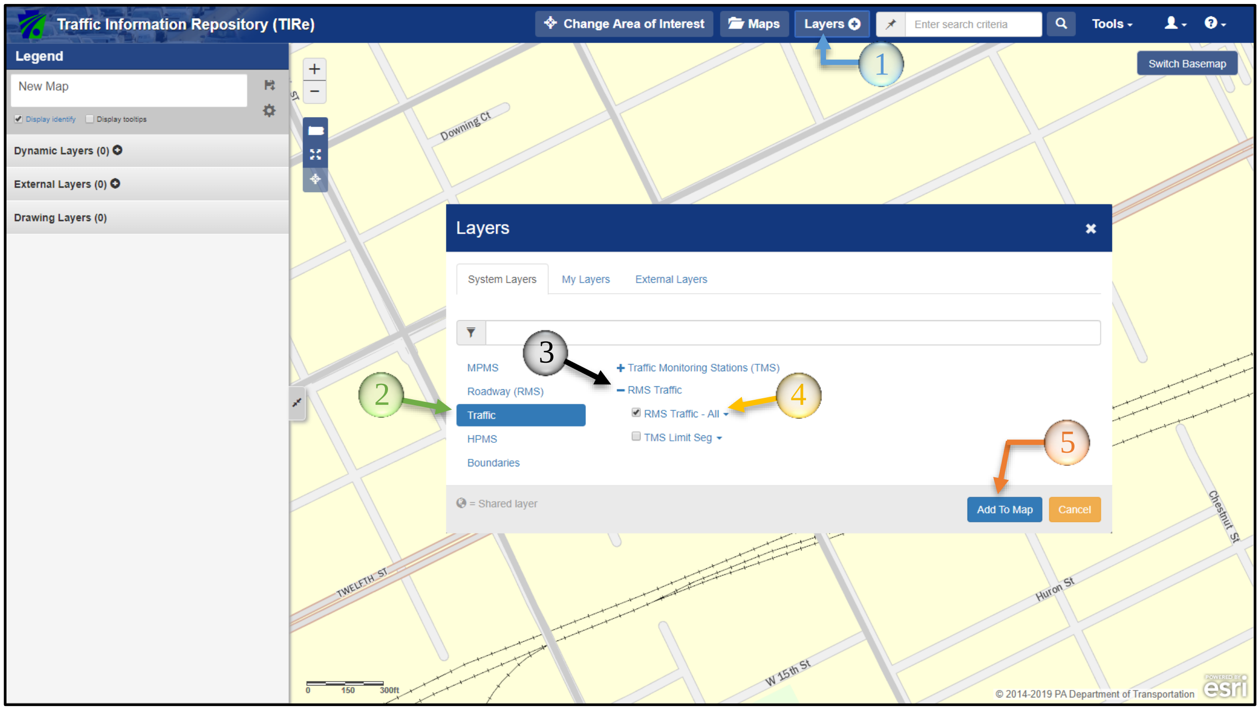

Figure C-10: Navigating PennDOT TIRe

<u>Step 6:</u> Calculate $N_{predicted}$ using the corresponding SPF equation, location specific base condition adjustments, and location specific calibration factors:

Calculate N_{total} and $N_{f\&i}$ using their respective SPF equations identified in Step 4 (Figure C-7). Once the SPF equations are calculated, they need to be modified by the district-level calibration factor to determine the value of $N_{predicted(total)}$ and $N_{predicted(f\&i)}$. The District 1-0 calibration factor can be identified in Table 2.13.3-3, District 1-0 (also shown in Figure C-8).

To complete the regionalization process using the PA SPF, apply the District 1-0 total crash calibration factor to the Statewide SPF total crash result. From Table 2.13.3-3 (Figure C-8), identified in Step 4, note that the district calibration factor for total crashes is 0.78. Multiplying N_{total} by the district total crash calibration factor yields a result of 2.49 predicted reportable crashes per year.

Similarly, apply the district F&I crash calibration factor to the Statewide SPF F&I crash result. From Table 2.13.3-3 (Figure C-8), note that the district calibration factor for F&I crashes is 0.74. Multiplying $N_{f\&i}$ by the district F&I crash calibration factor yields a result of 1.54 predicted reportable crashes per year.

N_{total} calculation:

$$\mathbf{N}_{total} = e^{-5.501} \times (11{,}615)^{0.403} \times (4{,}790)^{0.316} \times e^{0.053\times(1)} \times e^{0.126\times(0)} \times e^{0.056\times(1)} \times e^{0.045\times(0)} \times e^{0.101\times(1)} \times e^{0.290\times(0)} \times e^{0.075\times(0)}$$

$$\mathbf{N}_{total} = (0.0041 \times 43.4713 \times 14.5541 \times 1.0544 \times 1 \times 1.0576 \times 1 \times 1.1063 \times 1 \times 1)$$

$$\mathbf{N}_{total} = \mathbf{3.19\ total\ crashes\ per\ year}$$

$N_{f\&i}$ calculation:

$$N_{f\&i} = e^{-6.374} \times (11{,}615)^{0.411} \times (4{,}790)^{0.363} \times e^{0.130\times(1)} \times e^{0.053\times(1)} \times e^{0.226\times(0)}$$

$$N_{f\&i} = (0.0017 \times 46.8514 \times 21.6751 \times 1.1388 \times 1.0544 \times 1)$$

$$N_{f\&i} = \mathbf{2.08\ fatal\ and\ injury\ crashes\ per\ year}$$

$N_{predicted(total)}$ calculation:

$$\mathbf{N}_{predicted(total)} = \mathbf{N}_{total} \times District\ Adjustment\ Factor$$

$$\mathbf{N}_{predicted(total)} = 3.19 \times 0.78 = 2.49$$

Therefore, $N_{predicted(total)}$ = 2.49 predicted reportable total crashes per year at the analysis intersection.

$N_{predicted(f\&i)}$ calculation:

$$\mathbf{N}_{predicted(f\&i)} = \mathbf{N}_{f\&i} \times District\ Adjustment\ Factor$$

$$\mathbf{N}_{predicted(f\&i)} = 2.08 \times 0.74 = 1.54$$

Therefore, $N_{predicted(f\&i)}$ = 1.54 predicted reportable fatal and injury crashes per year at the analysis intersection.

Step 7: Apply the Empirical Bayes method to obtain the number of expected crashes, $N_{expected}$:

The first step in applying the EB method is to calculate ***w*** (the EB method adjustment factor) using Equation 1 from Section 1.4:

$$w = \frac{1}{1 + \frac{k}{L} \times \left(\sum_{\text{all study years}} N_{predicted}\right)}$$

Because five years of observed crash data was collected, $N_{predicted}$ must be calculated for each of those five years so it can be summed in the denominator of the equation. Due to the variation of traffic volume from year to year, historical traffic volumes should be collected for each study year. Historical statewide traffic volume maps can be found on the PennDOT Bureau of Planning and Research website at https://www.penndot.gov/ProjectAndPrograms/Planning/Maps/Pages/Traffic-Volume.aspx. Local road traffic volumes may be collected/counted by a District, planning partner or consultant, at the project level. At the time of development of this publication, some local road traffic volumes are available in the Local Road Traffic Counts database located on the PennDOT Safety Infrastructure Improvement Program website, which can be accessed at https://www.penndot.gov/TravelInPA/Safety/Pages/Safety-Infrastructure-Improvement-Programs.aspx. It is anticipated that additional local road traffic volumes will be added to the database through time.

If there is a lack of historical traffic volume data for the analysis intersection, it is acceptable to use the current year AADT when calculating the $N_{predicted}$ value for each study year. As shown in Table C-2, the $N_{predicted(total)}$ and $N_{predicted(f\&i)}$ values have been calculated for each study year using the corresponding SPF equations and District Calibration Factors that were used in Step 6. In this example, the current year AADT was used to compute $\sum N_{predicted}$.

Table C-2: $N_{predicted}$ Calculations based on each Study Year for Analysis Intersection

Study Year	$AADT_{Major}$	$AADT_{Minor}$	$N_{total,predicted}$	$N_{fatal\text{-}inj,predicted}$
2014	11,615	4,790	2.49	1.54
2015	11,615	4,790	2.49	1.54
2016	11,615	4,790	2.49	1.54
2017	11,615	4,790	2.49	1.54
2018	11,615	4,790	2.49	1.54

As determined in previous steps, the inputs needed to calculate the EB method adjustment factor ***w*** were gathered and summarized in Table C-3.

Table C-3: Empirical-Bayes Method Variables for Analysis Intersection

Base Condition Variable	Value	Source
L (Length of segment in miles (use L=1 for intersection))	**1**	Step 5: Gather all base condition data
$\Sigma N_{predicted(total)}$	$2.49 + 2.49 + 2.49 + 2.49 + 2.49 =$ **12.45 Predicted Crashes**	Table C-2
$\Sigma N_{predicted(f\&i)}$	$1.54 + 1.54 + 1.54 + 1.54 + 1.54 =$ **7.7 Predicted Crashes**	
k_{total} (Overdispersion parameter)	**0.356**	Step 4: Figure C-7 Statewide SPFs for Urban-Suburban Arterial – Four-leg with Signalized Control
$k_{f\&i}$ (Overdispersion parameter)	**0.432**	
$N_{predicted(total)}$	**2.49 Predicted Crashes per Year**	Step 6: Calculate $N_{predicted}$ using the corresponding SPF equation, location specific base condition adjustments, and location specific calibration factors
$N_{predicted(f\&i)}$	**1.54 Predicted Crashes per Year**	
$N_{observed(total)}$	**7.4 Observed Crashes per Year**	Step 3: Summarize $N_{observed}$ (historical crash data) for the location being analyzed
$N_{observed(f\&i)}$	**4.6 Observed Crashes per Year**	

Use the inputs listed in Table C-3 to calculate $w_{predicted(total)}$ and $w_{predicted(f\&i)}$ from Equation 1 located in Section 1.4. Once ***w*** is calculated, Equation 2 from Section 1.4 is used to find $\mathbf{N}_{expected}$.

$$w_{predicted(total)} = \frac{1}{1+\frac{(0.356)}{(1)}\times(12.45)} = 0.18$$

$$w_{predicted(f\&i)} = \frac{1}{1+\frac{(0.432)}{(1)}\times(7.7)} = 0.23$$

$$\mathbf{N}_{expected} = w \times \mathrm{N}_{predicted} + (1.00 - w) \times \mathbf{N}_{observed}$$

$$\mathbf{N}_{expected(total)} = (0.18) \times (2.49) + (1.00 - 0.18) \times 7.4 = \mathbf{6.5} \text{ crashes per year}$$

$$\mathbf{N}_{expected(f\&i)} = (0.23) \times (1.54) + (1.00 - 0.23) \times 4.6 = \mathbf{3.9} \text{ crashes per year}$$

<u>Step 8:</u> Compare $N_{observed}$, $N_{predicted}$, and $N_{expected}$ for the location being analyzed:

Use the results obtained from the predictive method, EB method, and the observed crash data to identify the potential for safety improvement or to evaluate the crash history and potential for improvement countermeasures in the analysis intersection.

The $N_{observed}$, $N_{expected}$, and $N_{predicted}$ are shown in Table C-4. In this case, $N_{expected}$ is greater than $N_{predicted}$. This is the circumstance illustrated by the red star in Figure C-11 and described in more detail in Section 1.1.

