PART C— PREDICTIVE METHOD

CHAPTER 10—PREDICTVE METHOD FOR RURAL TWO-LANE TWO-WAY ROADS

EXHIBITS

APPENDIX A

CHAPTER 10 PREDICTIVE METHOD FOR RURAL TWO-LANE TWO-WAY ROADS

10.1. INTRODUCTION

Chapter 10 explains the predictive method for rural two-lane two-way roads.

This chapter presents the predictive method for rural two-lane two-way roads. A general introduction to the Highway Safety Manual (HSM) Predictive Method is provided in the *Part C Introduction and Applications Guidance*.

The predictive method for rural two-lane two-way roads provides a structured methodology to estimate the expected average crash frequency, crash severity, and collision types for a rural two-lane two-way facility with known characteristics. All types of crashes involving vehicles of all types, bicycles, and pedestrians are included, with the exception of crashes between bicycles and pedestrians. The predictive method can be applied to existing sites, design alternatives to existing sites, new sites, or for alternative traffic volume projections. An estimate can be made for crash frequency of a prior time period (i.e. what did or would have occurred) or in the future (i.e., what is expected to occur). The development of the predictive method in Chapter 10 is documented by Harwood et al.[4]

This chapter presents the following information about the predictive method for rural two-lane two-way roads:

- A concise overview of the predictive method.
- The definitions of the facility types included in Chapter 10 and site types for which predictive models have been developed for Chapter 10.
- The steps of the predictive method in graphical and descriptive forms.
- Details for dividing a rural two-lane two-way facility into individual sites, consisting of intersections and roadway segments.
- Safety Performance Functions (SPFs) for rural two-lane two-way roads.
- Accident Modification Factors (AMFs) applicable to the SPFs in Chapter 10.
- Guidance for applying the Chapter 10 predictive method and limitations of the predictive method specific to Chapter 10.
- Sample problems illustrating the Chapter 10 predictive method for rural two-lane two-way roads.

10.2. OVERVIEW OF THE PREDICTIVE METHOD

The predictive method provides an 18 step procedure to estimate the "expected average crash frequency", $N_{expected}$ (by total crashes, crash severity or collision type), of a roadway network, facility, or site. In the predictive method the roadway is divided into individual sites, which are homogenous roadway segments and intersections. A facility consists of a contiguous set of individual intersections and roadway segments, referred to as "sites." Different facility types are determined by surrounding land use, roadway cross-section, and degree of access. For each facility type, a number of different site types may exist, such as divided and undivided roadway segments, and unsignalized and signalized intersections. A roadway network consists of a number of contiguous facilities.

The method is used to estimate the expected average crash frequency of an individual site, with the cumulative sum of all sites used as the estimate for an entire facility or network. The estimate is for a given time period of interest (in years) during which the geometric design and traffic control features are unchanged and traffic volumes (AADT) are known or forecasted. The estimate relies on estimates made using predictive models which are combined with observed crash data using the Empirical Bayes (EB) Method.

The EB Method is described in full detail in the Part C Appendix.

The predictive models used within the Chapter 10 predictive method are described in detail in Section 10.3.

The predictive models used in Chapter 10 to determine the predicted average crash frequency, $N_{predicted}$, are of the general form shown in Equation 10-1.

$$N_{predicted} = N_{spf\ x} \times (AMF_{1x} \times AMF_{2x} \times \ldots \times AMF_{yx}) \times C_x \qquad (10\text{-}1)$$

Where,

$N_{predicted}$ = predicted average crash frequency for a specific year for site type *x*;

$N_{spf\,x}$ = predicted average crash frequency determined for base conditions of the SPF developed for site type *x*;

AMF_{yx} = Accident Modification Factors specific to site type *x* and specific geometric design and traffic control features *y*;

C_x = calibration factor to adjust SPF for local conditions for site type *x*.

10.3. RURAL TWO-LANE TWO-WAY ROADS – DEFINITIONS AND PREDICTIVE MODELS IN CHAPTER 10

This section provides the definitions of the facility and site types included in Chapter 10, and the predictive models for each the site types included in Chapter 10. These predictive models are applied following the steps of the predictive method presented in Section 10.4.

10.3.1. Definition of Chapter 10 Facility and Site Types

The predictive method in Chapter 10 addresses all types of rural two-lane two-way highway facilities, including rural two-lane two-way highways with center two-way left-turn lanes or added passing lanes, and rural two-lane two-way highways containing short sections of rural four-lane highway that serve exclusively to increase passing opportunities (i.e., side-by-side passing lanes). Facilities with four or more lanes are not covered in Chapter 10.

The terms “highway” and “road” are used interchangeably in this chapter and apply to all rural two-way two-lane facilities independent of official state or local highway designation.

Classifying an area as urban, suburban or rural is subject to the roadway characteristics, surrounding population and land uses and is at the user’s discretion. In the HSM, the definition of “urban” and “rural” areas is based on Federal Highway Administration (FHWA) guidelines which classify “urban” areas as places inside urban boundaries where the population is greater than 5,000 persons. “Rural” areas are defined as places outside urban areas which have a population greater than 5,000 persons. The HSM uses the term “suburban” to refer to outlying portions of an urban area; the predictive method does not distinguish between urban and suburban portions of a developed area.

Exhibit 10-1 identifies the site types on rural two-lane two-way roads for which SPFs have been developed for predicting average crash frequency, severity, and collision type.