Table C-4: Intersection Analysis Results

Number of Crashes	Total Crashes per Year	Fatal & Injury Crashes per Year
$N_{observed}$	7.4	4.6
$N_{expected}$	6.5	3.9
$N_{predicted}$	2.49	1.54
Excess Crash Frequency ($N_{expected}$ - $N_{predicted}$)	4.01	2.36

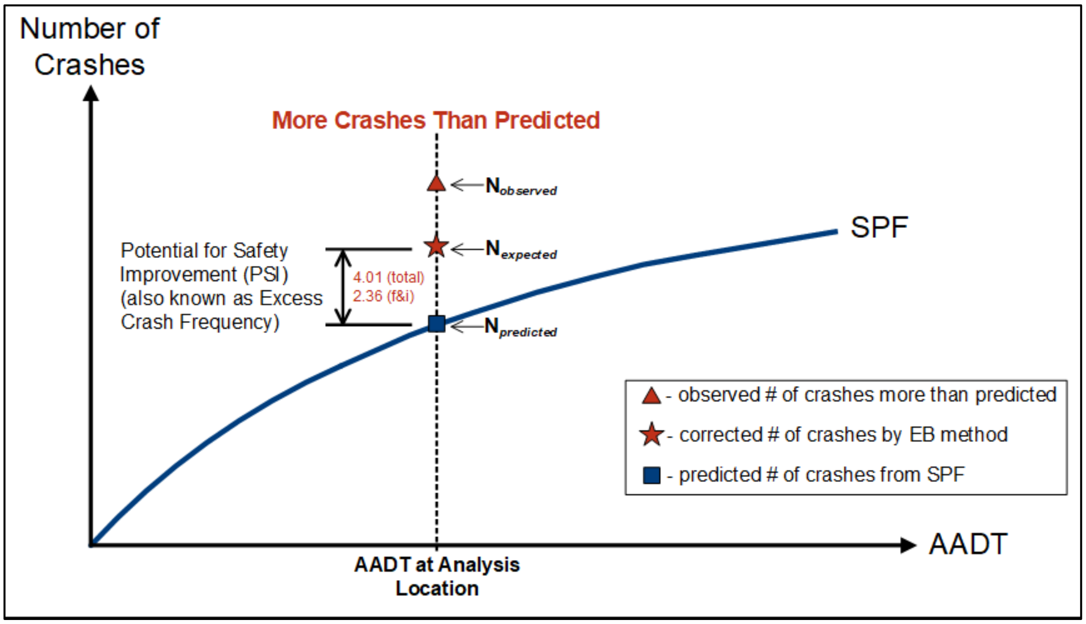

Figure C-11: Graphical Representation of SPF, $N_{expected}$, $N_{predicted}$, and EB Method Corrections for Analysis Intersection

Once the potential for safety improvement has been determined, countermeasures may be considered. Countermeasure evaluation and application is described in Chapter 5 as well as the 2010 HSM, Part D Analysis. Since the evaluation process is similar between a segment and intersection, Sample Problem 2 – Countermeasure Evaluation may be used as a reference during an intersection analysis.

Sample Problem 2 – Roadway Segment Analysis

Utilize the HSM predictive method with the Pennsylvania SPF equations to analyze crashes along the 2.0 mile section of Waterford Street (PA 97/SR 0197) northeast of Union City, PA depicted in Figure C-12.

Figure C-12: Location of Segment Analysis Area

Prior to analyzing the segment, it must be divided into contiguous roadway segments, split at intersections along the roadway. For the example, one intersection, circled in Figure C-13, is located within the segment analysis area. Due to this, the section to be evaluated will be split into two segments (Segment 1 and Segment 2) for predictive analysis. During the analysis, when reported crash history is collected, crashes that are attributable to the intersection should be omitted from the segment crash data for the segment analysis.

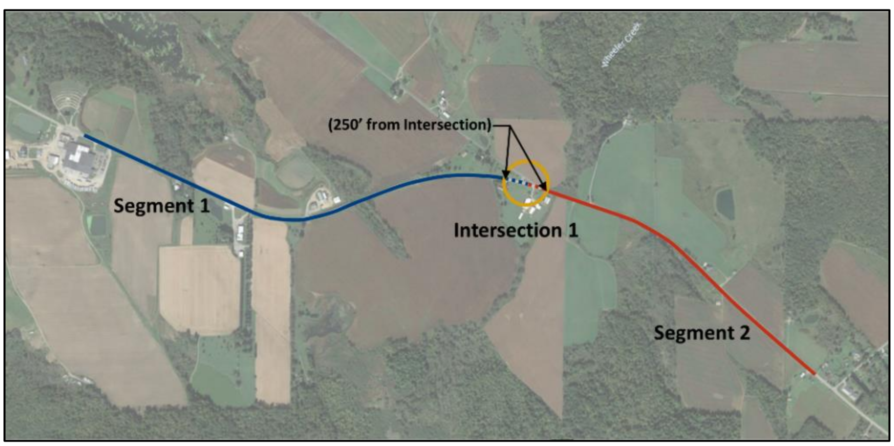

Figure C-13: Segment and Intersection Identification in Segment Analysis Area

The remaining example will detail the process for analyzing the segment portions of the corridor. The intersection would be analyzed separately and follow the analysis process in Sample Problem 1 – Intersection Analysis.

Solution:

Follow the problem steps outlined in Section 2.1.1 and summarized in Figure C-14.

2.1.1 Pennsylvania Highway Safety Predictive Analysis Method

To implement the 2010 HSM Part C predictive method utilizing the Pennsylvania Regionalized Safety Performance Functions the following steps should be followed:

1. Determine the location to be analyzed and identify District and county.
2. Categorize the analysis location into one of the roadway facility types from Table 2.1-1.

   Note: For roadway types not included in Table 1.5-1 (i.e., freeways, ramps, and ramp terminals) refer to the 2010 HSM Part C Supplement and use the nationwide SPF equations (with Pennsylvania calibration factors as described in Chapter 3 of this document) following the HSM predictive method.
3. Gather historical crash data and calculate $\mathbf{N}_{observed}$ (historical crash data) for the location being analyzed, ensuring only the applicable crash data is included (i.e., If $\mathbf{N}_{total}$ then include all crashes, if $\mathbf{N}_{f\&i}$ then only include fatal and injury crashes).
4. Determine the SPF equation, base condition variables, and calibration factors (if applicable).
5. Gather all base condition data for the variables identified based on the location being analyzed (the base conditions are listed in the corresponding sections below for each SPF).
6. Calculate $\mathbf{N}_{predicted}$ (Number of predicted crashes) using the corresponding SPF equation and location specific base condition adjustments (using data gathered in Step 5 and Step 6), and location specific calibration factors. Note that SPF equations are given to calculate $\mathbf{N}_{predicted}$ for either total predicted crashes ($\mathbf{N}_{total}$) or fatal and injury predicted crashes ($\mathbf{N}_{f\&i}$).
7. Apply the Empirical Bayes method (EB Method) described in Sections 1.4 and 1.5 to obtain the number of expected crashes, $\mathbf{N}_{expected}$, using the equations:

$$N_{expected} = w \times N_{predicted} + (1.00 - w) \times N_{observed}$$

   Where w for segment SPF equations equals:

$$w = \frac{1}{1 + \frac{k}{L} \times \left(\sum_{\text{all study years}} N_{predicted} \right)}$$

   And w for intersection SPF equations equals:

$$w = \frac{1}{1 + k \times \left(\sum_{\text{all study years}} N_{predicted} \right)}$$

8. Compare $\mathbf{N}_{observed}$, $\mathbf{N}_{predicted}$, and $\mathbf{N}_{expected}$ for the location being analyzed.

Figure C-14: Problem Steps outlined in Section 2.1.1 for Analysis Segment

<u>Step 1:</u> Identify the District and County of each analysis segment:

The location can be determined by utilizing PennDOT District Maps, PennDOT OneMap, and/or other online navigation aids such as Google Maps. In this example, Google Maps and a PennDOT District Map were utilized to determine the District and county of the section of PA 197 to be analyzed. Both Segment 1 and Segment 2 are located in:

- Erie County
- PennDOT Engineering District 1-0.

Additional details of using PennDOT OneMap are provided in Sample Problem 1 – Intersection Analysis.

<u>Step 2:</u> Identify the roadway facility type of each analysis segment:

Use online navigation aids and PennDOT VideoLog to determine number of lanes and functional class of roadway for each component of analysis (Segment 1, Segment 2). If information regarding the specific analysis segment is limited, then a site visit may be necessary. PennDOT VideoLog Admin Data provides the number of lanes, and whether the roadway is in an urban or rural area. Figure C-15 shows the PennDOT VideoLog Admin Data for Segment 1.

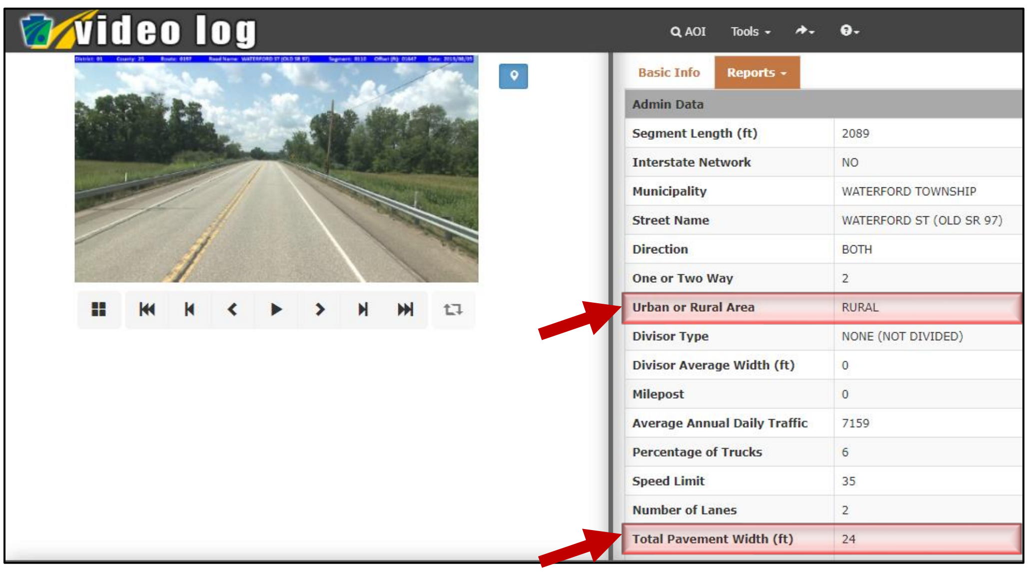

Figure C-15: PennDOT VideoLog Admin Data for Analysis Segment 1

In this case, Segment 1 is:

- Two-lane
- Rural roadway

Segment 2, by similar method, is:

- Two-lane
- Rural roadway

<u>Step 3:</u> Gather historical crash data and calculate $N_{observed}$ for each analysis segment:

The analyst should collect historical crash data for each segment, if available, to compare the predicted number of crashes with the expected number of crashes (as described in Step 8). Historical crash data can be obtained from CDART or the Custom Query Tool located on the Pennsylvania Crash Information Tool (PCIT) website at https://crashinfo.penndot.gov/PCIT/queryTool.html.

As shown in Figure C-16 and Figure C-17, point maps were generated from PCIT to depict the crashes along Segment 1 and Segment 2. In a case where an intersection is at the end of a segment, crashes that are attributable to the intersection should be omitted from the segment analysis. Any intersection crashes are reflective of the intersection SPFs and will require a separate intersection-specific analysis, if desired. Intersection analysis is detailed in Sample Problem 1 – Intersection Analysis.

To determine if a crash is attributable to an intersection, crash descriptions should be reviewed for all crashes that occurred within 250 feet of the intersection, and if they are attributable to the intersection should not be considered in the segment analysis. Typically, these intersection-attributable crashes would be angle crashes or rear-end crashes. For this sample problem, Figure C-18 identifies one crash along Segment 2 that occurred within 250 feet of the intersection. This crash was not omitted from the Segment 2 analysis because the crash type was unknown, consisted of one vehicle, and was not attributable to the intersection.

Crash History Reports can be exported from CDART or PCIT to see the crash severity level by year for each analysis segment (Figure C-19 and Figure C-20). The analyst should remember to omit any intersection related crashes from the data set.

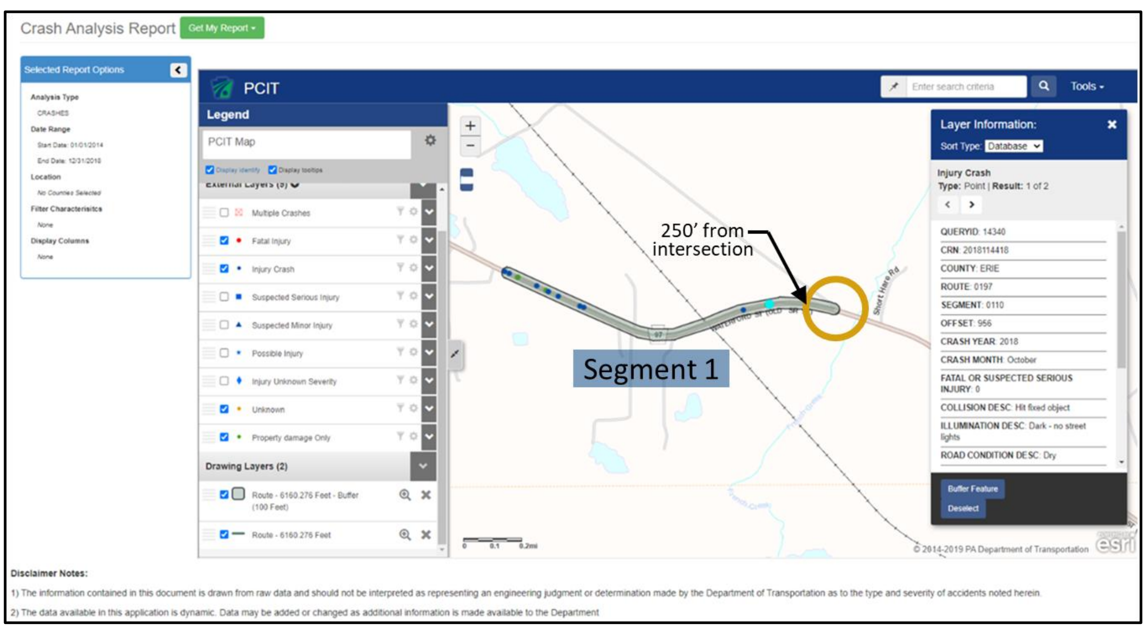

Figure C-16: PCIT Point Map Results for Segment 1

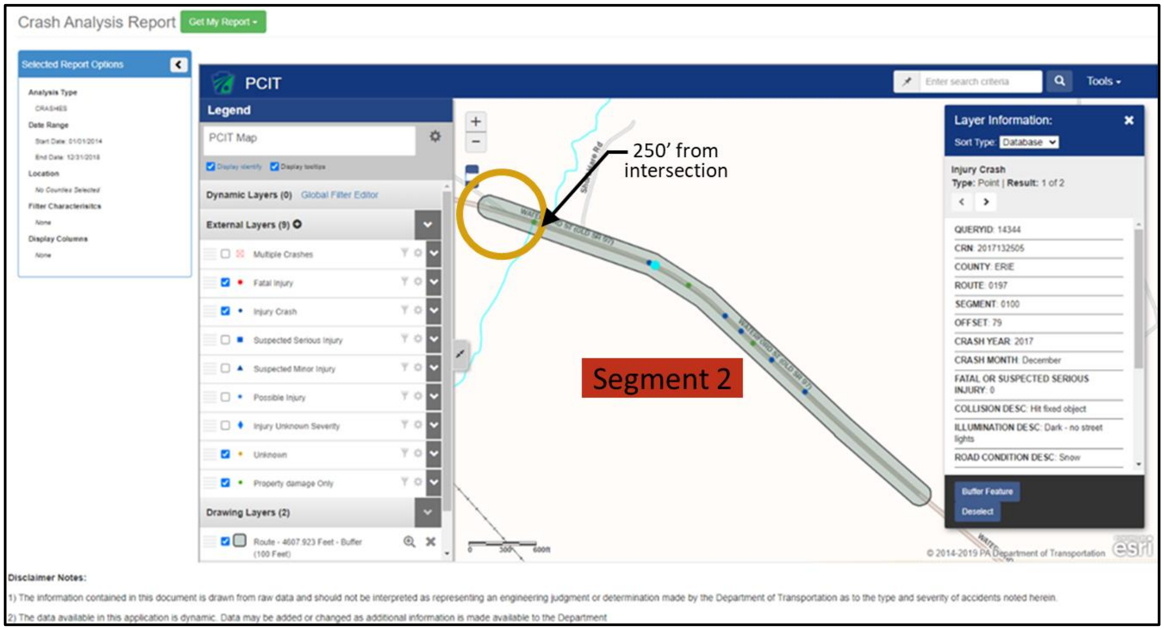

Figure C-17: PCIT Point Map Results for Segment 2

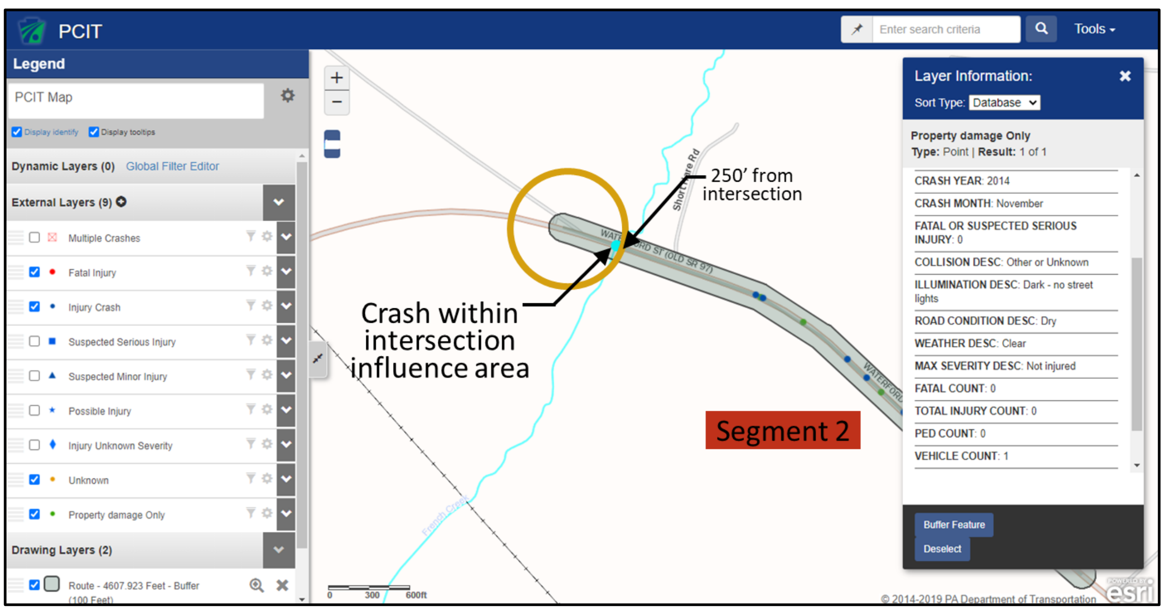

Figure C-18: Intersection Attributable Crash Analysis of PCIT Point Map Results

Date Range: 01/01/2014 to 12/31/2018*

CRASH SEVERITY LEVEL BY YEAR

	2015 CRASHES	2016 CRASHES	2017 CRASHES	2018 CRASHES	ALL YEARS CRASHES
SUSPECTED MINOR INJURY	0	2	1	4	7
POSSIBLE INJURY	0	0	1	1	2
PROPERTY DMG ONLY	2	1	1	0	4
TOTAL	2	3	3	5	13

Figure C-19: PCIT Crash History Report Summary for Segment 1

From the PCIT Crash History Report for Segment 1, shown in Figure C-19, the five-year crash data (January 2014 – December 2018) indicated there were a total of 13 reportable crashes in the segment, yielding an average of 2.6 crashes per year. This value will be used as $\mathbf{N}_{\mathit{observed(total)}}$ during analysis in Steps 7 and 8.

$$\text{Segment 1 } \mathrm{N}_{observed(total)} = \frac{13\ crashes}{5\ years} = \text{ 2.6 crashes per year}$$

The data also showed there were zero fatal crashes and nine injury crashes (seven suspected minor injury and two possible injury) in Segment 1 during the same time frame. This yields an average of 1.8 F&I crashes per year. This value will be used as $\mathbf{N}_{\mathit{observed(f\&i)}}$ during analysis in Steps 7 and 8.

$$\text{Segment 1 } \mathrm{N}_{observed(f\&i)} = \frac{0\ fatal\ crashes + 9\ injury\ crashes}{5\ years} = \text{ 1.8 F\&I crashes per year}$$

Date Range: 01/01/2014 to 12/31/2018*

CRASH SEVERITY LEVEL BY YEAR

	2014 CRASHES	2015 CRASHES	2016 CRASHES	2017 CRASHES	2018 CRASHES	ALL YEARS CRASHES
SUSPECTED MINOR INJURY	0	0	0	1	0	1
POSSIBLE INJURY	1	2	0	0	0	3
UNKNOWN SEVERITY	0	0	1	1	0	2
PROPERTY DMG ONLY	2	0	0	1	1	4
TOTAL	3	2	1	3	1	10

Figure C-20: PCIT Crash History Report Summary for Segment 2

From the PCIT Crash History Report for Segment 2, shown in Figure C-20, the five-year crash data (January 2014 – December 2018) indicated there were a total of 10 reportable crashes in Segment 2, yielding an average of 2.0 crashes per year. This value will be used as $\mathbf{N}_{observed(total)}$ during analysis in Step 8.

$$\text{Segment 2 } N_{observed(total)} = \frac{10\ crashes}{5\ years} = 2.0 \text{ crashes per year}$$

The data also showed there were zero fatal crashes and six injury crashes (one suspected minor injury, three possible injury, and two unknown severity) in Segment 2 during the same time frame. This yields an average of 1.2 F&I crashes per year. This value will be used as $\mathbf{N}_{observed(f\&i)}$ during analysis in Step 8.

$$\text{Segment 2 } N_{observed(f\&i)} = \frac{0\ fatal\ crashes + 6\ injury\ crashes}{5\ years} = 1.2 \text{ F\&I crashes per year}$$

<u>Step 4:</u> Determine the SPF equation, base condition variables, and calibration factors for each segment:

For this step, the SPF equations, base condition variables, and calibration factors for $\mathbf{N}_{predicted}$ total crashes and F&I crashes are found using the District, county, and roadway facility type for each segment. For this example, both segments are located in PennDOT District 1-0, Erie County, and are classified as a two-lane rural roadway. The required SPF equations are identified in Table 2.2-2, District 1-0 (also shown in Figure C-21). Table 2.1-1 can be used to quickly identify the section of Chapter 2 with the required SPF equation and its regionalization level.

Table 2.2-2: Regionalized SPFs for Two-lane Rural Roadway Segments

Regionalized SPF Predictive Equations		Overdispersion Parameter
District 1		
Total Predicted	$N_{total} = e^{-4.946} \times L \times AADT^{0.587} \times e^{0.333 \times RHR34} \times e^{0.435 \times RHR567} \times e^{-0.173 \times PZ} \times e^{-0.086 \times SRS} \times e^{0.009 \times AD} \times e^{0.056 \times HCD} \times e^{0.002 \times DCPM}$	*k*= 0.450
Fatal Inj Predicted	$N_{fatal\_inj} = e^{-5.554} \times L \times AADT^{0.568} \times e^{0.551 \times RHR34} \times e^{0.632 \times RHR567} \times e^{-0.183 \times PZ} \times e^{-0.123 \times SRS} \times e^{0.010 \times AD} \times e^{0.055 \times HCD} \times e^{0.002 \times DCPM}$	*k*= 0.582

Figure C-21: Markup of Table 2.2-2 for Analysis Segment

As identified in Section 2.2, a calibration factor is required to modify the District-level SPF to be applied to a specific county. The Erie County calibration factor can be identified in Table 2.2-3, District 1-0, Erie County (also shown in Figure C-22).

Table 2.2-3: County Calibration Factors for Two-lane Rural Road Segments

District	County	County Calibration Factor for Total Crash SPF	County Calibration Factor for Fatal + Injury SPF
1	Crawford, Erie, Mercer	1.00	1.00
	Forest, Venango, Warren	0.78	0.76

Figure C-22: Markup of Table 2.2-3 for Analysis Segment

Table 2.2-1, in Section 2.2 (SPFs for Rural Two-Lane Roadway Segments), identifies the base condition variables required to compute the SPF for District 1-0 (see Figure C-23). Note that the base condition variables may differ for each District and SPF equation.

Table 2.2-1: Base Condition Variables for Two-lane Rural Roadway Segments

Base Condition Variables		District										
		1	2	3	4	5	6	8	9	10	11	12
L	length of segment (miles)	X	X	X	X	X	X	X	X	X	X	X
AADT	annual average daily traffic on the segment (veh/day)	X	X	X	X	X	X	X	X	X	X	X
RHR567	roadside hazard rating on the segment of 5, 6 or 7 (1 if RHR is 5, 6 or 7; 0 otherwise)	X	X			X			X	X		
RHR4	roadside hazard rating on the segment of 4 (1 if RHR is 4; 0 otherwise)		X							X		
RHR34	roadside hazard rating on the segment of 3 or 4 (1 if RHR is 3 or 4; 0 otherwise)	X										
RHR45	roadside hazard rating on the segment of 4 or 5 (1 if RHR is 4 or 5; 0 otherwise)						X					
RHR67	roadside hazard rating on the segment of 6 or 7 (1 if RHR is 6 or 7; 0 otherwise)						X				X	
RHR4567	roadside hazard rating on the segment of 4,5,6 or 7 (1 if RHR is 4,5,6 or 7; 0 otherwise)		X									
RHR5	roadside hazard rating on the segment of 5 (1 if RHR is 5; 0 otherwise)										X	
PZ	presence of a passing zone in the segment (1 if present; 0 otherwise)	X	X	X	X	X		X	X	X		X
SRS	presence of shoulder rumble strips in the segment (1 If present; 0 otherwise)	X		X					X	X		
AD	access density in the segment, total driveways and intersections per mile of segment length (Access Points/Mile)	X	X	X	X	X	X	X	X	X	X	X
HCD	horizontal curve density in the segment, number of curves in the segment per mile (Hor. Curves/Mile)	X	X	X	X	X	X	X	X	X	X	
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)	X	X	X	X	X	X	X	X	X	X	X

Note: Appendix A provides guidance on determining RHR and Appendix B provides guidance on using Google Earth to determine DCPM.

Figure C-23: Markup of Table 2.2-1 for Analysis Segment

Based on Table 2.2-1 (Figure C-23), the variables for which data must be collected for each analysis segment in this example are:

- **L** – Length of segment to be analyzed (miles)
- **AADT –** Annual average daily traffic (veh/day)
- **RHR** – Roadside hazard rating on the segment, on a scale of 1 to 7 (See Appendix A)
- **PZ** – Presence of passing zone
- **SRS** – Presence of shoulder rumble strips
- **AD** – Access density
- **HCD** – Horizontal curve density
- **DCPM** – Degree of curvature per mile

Step 5: Gather all base condition data for the variables identified in the two-lane rural roadway segment SPF equations:

Gather data for the base condition variables determined in Step 4 for the two-lane rural roadway segment SPF for District 1-0.

Google Maps or PennDOT VideoLog can be used to identify most of the required SPF variables. PennDOT TIRe can be utilized to find the AADT for state roads. If data is unavailable in PennDOT TIRe, local road traffic counts may be available on the Safety Infrastructure Improvement Programs page from the PennDOT Website. If no data is available, traffic counts must be obtained prior to computation.

For this example, the Segment 1 base condition variable values and data sources were identified and are shown in Table C-5.

Table C-5: SPF Equation Base Condition Variables for Segment 1

Base Condition Variable		Segment 1	Data Source
L	Length of segment to be analyzed (miles)	**1.2 Miles**	Google Maps[1] PennDOT LRS[2]
AADT	Annual average daily traffic (veh/day)	**7159 veh/day**	PennDOT TIRe[3] (Figure C-25)
RHR34	Roadside hazard rating on the segment of 3 or 4 (1 if RHR is 3 or 4; 0 otherwise)	**3 (Equation Input = 1)**	Google Maps[4]PennDOT VideoLog[2]
RHR567	Roadside hazard rating on the segment of 5, 6 or 7 (1 if RHR is 5, 6 or 7; 0 otherwise)	**N/A (Equation Input = 0)**	Google Maps[4] PennDOT VideoLog[2]
PZ	Presence of passing zone (1 if present; 0 otherwise)	**Yes (Equation Input = 1)**	Google Maps[4] PennDOT VideoLog[2]
SRS	Presence of shoulder rumble strips (1 If present; 0 otherwise)	**No (Equation Input = 0)**	Google Maps[4] PennDOT VideoLog[2]
AD	Access density	$\frac{10 \text{ driveways}}{1.2 \text{ miles}} = \mathbf{8.3}$	Google Maps[4] PennDOT VideoLog[2]
HCD	Horizontal curve density	$\frac{2 \text{ curves}}{1.2 \text{ miles}} = \mathbf{1.7}$	Google Maps[4] PennDOT VideoLog[2]
DCPM	Degree of curvature per mile	$R_2 = 2324$ ft $R_3 = 1256$ ft $D = \frac{5729.578}{R}$ $D_2 = 2.465$ $D_3 = 4.562$ $\frac{2.465 + 4.562}{1.2 \text{ Miles}} = \mathbf{5.9}$	PennDOT Curve Inventory[5]

[1] – The Google Maps measuring tool can be utilized.

[2] – PennDOT Location Reference System can be identified by using PennDOT VideoLog. In addition to Google Maps, PennDOT VideoLog can also be used to identify the field condition of the analysis segment.

[3] – To generate the study area map in PennDOT TIRe, fill out the county and route specific to the analysis location (see Figure C-24 for details). Segment information is not necessary to generate the map. If data is unavailable in PennDOT TIRe, local road traffic counts may be available on the Safety Infrastructure Improvement Programs page from the PennDOT Website. If no data is available, traffic counts must be obtained prior to computation.

[4] – Google Maps street view can be used to identify the field condition of the analysis segment. If street view is unavailable or outdated, a field observation may be required.

[5] – PennDOT State Road Horizontal Curve Inventory can be used to identify the radius of each curve along the analysis segment. If the analysis segment is not listed in the curve inventory, Appendix B shows the process of how to approximate a curve radius using Google Earth.

The Segment 2 base condition variable values and data sources were identified and are shown in Table C-13.

Table C-6: SPF Equation Base Condition Variables for Segment 2

Base Condition Variable		Segment 2	Data Source
L	Length of segment to be analyzed (miles)	**0.8 Miles**	Google Maps[1] PennDOT LRS[2]
AADT	Annual average daily traffic (veh/day)	**7159 veh/day**	PennDOT TIRe[3] (Figure C-25)
RHR34	Roadside hazard rating on the segment of 3 or 4 (1 if RHR is 3 or 4; 0 otherwise)	**4 (Equation Input = 1)**	Google Maps[4]PennDOT VideoLog[2]
RHR567	Roadside hazard rating on the segment of 5, 6 or 7 (1 if RHR is 5, 6 or 7; 0 otherwise)	**N/A (Equation Input = 0)**	Google Maps[4] PennDOT VideoLog[2]
PZ	Presence of passing zone (1 if present; 0 otherwise)	**Yes (Equation Input = 1)**	Google Maps[4] PennDOT VideoLog[2]
SRS	Presence of shoulder rumble strips (1 If present; 0 otherwise)	**No (Equation Input = 0)**	Google Maps[4] PennDOT VideoLog[2]
AD	Access density	$\frac{9 \text{ driveways}}{0.8 \text{ miles}} = \mathbf{11.3}$	Google Maps[4] PennDOT VideoLog[2]
HCD	Horizontal curve density	$\frac{1 \text{ curves}}{0.8 \text{ miles}} = \mathbf{1.3}$	Google Maps[4] PennDOT VideoLog[2]
DCPM	Degree of curvature per mile	$R_1 = 1629$ ft $D = \frac{5729.578}{R}$ $D_1 = 3.517$ $\frac{3.517}{0.8 \text{ Miles}} = \mathbf{4.4}$	PennDOT Curve Inventory[5]

1 – The Google Maps measuring tool can be utilized.
2 – PennDOT Location Reference System can be identified by using PennDOT VideoLog. In addition to Google Maps, PennDOT VideoLog can also be used to identify the field condition of the analysis segment.
3 – To generate the study area map in PennDOT TIRe, fill out the county and route specific to the analysis location (see Figure C-24 for details). Segment information is not necessary to generate the map. If data is unavailable in PennDOT TIRe, local road traffic counts may be available on the Safety Infrastructure Improvement Programs page from the PennDOT Website. If no data is available, traffic counts must be obtained prior to computation.
4 – Google Maps street view can be used to identify the field condition of the analysis segment. If street view is unavailable or outdated, a field observation may be required.
5 – PennDOT State Road Horizontal Curve Inventory can be used to identify the radius of each curve along the analysis segment. If the analysis segment is not listed in the curve inventory, Appendix B shows the process of how to approximate a curve radius using Google Earth.

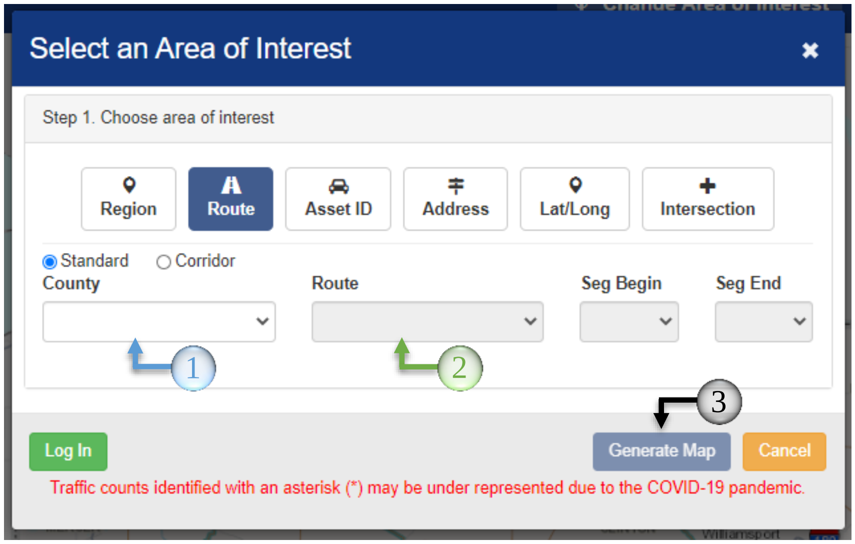

Figure C-24: Navigating PennDOT TIRe Area of Interest

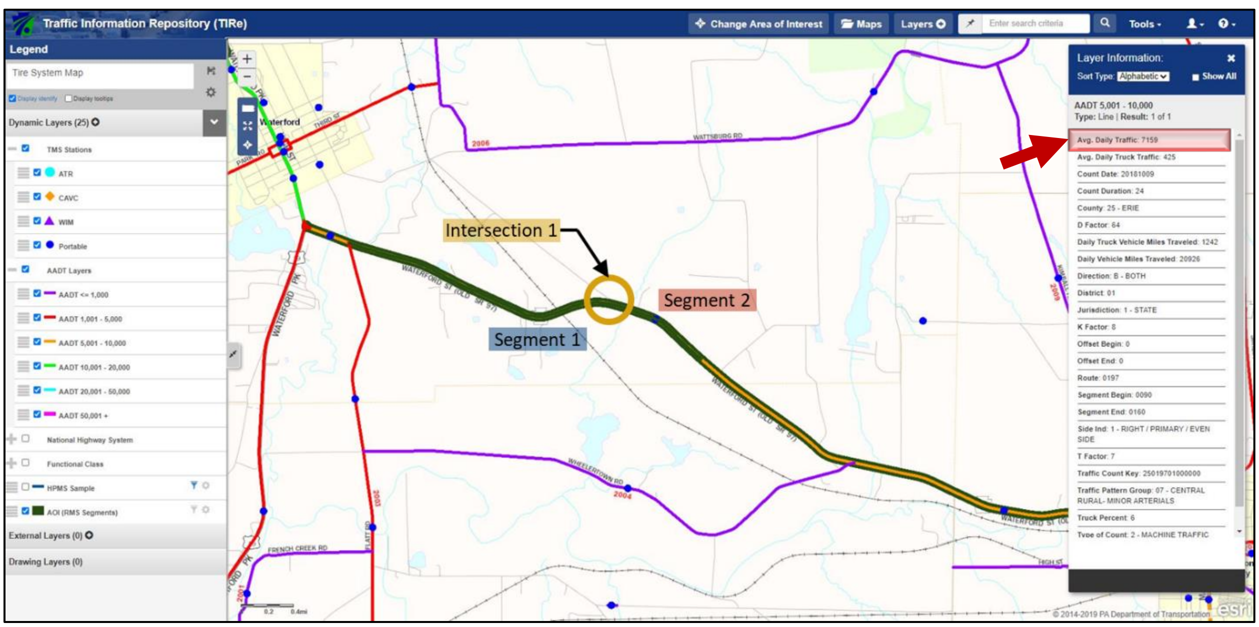

Figure C-25: PennDOT TIRe for Segment 1 and Segment 2

Step 6: Calculate $N_{predicted}$ using the corresponding SPF equation, location specific base condition variables, and location specific calibration factors for each segment:

Calculate $\mathbf{N}_{total}$ and $\mathbf{N}_{f\&i}$ for Segment 1 and Segment 2 using the SPF equations identified in Step 4 (Figure C-21). Once the SPF equations are calculated, they must be modified by the county-level calibration factor to determine the value of $\mathbf{N}_{predicted(total)}$ and $\mathbf{N}_{predicted(f\&i)}$. The Erie County calibration factor can be identified in Table 2.2-3, District 1-0, Erie County (also shown in Figure C-22).

To complete the regionalization process using the PA SPF, apply the Erie County total crash calibration factor to the District 1-0 SPF total crash result. From Table 2.2-3 (Figure C-22), identified in Step 4, note that the county calibration factor for total crashes is 1.00. Multiplying $\mathbf{N}_{\boldsymbol{total}}$ by the county total crash calibration factor yields a result of 2.20 and 1.47 predicted reportable crashes per year, for Segment 1 and Segment 2 respectively.

Similarly, apply the county F&I crash calibration factor to the District 1-0 SPF F&I crash result. From Table 2.2-3: County Calibration Factors for Two-lane Rural Road Segments (Figure C-22), note that the county calibration factor for the F&I crash SPF is 1.00. Multiplying $\mathbf{N}_{\boldsymbol{f\&i}}$ by the county F&I crash calibration factor yields a result of 1.30 and 0.87 predicted reportable crashes per year, for Segment 1 and Segment 2 respectively.

Segment 1 Calculations:

$\mathbf{N}_{\boldsymbol{total}}$ calculation:

$$\boldsymbol{N_{total}} = e^{-4.946} \times (1.2) \times (7159)^{0.587} \times \mathrm{e}^{0.333\times(1)} \times \mathrm{e}^{0.435\times(0)} \times \mathrm{e}^{-0.173\times(1)} \times \mathrm{e}^{-0.086\times(0)} \times \mathrm{e}^{0.009\times(8.3)} \times \mathrm{e}^{0.056\times(1.7)} \times \mathrm{e}^{0.002\times(5.9)}$$

$$\boldsymbol{N_{total}} = (0.0071 \times 1.2 \times 183.146 \times 1.395 \times 1 \times 0.841 \times 1 \times 1.078 \times 1.100 \times 1.012)$$

$$\boldsymbol{N_{total}} = \mathbf{2.20\ total\ crashes\ per\ year}$$

$\mathbf{N}_{\boldsymbol{predicted(total)}}$ calculation:

$$\mathbf{N}_{\boldsymbol{predicted(total)}} = \mathbf{N}_{\boldsymbol{total}} \times County\ Calibration\ Factor$$

$$\textbf{Segment 1 } \mathbf{N}_{\boldsymbol{predicted(total)}} = 2.20 \times 1.0 = 2.20$$

> Therefore, the Segment 1 $\mathbf{N}_{\boldsymbol{predicted(total)}}$ = 2.20 predicted reportable total crashes per year in the 1.2 mile long segment.

$\mathbf{N}_{\boldsymbol{f\&i}}$ calculation:

$$\boldsymbol{N_{f\&i}} = e^{-5.554} \times (1.2) \times (7159)^{0.568} \times e^{0.551\times(1)} \times e^{0.632\times(0)} \times e^{-0.183\times(1)} \times e^{-0.123\times(0)} \times e^{0.010\times(8.3)} \times e^{0.055\times(1.7)} \times e^{0.002\times(5.9)}$$

$$\boldsymbol{N_{f\&i}} = (0.004 \times 1.2 \times 154.723 \times 1.735 \times 1 \times 0.833 \times 1 \times 1.087 \times 1.098 \times 1.012)$$

$$\boldsymbol{N_{f\&i}} = \mathbf{1.30\ fatal\ and\ injury\ crashes\ per\ year}$$

$\mathbf{N}_{\boldsymbol{predicted(f\&i)}}$ calculation:

$$\mathbf{N}_{\boldsymbol{predicted(f\&i)}} = \mathbf{N}_{\boldsymbol{f\&i}} \times County\ Calibration\ Factor$$

$$\textbf{Segment 1 } \mathbf{N}_{\boldsymbol{predicted(f\&i)}} = 1.30 \times 1.0 = 1.30$$

> Therefore, the Segment 1 $\mathbf{N}_{\boldsymbol{predicted(f\&i)}}$ = 1.30 predicted reportable fatal and injury crashes per year in the 1.2 mile long segment.

Segment 2 Calculations:

N$_{total}$ calculation:

$$N_{total} = e^{-4.946} \times (0.8) \times (7159)^{0.587} \times e^{0.333\times(1)} \times e^{0.435\times(0)} \times e^{-0.173\times(1)} \times e^{-0.086\times(0)} \times e^{0.009\times(11.3)} \times e^{0.056\times(1.3)} \times e^{0.002\times(4.4)}$$

$$N_{total} = (0.0071 \times 0.8 \times 183.146 \times 1.395 \times 1 \times 0.841 \times 1 \times 1.107 \times 1.076 \times 1.009)$$

$$N_{total} = \mathbf{1.47} \textbf{ total crashes per year}$$

N$_{predicted(total)}$ calculation:

$$\mathbf{N}_{predicted(total)} = \mathbf{N}_{total} \times County\ Calibration\ Factor$$

$$\textbf{Segment 2 } \mathbf{N}_{predicted(total)} = 1.47 \times 1.0 = 1.47$$

Therefore, the Segment 2 **N**$_{predicted(total)}$ = 1.47 predicted reportable total crashes per year in the 0.8 mile long segment.

N$_{f\&i}$ calculation:

$$N_{f\&i} = e^{-5.554} \times (0.8) \times (7159)^{0.568} \times e^{0.551\times(1)} \times e^{0.632\times(0)} \times e^{-0.183\times(1)} \times e^{-0.123\times(0)} \times e^{0.010\times(11.3)} \times e^{0.055\times(1.3)} \times e^{0.002\times(4.4)}$$

$$N_{f\&i} = (0.004 \times 0.8 \times 154.723 \times 1.735 \times 1 \times 0.833 \times 1 \times 1.120 \times 1.074 \times 1.009)$$

$$N_{f\&i} = \mathbf{0.87} \textbf{ fatal and injury crashes per year}$$

N$_{predicted(f\&i)}$ calculation:

$$\mathbf{N}_{predicted(f\&i)} = \mathbf{N}_{f\&i} \times County\ Calibration\ Factor$$

$$\textbf{Segment 2 } \mathbf{N}_{predicted(f\&i)} = 0.87 \times 1.0 = 0.87$$

Therefore, the Segment 2 **N**$_{predicted(f\&i)}$ = 0.87 predicted reportable fatal and injury crashes per year in the 0.8 mile long segment.

Step 7: Apply the Empirical Bayes method to obtain the number of expected crashes, $N_{expected}$, for each segment:

The first step in applying the EB method is to calculate ***w*** for Segment 1 and Segment 2 (the EB method adjustment factor) using Equation 1 from Section 1.4:

$$w = \frac{1}{1 + \frac{k}{L} \times \left(\sum_{\text{all study years}} N_{predicted}\right)}$$

Because five years of observed crash data was collected, $N_{predicted}$ must be calculated for each year to be summed in the denominator of the equation. Due to the variation of traffic volume from year to year, historical traffic volumes should be collected for each study year. Historical statewide traffic volume maps can be found on the PennDOT Bureau of Planning and Research website at https://www.penndot.gov/ProjectAndPrograms/Planning/Maps/Pages/Traffic-Volume.aspx.
Local road traffic volumes may be collected/counted by a District, planning partner or consultant, at the project level. At the time of development of this publication, some local road traffic volumes are available in the Local Road Traffic Counts database located on the PennDOT Safety Infrastructure Improvement Program website, which can be accessed at https://www.penndot.gov/TravelInPA/Safety/Pages/Safety-Infrastructure-Improvement-Programs.aspx. It is anticipated that additional local road traffic volumes will be added to the database through time.

If there is a lack of historical traffic volume data for the analysis segment(s), it is acceptable to use the current year AADT when calculating the $N_{predicted}$ value for each study year. As shown in Table C-7 and Table C-8 the $N_{predicted(total)}$ and $N_{predicted(f\&i)}$ values have been calculated for Segment 1 and Segment 2 during each study year using the corresponding SPF equations and County Calibration Factors that were used in Step 6. In this example, the current year AADT was used to compute $\sum N_{predicted}$.

Table C-7: $N_{predicted}$ Calculations based on each Study Year for Segment 1

Study Year	AADT	Segment 1	
		$N_{predicted,total}$	$N_{predicted,total}$
2014	7,159	2.20	1.30
2015	7,159	2.20	1.30
2016	7,159	2.20	1.30
2017	7,159	2.20	1.30
2018	7,159	2.20	1.30

Table C-8: $N_{predicted}$ Calculations based on each Study Year for Segment 2

Study Year	AADT	Segment 2	
		$N_{predicted,f\&i}$	$N_{predicted,f\&i}$
2014	7,159	1.47	0.87
2015	7,159	1.47	0.87
2016	7,159	1.47	0.87
2017	7,159	1.47	0.87
2018	7,159	1.47	0.87

With the $N_{predicted}$ values for each study year, the rest of the variables required to compute w can be obtained through previous steps or the SPF tables listed in Section 2.2. The values obtained for Segment 1 are listed in Table C-9, and the values obtained for Segment 2 are listed in Table C-10.

Table C-9: Empirical-Bayes Method Variables for Segment 1

Base Condition Variable	Segment 1	Source
L (length of segment to be analyzed)	**1.2 Miles**	Step 5: Gather all base condition data
$\Sigma N_{predicted(total)}$	$2.20 + 2.20 + 2.20 + 2.20 + 2.20 =$ **11.00 Predicted Crashes**	Table C-7
$\Sigma N_{predicted(f\&i)}$	$1.30 + 1.30 + 1.30 + 1.30 + 1.30 =$ **6.50 Predicted Crashes**	
k_{total} (Overdispersion parameter)	**0.450**	Step 4: Figure C-21 Regionalized SPFs for Two-lane Rural Roadway Segments
$k_{f\&i}$ (Overdispersion parameter)	**0.582**	
$N_{predicted(total)}$	**2.20 Predicted Crashes per Year**	Step 6: Calculate $N_{predicted}$ using the corresponding SPF equation, location specific base condition adjustments, and location specific calibration factors
$N_{predicted(f\&i)}$	**1.30 Predicted Crashes per Year**	
$N_{observed(total)}$	**2.6 Observed Crashes per Year**	Step 3: Summarize $N_{observed}$ (historical crash data) for the location being analyzed
$N_{observed(f\&i)}$	**1.8 Observed Crashes per Year**	

Table C-10: Empirical-Bayes Method Variables for Segment 2

Base Condition Variable	Segment 2	Source
L (length of segment to be analyzed)	**0.8 Miles**	Step 5: Gather all base condition data
$\Sigma N_{predicted(total)}$	$1.47 + 1.47 + 1.47 + 1.47 + 1.47 =$ **7.35 Predicted Crashes**	Table C-8
$\Sigma N_{predicted(f\&i)}$	$0.87 + 0.87 + 0.87 + 0.87 + 0.87 =$ **4.35 Predicted Crashes**	
k_{total} (Overdispersion parameter)	**0.450**	Step 4: Figure C-21 Regionalized SPFs for Two-lane Rural Roadway Segments
$k_{f\&i}$ (Overdispersion parameter)	**0.582**	
$N_{predicted(total)}$	**1.47 Predicted Crashes per Year**	Step 6: Calculate $N_{predicted}$ using the corresponding SPF equation, location specific base condition adjustments, and location specific calibration factors
$N_{predicted(f\&i)}$	**0.87 Predicted Crashes per Year**	
$N_{observed(total)}$	**2.0 Observed Crashes per Year**	Step 3: Summarize $N_{observed}$ (historical crash data) for the location being analyzed
$N_{observed(f\&i)}$	**1.2 Observed Crashes per Year**	

Use the inputs listed in Table C-9 and Table C-10 to calculate $\boldsymbol{w_{predicted(total)}}$ and $\boldsymbol{w_{predicted(f\&i)}}$ for Segment 1 and Segment 2 from Equation 1 located in Section 1.4. Once ***w*** is calculated, Equation 2 from Section 1.4 is used to find $\mathbf{N}_{expected}$.

Segment 1 Calculations:

$$\textbf{Segment 1 } \boldsymbol{w_{predicted(total)}} = \frac{1}{1+\frac{(0.450)}{(1.2)}\times(11.00)} = 0.20$$

$$\textbf{Segment 1 } \boldsymbol{w_{predicted(f\&i)}} = \frac{1}{1+\frac{(0.582)}{(1.2)}\times(6.50)} = 0.24$$

$$\boldsymbol{N_{expected}} = w \times N_{\boldsymbol{predicted}} + (1.00 - w) \times \boldsymbol{N_{observed}}$$

$$\textbf{Segment 1 } \mathbf{N}_{\boldsymbol{expected(total)}} = (0.20) \times (2.20) + (1.00 - 0.20) \times 2.6 = \mathbf{2.5} \text{ crashes per year}$$

$$\textbf{Segment 1 } \mathbf{N}_{\boldsymbol{expected(f\&i)}} = (0.24) \times (1.30) + (1.00 - 0.24) \times 1.8 = \mathbf{1.7} \text{ crashes per year}$$

Segment 2 Calculations:

$$\textbf{Segment 2 } \boldsymbol{w_{predicted(total)}} = \frac{1}{1+\frac{(0.450)}{(0.8)}\times(7.35)} = 0.19$$

$$\textbf{Segment 2 } \boldsymbol{w_{predicted(f\&i)}} = \frac{1}{1+\frac{(0.582)}{(0.8)}\times(4.35)} = 0.24$$

$$\boldsymbol{N_{expected}} = w \times N_{\boldsymbol{predicted}} + (1.00 - w) \times \boldsymbol{N_{observed}}$$

$$\textbf{Segment 2 } \mathbf{N}_{\boldsymbol{expected(total)}} = (0.19) \times (1.47) + (1.00 - 0.19) \times 2.0 = \mathbf{1.9} \text{ crashes per year}$$

$$\textbf{Segment 2 } \mathbf{N}_{\boldsymbol{expected(f\&i)}} = (0.24) \times (0.87) + (1.00 - 0.24) \times 1.2 = \mathbf{1.1} \text{ crashes per year}$$

Step 8: Compare $N_{observed}$, $N_{predicted}$, and $N_{expected}$ for each analysis segment:

Use the results obtained from the predictive method, EB method, and the observed crash data to identify the potential for safety improvement or to evaluate the crash history and potential for improvement countermeasures in the analysis segments.

The $N_{observed}$, $N_{expected}$, and $N_{predicted}$ for Segment 1, Segment 2, and over the entire analysis segment are shown in Table C-11. For both analysis segments, $N_{expected}$ is greater than $N_{predicted}$. This is the circumstance illustrated by the red star in Figure C-26 and described in more detail in Section 1.1.

Table C-11: Segment Analysis Results

Number of Crashes	Segment 1		Segment 2		Entire Analysis Segment	
	Total Crashes per Year	Fatal & Injury Crashes per Year	Total Crashes per Year	Fatal & Injury Crashes per Year	Total Crashes per Year	Fatal & Injury Crashes per Year
$N_{observed}$	2.60	1.80	2.00	1.20	4.60	3.00
$N_{expected}$	2.50	1.70	1.90	1.10	4.40	2.80
$N_{predicted}$	2.20	1.30	1.47	0.87	3.67	2.17
Excess Crash Frequency ($N_{expected}$ - $N_{predicted}$)	0.30	0.40	0.43	0.23	0.73	0.63

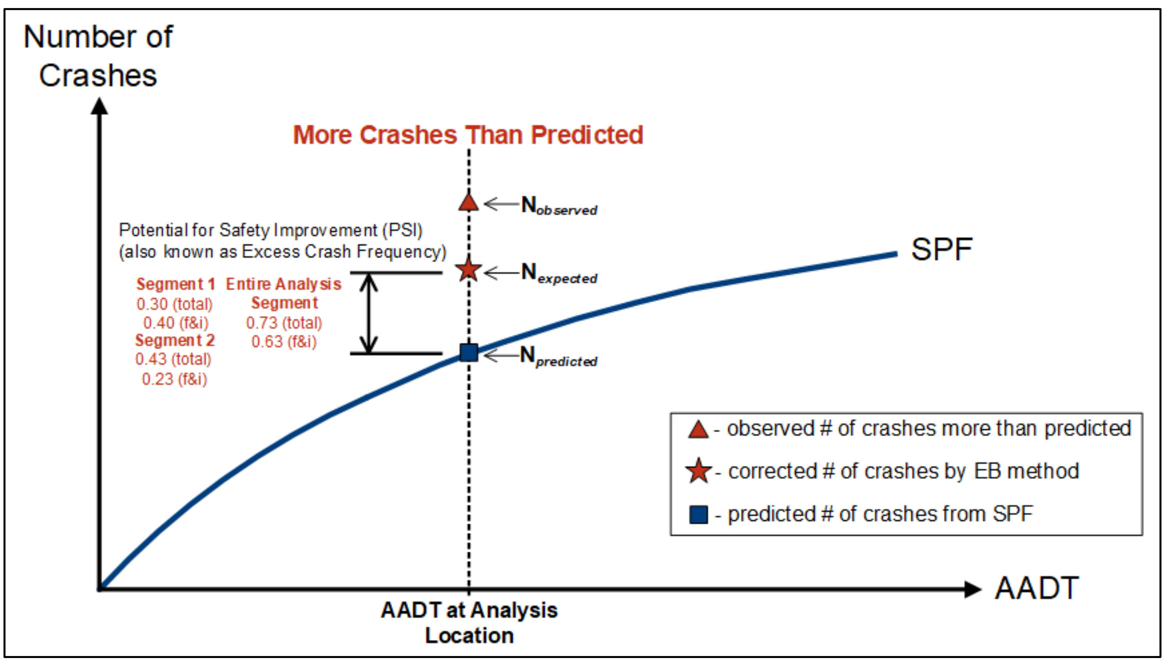

Figure C-26: Graphical Representation of SPF, $N_{expected}$, $N_{predicted}$, and EB Method Corrections for Analysis Segment

Sample Problem 2 – Countermeasure Evaluation

The following steps to evaluate countermeasures are applicable to both roadway segments and intersections. For this example, the data and values generated from the roadway segment analysis in Sample Problem 2 were utilized. Note that this example is for illustrative purposes only.

Countermeasure evaluation and application is described in Chapter 5 as well as the 2010 HSM, Part D Analysis. The basic steps of countermeasure evaluation are:

1. Use available crash data and the facility distribution tables for crash severity and lighting to inform effective countermeasures
2. Assess Site Conditions
3. Identify Potential Countermeasures
4. Select appropriate Crash Modification Factors (CMFs)
5. Determine the CMF combination method based on the effect direction and amount of countermeasure overlap
6. Compute number of crashes expected after countermeasure treatment(s) ($N_{treatment}$) using the appropriate CMF combination method

<u>Step 1:</u> Use available crash data and the facility distribution tables for crash severity and lighting to inform effective countermeasures

Each facility type described in Chapter 2 has corresponding distribution tables with the percentage distribution of crashes based on collision type and severity level as well as lighting and severity level. Figure C-27 shows the collision type and severity level distribution table for the rural two-lane highway segment facility type, which corresponds to both analysis segments (Segment 1 and Segment 2). The selection of applicable countermeasures will be informed by addressing collision types with higher crash distribution percentages. Note that the lighting and severity level distribution table was not used for this analysis but would be required to select any lighting-related countermeasures.

As shown in Figure C-27, 60.91% of the total collisions on rural two-lane highway segments are hit fixed object crashes, indicating that run-off-road crashes are predominant on this type of roadway.

Table 2.2-4: Distribution of Collision Type and Severity for Crashes on Rural Two-lane Highway Segments

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision (lane departure)	0.08%	0.19%	0.55%	1.08%	0.28%	0.06%	1.73%	**3.98%**
Non-collision (lane crash)	0.04%	0.16%	0.50%	0.72%	0.23%	0.02%	1.29%	**2.97%**
Rear-end	0.06%	0.21%	0.98%	3.36%	0.96%	0.16%	4.75%	**10.48%**
Head-on	0.32%	0.42%	0.65%	0.77%	0.31%	0.03%	0.71%	**3.22%**
Rear-to-rear (backing)	0.00%	0.00%	0.00%	0.01%	0.00%	0.00%	0.02%	**0.04%**
Angle	0.27%	0.39%	1.10%	2.14%	0.65%	0.09%	3.35%	**7.99%**
Sideswipe (same direction)	0.01%	0.03%	0.08%	0.25%	0.06%	0.04%	0.58%	**1.05%**
Sideswipe (opposite direction)	0.04%	0.08%	0.25%	0.65%	0.14%	0.06%	0.90%	**2.11%**
Hit fixed object	1.10%	2.10%	6.58%	15.87%	4.03%	1.38%	29.84%	**60.91%**
Hit pedestrian	0.08%	0.13%	0.18%	0.20%	0.07%	0.00%	0.00%	**0.66%**
Other or unknown	0.05%	0.12%	0.46%	0.92%	0.20%	0.04%	4.81%	**6.60%**
Total	**2.06%**	**3.84%**	**11.33%**	**25.98%**	**6.95%**	**1.88%**	**47.97%**	**100.00%**

*Based on 2009-2013 Reportable Crash Data

Figure C-27: Markup of Table 2.2-4 for Analysis Segments

In addition to the distribution tables, the historical crash data and roadway features/condition of the analysis segment provide further insight on countermeasure selection. The locations of reported crashes along Segment 1 and Segment 2 are shown in Figure C-28 and Figure C-29 and the reportable crash descriptions are shown in Figure C-30 and Figure C-31. The crash data was gathered in Step 3 of the previous example problem, which provides additional information regarding the use of PCIT.

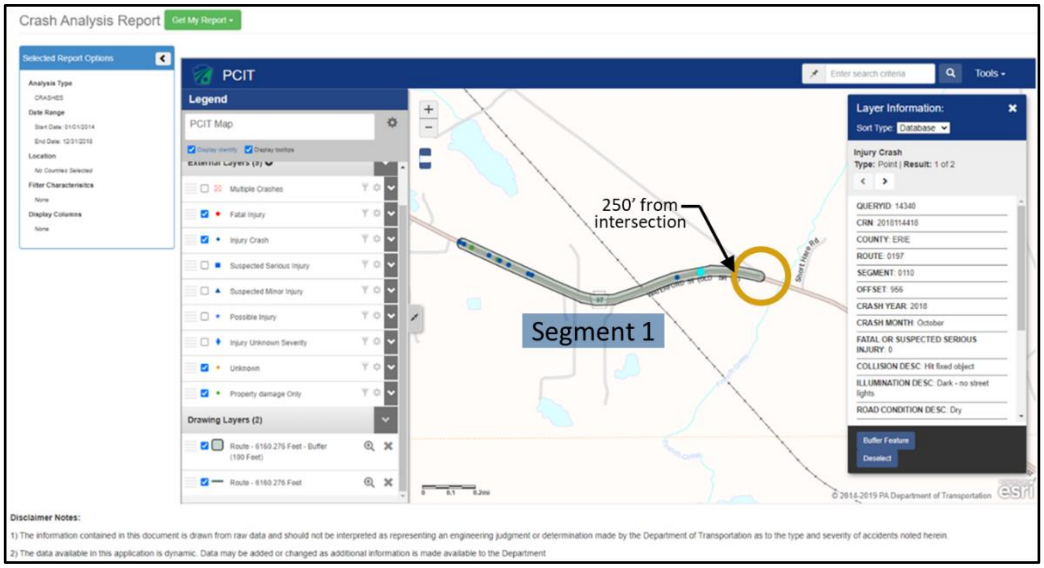

Figure C-28: PCIT Point Map Results for Segment 1

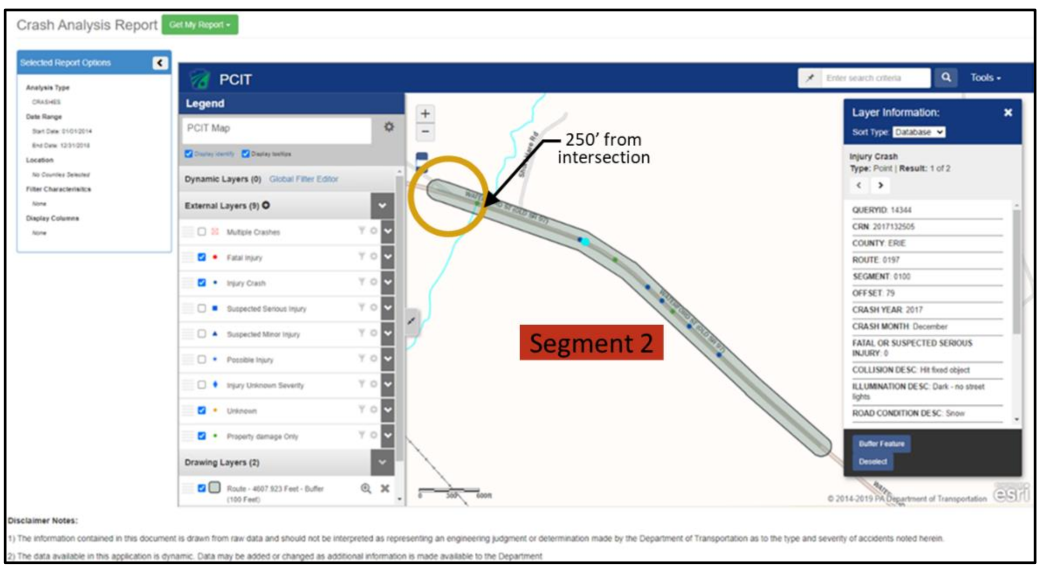

Figure C-29: PCIT Point Map Results for Segment 2

Date Range: 01/01/2014 to 12/31/2018*

CRASH SEVERITY LEVEL BY YEAR

	2015 CRASHES	2016 CRASHES	2017 CRASHES	2018 CRASHES	ALL YEARS CRASHES
SUSPECTED MINOR INJURY	0	2	1	4	7
POSSIBLE INJURY	0	0	1	1	2
PROPERTY DMG ONLY	2	1	1	0	4
TOTAL	2	3	3	5	13

CRASH DESCRIPTION TYPES BY YEAR

	2015 CRASHES	2016 CRASHES	2017 CRASHES	2018 CRASHES	ALL YEARS CRASHES
ANGLE	1	0	1	0	2
HEAD ON	0	0	0	1	1
HIT FIXED OBJECT	0	1	1	2	4
REAR END	1	2	0	2	5
UNKNOWN TYPE	0	0	1	0	1
TOTAL	2	3	3	5	13

Figure C-30: Markup of PCIT Crash History Report Summary for Segment 1

Date Range: 01/01/2014 to 12/31/2018*

CRASH SEVERITY LEVEL BY YEAR

	2014 CRASHES	2015 CRASHES	2016 CRASHES	2017 CRASHES	2018 CRASHES	ALL YEARS CRASHES
SUSPECTED MINOR INJURY	0	0	0	1	0	1
POSSIBLE INJURY	1	2	0	0	0	3
UNKNOWN SEVERITY	0	0	1	1	0	2
PROPERTY DMG ONLY	2	0	0	1	1	4
TOTAL	3	2	1	3	1	10

CRASH DESCRIPTION TYPES BY YEAR

	2014 CRASHES	2015 CRASHES	2016 CRASHES	2017 CRASHES	2018 CRASHES	ALL YEARS CRASHES
HIT FIXED OBJECT	1	1	1	1	0	4
NON COLLISION	1	1	0	0	0	2
REAR END	0	0	0	1	1	2
UNKNOWN TYPE	1	0	0	1	0	2
TOTAL	3	2	1	3	1	10

Figure C-31: Markup of PCIT Crash History Report Summary for Segment 2

By comparing historical crash data to the distribution tables, it can suggest there may be site-specific features that result in a different distribution of crash types. Table C-12 compares the historical crash distribution to the statewide distribution of rural two-lane highway segments. For the analysis segments, the percentage of rear-end collisions are significantly greater than the statewide average, which may suggest that there are site-specific issues causing a higher amount of rear-end crashes.

It should be noted that the observed crash distribution may be due to randomness in the data and not indicative of issues at the location.

Since crashes are rare events and prone to randomness, the occurrence of one or more crashes of a specific type might lead to a different distribution obtained from similar sites of that type. In this case, the high rear-end percentage in Segment 1 is associated with five crashes. The engineer should further analyze the crash data and crash reports to determine if the high percentage of rear-end crashes can be attributed to specific problems that need to be addressed, or if it might simply be associated with randomness.

Table C-12: Comparison between Statewide and Site-Specific Distribution of Crashes for Segment 1 and Segment 2

Collision Type	Total Percentage (Statewide Distribution Table)	Site Specific Historical Crash Data (2014-2018)			
		Segment 1		Segment 2	
		Proportion of Crash Type	Number of Crashes	Proportion of Crash Type	Number of Crashes
Non-collision (lane departure)	3.98%	0.00%		20.00%	2
Non-collision (lane crash)	2.97%	0.00%		0.00%	
Rear-end	10.48%	38.46%	5	20.00%	2
Head-on	3.22%	7.69%	1	0.00%	
Rear-to-rear (backing)	0.04%	0.00%		0.00%	
Angle	7.99%	15.38%	2	0.00%	
Sideswipe (same direction)	1.05%	0.00%		0.00%	
Sideswipe (opposite direction)	2.11%	0.00%		0.00%	
Hit fixed object	60.91%	30.77%	4	40.00%	4
Hit pedestrian	0.66%	0.00%		0.00%	
Other or unknown	6.60%	7.69%	1	20.00%	2
Total	**100.00%**	**100.00%**	**13**	**100.00%**	**10**

Step 2: Assess Site Conditions

In addition to analyzing the statewide distribution percentages and the historical crash data, it is important to assess the site conditions. This assessment provides additional insight on the historical crash data by identifying possible factors that would contribute to crashes. Data gathered during this assessment may include:

- Roadway geometry
- Traffic volume
- Sight distance of curves and driveways
- Land use activities in the vicinity (e.g., the presence of driveways, schools, shopping malls, etc.)
- Evidence of crashes (e.g., debris, tire tracks, damaged guiderail, etc.)
- Pavement condition or drainage issues

For the roadway segment analysis, the site condition was assessed using google maps, but a field visit may be required. Possible site-specific contributing factors of the analysis segment are shown in Figure C-32 and Figure C-33.

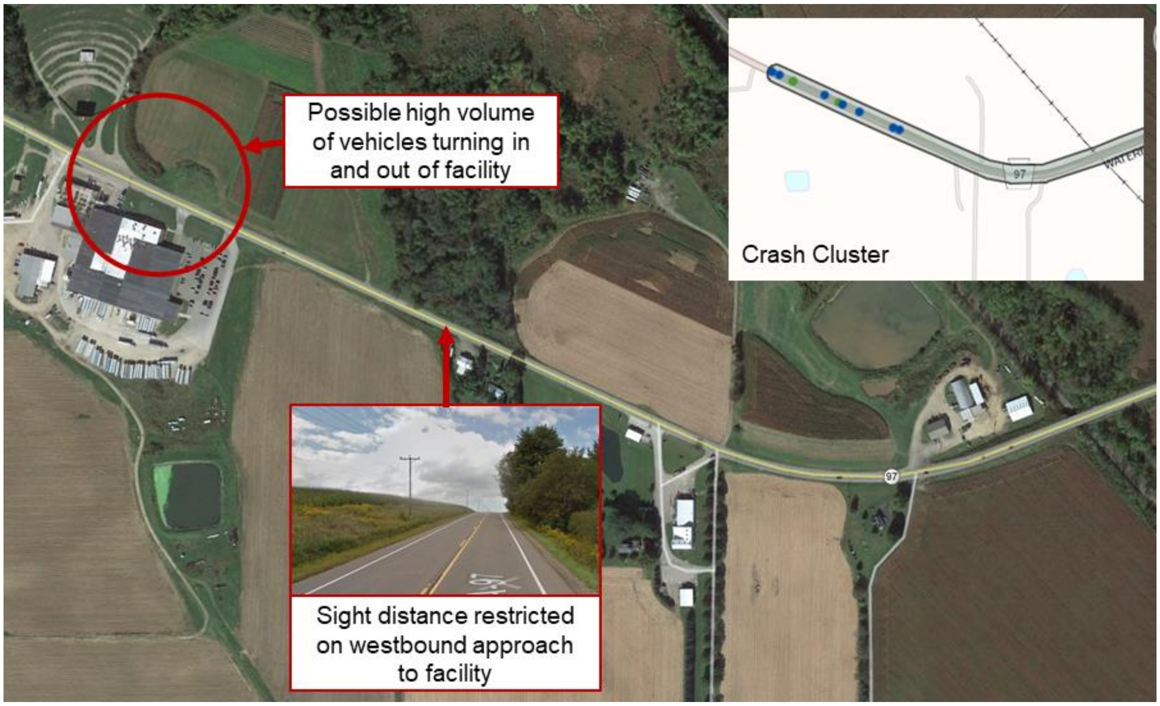

Figure C-32: Site Condition Assessment for Segment 1

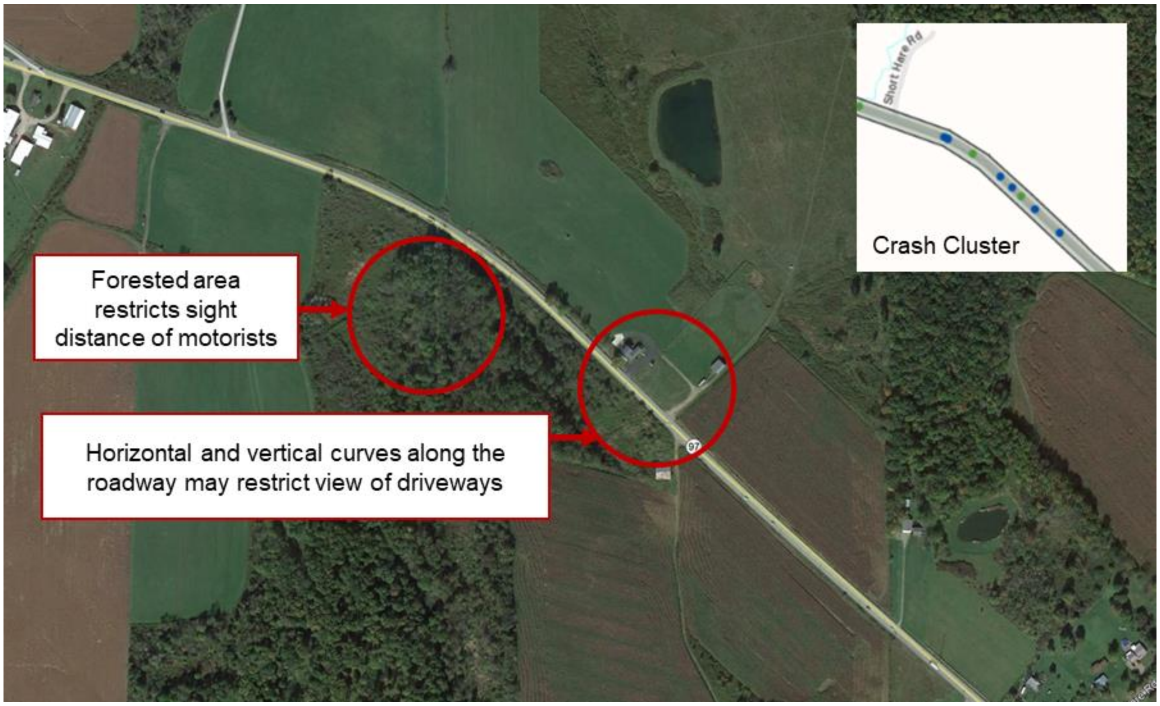

Figure C-33: Site Condition Assessment for Segment 2

Step 3: Identify Potential Countermeasures

Using the information gathered in Steps 1 and 2 as well as engineering judgement, potential countermeasures should be identified. The following methods may be used to assist in countermeasure identification:

- Conduct a road safety audit (RSA)
- Search literature on effective countermeasures
- Align with PennDOT policy
- Engage stakeholders

For the purpose of providing a countermeasure analysis of the segments, two countermeasures were determined to be evaluated and are listed in Table C-13.

Table C-13: Countermeasures Identified for Analysis Segment

Countermeasure	Justification	Source
Install edgeline rumble strips	High statewide percentage of hit fixed object collision type	Statewide Distribution Table (Figure C-27)
Increase triangle sight distance	High percentage of rear-end crashes from crash history at driveway intersections within analysis segment	Historical Crash Data (Figure C-30)

Step 4: Select appropriate Crash Modification Factors (CMFs)

CMFs, defined in Section 5.1.1, are used to determine the effect a countermeasure would likely have on $N_{expected}$. CMFs are found using several resources, which are identified in Section 5.2. For this example, CMFs were determined using the FHWA CMF Clearinghouse. In the Clearinghouse, CMFs for specific treatments can be searched for directly by key words, or browsed and filtered by the drop-down menus shown in Figure C-34.

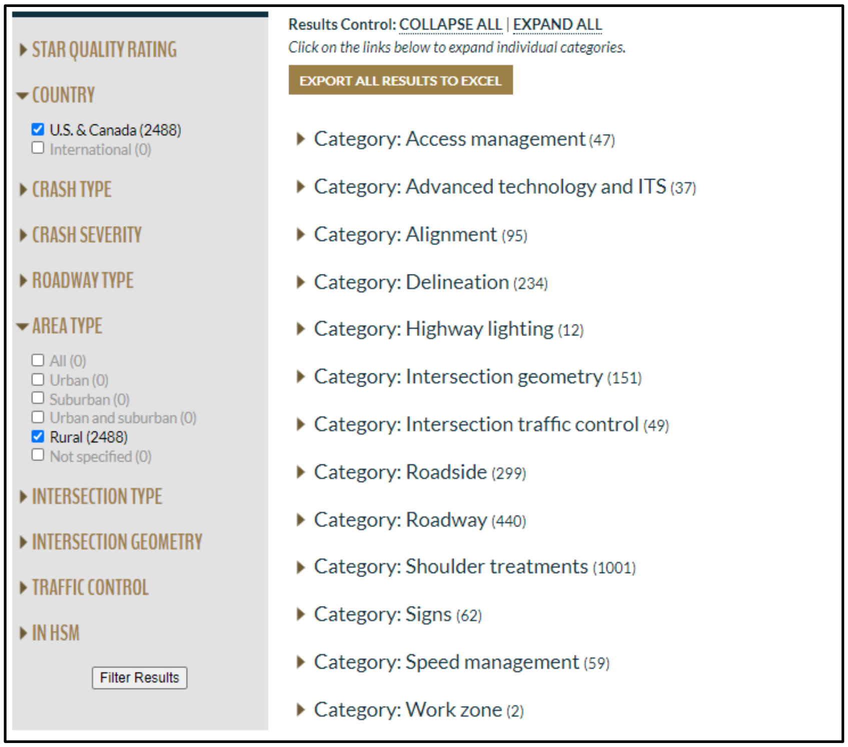

Figure C-34: FHWA CMF Clearinghouse Drop-down Menu

Each CMF is specific to various conditions such as, traffic volumes, roadway types, crash types, and severity. As the CMF values are determined, the analysis segment must meet the required conditions in order for the CMF to be applied. The CMF conditions required to install edgeline rumble strips and to increase the triangle sight distance are shown in Figure C-35 and Figure C-36, respectively.

Applicability	
Crash Type:	Run off road
Crash Severity:	K (fatal),A (serious injury),B (minor injury),C (possible injury)
Roadway Types:	Not Specified
Number of Lanes:	2
Road Division Type:	Undivided
Speed Limit:	
Area Type:	Rural
Traffic Volume:	180 to 12776 *Average Daily Traffic (ADT)*
Time of Day:	All

Figure C-35: Applicability Conditions for the Installation of Edgeline Rumble Strips CMF

Applicability	
Crash Type:	All
Crash Severity:	A (serious injury),B (minor injury),C (possible injury)
Roadway Types:	Not specified
Number of Lanes:	
Road Division Type:	
Speed Limit:	
Area Type:	Not specified
Traffic Volume:	
Time of Day:	

Figure C-36: Applicability Conditions for the Increase Triangle Sight Distance CMF

<u>Step 5:</u> Determine the CMF combination method based on the effect direction and amount of countermeasure overlap

Once CMFs are found that meet the analysis segment parameters, the CMF value, description, crash type, and crash severity should be documented and compared. Based on the amount of overlap of the applicability of each CMF, different combination methods are to be used. Countermeasure overlap is described in Section 5.4.2.

For the analysis segments, $\boldsymbol{CMF_1}$ applies only to run-off-road crashes, while $\boldsymbol{CMF_2}$ applies to all crashes (including run-off-road). The crash severity of $\boldsymbol{CMF_1}$ applies to K, A, B, C levels of severity, while $\boldsymbol{CMF_2}$ applies to levels A, B, and C (not K) (see Section 1.2 for KABCO scale designations). The CMFs used for the analysis segments are detailed in Table C-14.

Note that the process of applying a single CMF is described in Section 5.3.

Table C-14: Countermeasures Identified for Analysis Segment

CMF Details	CMF_1	CMF_2
CMF ID	3394	307
Value	0.67	0.53
Description	Install edgeline rumble strips	Increase triangle sight distance
Crash Type	Run-off-road	All
Crash Severity	K, A, B, C	A, B, C

Since both CMF values are less than one and there is some overlap between $\boldsymbol{CMF_1}$ and $\boldsymbol{CMF_2}$, both the dominant effect and dominant common residual combination methods must be considered. See Figure C-37 for an overview of which method should be chosen based on the CMF magnitude and amount of overlap.

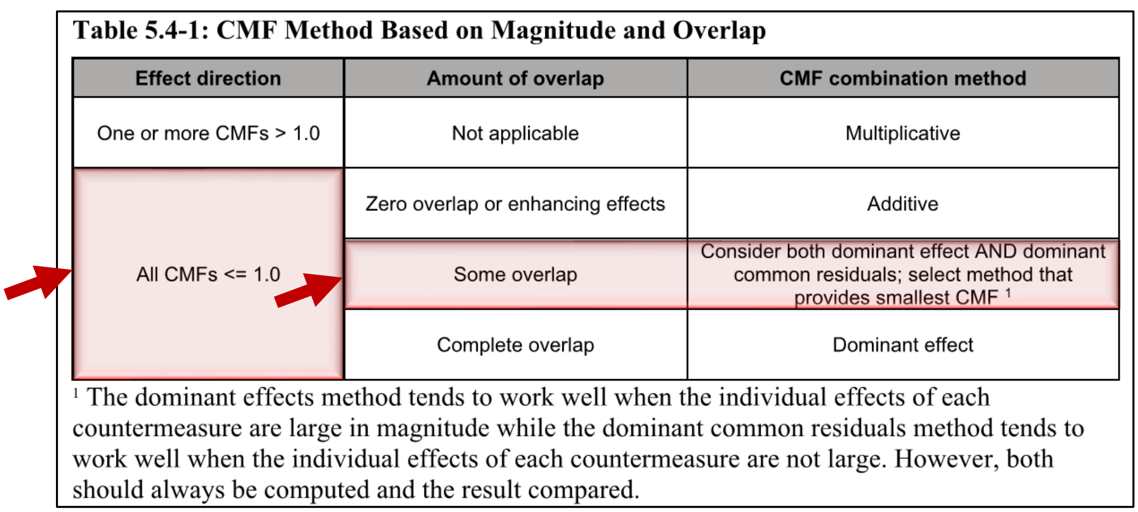

Table 5.4-1: CMF Method Based on Magnitude and Overlap

Effect direction	Amount of overlap	CMF combination method
One or more CMFs > 1.0	Not applicable	Multiplicative
All CMFs <= 1.0	Zero overlap or enhancing effects	Additive
	Some overlap	Consider both dominant effect AND dominant common residuals; select method that provides smallest CMF [1]
	Complete overlap	Dominant effect

[1] The dominant effects method tends to work well when the individual effects of each countermeasure are large in magnitude while the dominant common residuals method tends to work well when the individual effects of each countermeasure are not large. However, both should always be computed and the result compared.

Figure C-37: Markup of CMF Method Based on Magnitude and Overlap for Roadway Analysis

To determine $\boldsymbol{CMF_{combined}}$ by using the dominant effect method, compare the magnitude of the CMFs and select the smaller value. The dominant effect method was calculated for the roadway analysis by using the following equation:

$$CMF_{combined} = \begin{cases} CMF_1 & CMF_1 < CMF_2 \\ CMF_2 & CMF_2 < CMF_1 \end{cases}$$

$$CMF_{combined} = \begin{cases} 0.67 & 0.67 < 0.53 \text{ FALSE} \\ 0.53 & 0.53 < 0.67 \text{ TRUE} \end{cases}$$

$$\text{Dominant Effect Method } CMF_{combined} = 0.53$$

To determine $\boldsymbol{CMF_{combined}}$ by using the dominant common residuals method for the roadway analysis, the following equation was computed:

$$CMF_{combined} = \begin{cases} (CMF_1 \times CMF_2)^{CMF_1} & CMF_1 < CMF_2 \\ (CMF_1 \times CMF_2)^{CMF_2} & CMF_2 < CMF_1 \end{cases}$$

$$CMF_{combined} = \begin{cases} (0.67 \times 0.53)^{0.67} & 0.67 < 0.53 \text{ FALSE} \\ (0.67 \times 0.53)^{0.53} & 0.53 < 0.67 \text{ TRUE} \end{cases}$$

$$\text{Dominant Common Residual Method } CMF_{combined} = 0.58$$

In this case, the $\boldsymbol{CMF_{combined}}$ generated from the dominant common residual method (.58) was greater than the dominant effect method (.53) $\boldsymbol{CMF_{combined}}$. Therefore, 0.53 (the lesser of the two) was selected to be $\boldsymbol{CMF_{combined}}$.

$$CMF_{combined} = 0.53$$

<u>Step 6:</u> Compute number of crashes expected after countermeasure treatment(s) ($N_{treatment}$) using the appropriate CMF combination method

Once $\boldsymbol{CMF_{combined}}$ has been computed, determine which severity levels and crash types are unique to each CMF and which are commonalities between the two (which are designated under $\boldsymbol{CMF_{combined}}$). Table C-15 indicates which severity levels and crash types are unique, and which are common between $\boldsymbol{CMF_1}$ and $\boldsymbol{CMF_2}$ used for the roadway analysis.

In order to determine the fraction of $\boldsymbol{N_{expected}}$ that is modified by each CMF, the statewide distribution table (Figure C-27) must be used. For Segment 1 and Segment 2, the total $\boldsymbol{N_{expected}}$ was multiplied by each percentage in the rural two-lane highway distribution table. The numbers in Table C-16 and Table C-17 represent the results of the calculation for each segment.

The affect each CMF has on $\boldsymbol{N_{expected}}$ for each segment based on crash type and severity are shown in Table C-16 and Table C-17. Each color corresponds to a CMF or CMF combination as indicated in Table C-15.

Table C-15: Unique Crash Type and Severity Levels of CMFs for Roadway Analysis

CMF Details	CMF_1	CMF_2	$CMF_{combined}$	No Modification
CMF ID	3394	307	Calculated using the Dominant Effect Method	Remaining collision types and crash severity levels unmodified by CMFs
Description	Install edgeline rumble strips	Increase triangle sight distance	Combined CMF	No modification
Value	0.67	0.53	0.53	0.00
Crash Type	Run-off-road (Applies to hit fixed object and Non-collision (lane departure) crashes)	All except run-off-road (Run-off-road now being modified by $CMF_{combined}$)	Run-off-road (Applies to hit fixed object and Non-collision (lane departure) crashes)	All except Run-off-road modified by CMF_1
Crash Severity	K only (A, B, C now being modified by $CMF_{combined}$)	A, B, C (No change)	A, B, C (Commonality between CMF_1 and CMF_2)	K, U, O

Table C-16: Distribution of Segment 1 $N_{expected}$ based on Collision Type and Severity Level

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision (lane departure)	0.00	0.00	0.01	0.03	0.01	0.00	0.04	0.10
Non-collision (lane crash)	0.00	0.00	0.01	0.02	0.01	0.00	0.03	0.07
Rear-end	0.00	0.01	0.02	0.08	0.02	0.00	0.12	0.26
Head-on	0.01	0.01	0.02	0.02	0.01	0.00	0.02	0.08
Rear-to-rear (backing)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Angle	0.01	0.01	0.03	0.05	0.02	0.00	0.08	0.20
Sideswipe (same direction)	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.03
Sideswipe (opposite direction)	0.00	0.00	0.01	0.02	0.00	0.00	0.02	0.05
Hit fixed object	0.03	0.05	0.16	0.40	0.10	0.03	0.75	1.52
Hit pedestrian	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.02
Other or unknown	0.00	0.00	0.01	0.02	0.01	0.00	0.12	0.17
Total	0.05	0.10	0.28	0.65	0.17	0.05	1.20	2.50[1]

[1] – The values in this table were derived from multiplying $N_{expected}$ (4.4 crashes /year) by the values in Figure C-27.

Table C-17: Distribution of Segment 2 $N_{expected}$ based on Collision Type and Severity Level

Collision Type	Crash Severity Level							
	Fatal (K)	Suspected Serious Injury (A)	Suspected Minor Injury (B)	Possible Injury (C)	Injury/ Unknown Severity (C)	Unknown (U)	Not Injured (O)	Sum
Non-collision (lane departure)	0.00	0.00	0.01	0.02	0.01	0.00	0.03	0.08
Non-collision (lane crash)	0.00	0.00	0.01	0.01	0.00	0.00	0.02	0.06
Rear-end	0.00	0.00	0.02	0.06	0.02	0.00	0.09	0.20
Head-on	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.06
Rear-to-rear (backing)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Angle	0.01	0.01	0.02	0.04	0.01	0.00	0.06	0.15
Sideswipe (same direction)	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02
Sideswipe (opposite direction)	0.00	0.00	0.00	0.01	0.00	0.00	0.02	0.04
Hit fixed object	0.02	0.04	0.13	0.30	0.08	0.03	0.57	1.16
Hit pedestrian	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Other or unknown	0.00	0.00	0.01	0.02	0.00	0.00	0.09	0.13
Total	0.04	0.07	0.22	0.49	0.13	0.04	0.91	1.90[1]

[1] – The values in this table were derived from multiplying $N_{expected}$ (4.4 crashes /year) by the values in Figure C-27.

To determine $N_{treatment}$ for Segment 1 and Segment 2, each CMF was multiplied by the expected number of crashes of the severity level and collision type unique to the CMF. The expected number of crashes that are affected by both CMFs were multiplied by $CMF_{combined}$. The remaining expected crashes were not modified as no CMF had an effect on either the collision type or severity level. The equation to determine $N_{treatment}$ for this analysis segment is as follows:

$$N_{treatment} = CMF_1 \times \sum_{\substack{\text{Run-off-road crash type} \\ \text{(K severity)}}} N_{expected} + CMF_2 \times \sum_{\substack{\text{All except run-off-road crash types} \\ \text{(A,B,C severity)}}} N_{expected} + CMF_{combined} \times \sum_{\substack{\text{Run-off-road crash type} \\ \text{(A,B,C severity)}}} N_{expected}$$

$$+ \sum_{\substack{\text{All crash types} \\ \text{(O,U severity)}}} N_{expected} + \sum_{\substack{\text{All except run-off-road crash types} \\ \text{(K severity)}}} N_{expected}$$

The difference between $N_{treatment}$ and $N_{expected}$ will result in the expected crash reduction of the roadway segment as shown in the following equation:

$$N_{Expected} - N_{Treatment} = \text{Expected Crash Reduction}$$

Segment 1 Calculations:

Segment 1 $N_{Treatment} = 2.19$ crashes per year

Segment 1 Expected Crash Reduction = $2.50 - 2.19 = 0.31$ crashes/year

Segment 2 Calculations:

Segment 2 $N_{Treatment} = 1.67$ crashes per year

Segment 2 Expected Crash Reduction = $1.90 - 1.67 = 0.23$ crashes/year

Therefore, it can be expected that by applying CMF_1 and CMF_2, the crash frequency would be reduced by 0.31 crashes/year in Segment 1, and 0.23 crashes/year in Segment 2.