SPFs are available for: undivided roadway segments, three-leg intersections with STOP control, four-leg intersections with STOP control, and four-leg signalized intersections.

Exhibit 10-1: Rural Two-Lane Two-Way Road Site Type with SPFs in Chapter 10

Site Type	Site Types with SPFs in Chapter 10
Roadway Segments	Undivided rural two-lane two-way roadway segments (2U)
Intersections	Unsignalized three-leg (STOP control on minor-road approaches)(3ST)
	Unsignalized four-leg (STOP control on minor-road approaches) (4ST)
	Signalized four-leg (4SG)

These specific site types are defined as follows:

- Undivided roadway segment (2U) – a roadway consisting of two lanes with a continuous cross-section providing two directions of travel in which the lanes are not physically separated by either distance or a barrier. In addition, the definition includes a section with three lanes where the center lane is a two-way left-turn lane (TWLTL) or a section with added lanes in one or both directions of travel to provide increased passing opportunities (e.g., passing lanes, climbing lanes, and short four-lane sections).
- Three-leg intersection with STOP control (3ST) – an intersection of a rural two-lane two-way road and a minor road. A STOP sign is provided on the minor road approach to the intersection only.
- Four-leg intersection with STOP control (4ST) – an intersection of a rural two-lane two-way road and two minor roads. A STOP sign is provided on both minor road approaches to the intersection.
- Four-leg signalized intersection (4SG) - an intersection of a rural two-lane two-way road and two other rural two-lane two-way roads. Signalized control is provided at the intersection by traffic lights.

10.3.2. Predictive Models for Rural Two-Lane Two-Way Roadway Segments

The predictive models can be used to estimate total predicted average crash frequency (i.e., all crash severities and collision types) or can be used to predict average crash frequency of specific crash severity types or specific collision types. The predictive model for an individual roadway segment or intersection combines a SPF with AMFs and a calibration factor.

For rural two-lane two-way undivided roadway segments the predictive model is shown in Equation 10-2:

$$N_{predicted\ rs} = N_{spf\ rs} \times C_r \times (AMF_{1r} \times AMF_{2r} \times \ldots \times AMF_{12r}) \quad (10\text{-}2)$$

Where,

$N_{predicted\ rs}$ = predicted average crash frequency for an individual roadway segment for a specific year;

$N_{spf\ rs}$ = predicted average crash frequency for base conditions for an individual roadway segment;

C_r = calibration factor for roadway segments of a specific type developed for a particular jurisdiction or geographical area;

$AMF_{1r} \ldots AMF_{12r}$ = Accident Modification Factors for rural two-way two-lane roadway segments;

This model estimates the predicted average crash frequency of non-intersection related crashes (i.e. crashes that would occur regardless of the presence of an intersection).

10.3.3. Predictive Models for Rural Two-Lane Two-Way Intersections

The predictive models for intersections estimate the predicted average crash frequency of crashes occurring within the limits of an intersection (i.e., at-intersection crashes) and crashes that occur on the intersection legs and are attributed to the presence of an intersection (i.e., intersection-related crashes).

The SPFs for rural two-lane two-way roads are presented in Section 10.6. The associated AMFs for each of the SPFs are presented in Section 10.7 and summarized in Exhibit 10-13.

For all intersection types in Chapter 10 the predictive model is shown in Equation 10-3:

$$N_{predicted\ int} = N_{spf\ int} \times C_i \times (AMF_{1i} \times AMF_{2i} \times \ldots \times AMF_{4i}) \qquad (10\text{-}3)$$

Where,

$N_{predicted\ int}$ = predicted average crash frequency for an individual intersection for the selected year;

$N_{spf\ int}$ = predicted average crash frequency for an intersection with base conditions;

$AMF_{1i} \ldots AMF_{4i}$ = Accident Modification Factors for intersections;

C_i = calibration factor for intersections of a specific type developed for use for a particular jurisdiction or geographical area.

The SPFs for rural two-lane two-way roads are presented in Section 10.6. The associated AMFs for each of the SPFs are presented in Section 10.7, and summarized in Exhibit 10-13. Only the specific AMFs associated with each SPF are applicable to an SPF as these AMFs have base conditions which are identical to the base conditions. The calibration factors, C_r and C_i, are determined in the *Part C* Appendix A.1.1. Due to continual change in the crash frequency and severity distributions with time, the value of the calibration factors may change for the selected year of the study period.

10.4. PREDICTIVE METHOD FOR RURAL TWO-LANE TWO-WAY ROADS

The predictive method for rural two-lane two-way road is shown in Exhibit 10-2. Applying the predictive method yields an estimate of the expected average crash frequency (and/or crash severity and collision types) for a rural two-lane two-way facility. The components of the predictive models in Chapter 10 are determined and applied in Steps 9, 10, and 11 of the predictive method. The information that is needed to apply each step is provided in the following sections and in the *Part C* Appendix.

There are 18 steps in the predictive method. In some situations, certain steps will not be needed because the data is not available or the step is not applicable to the situation at hand. In other situations, steps may be repeated, if an estimate is desired for several sites or for a period of several years. In addition, the predictive method can be repeated as necessary to undertake crash estimation for each alternative design, traffic volume scenario or proposed treatment option (within the same period to allow for comparison).

The following explains the details of each step of the method as applied to two-lane two-way rural roads.

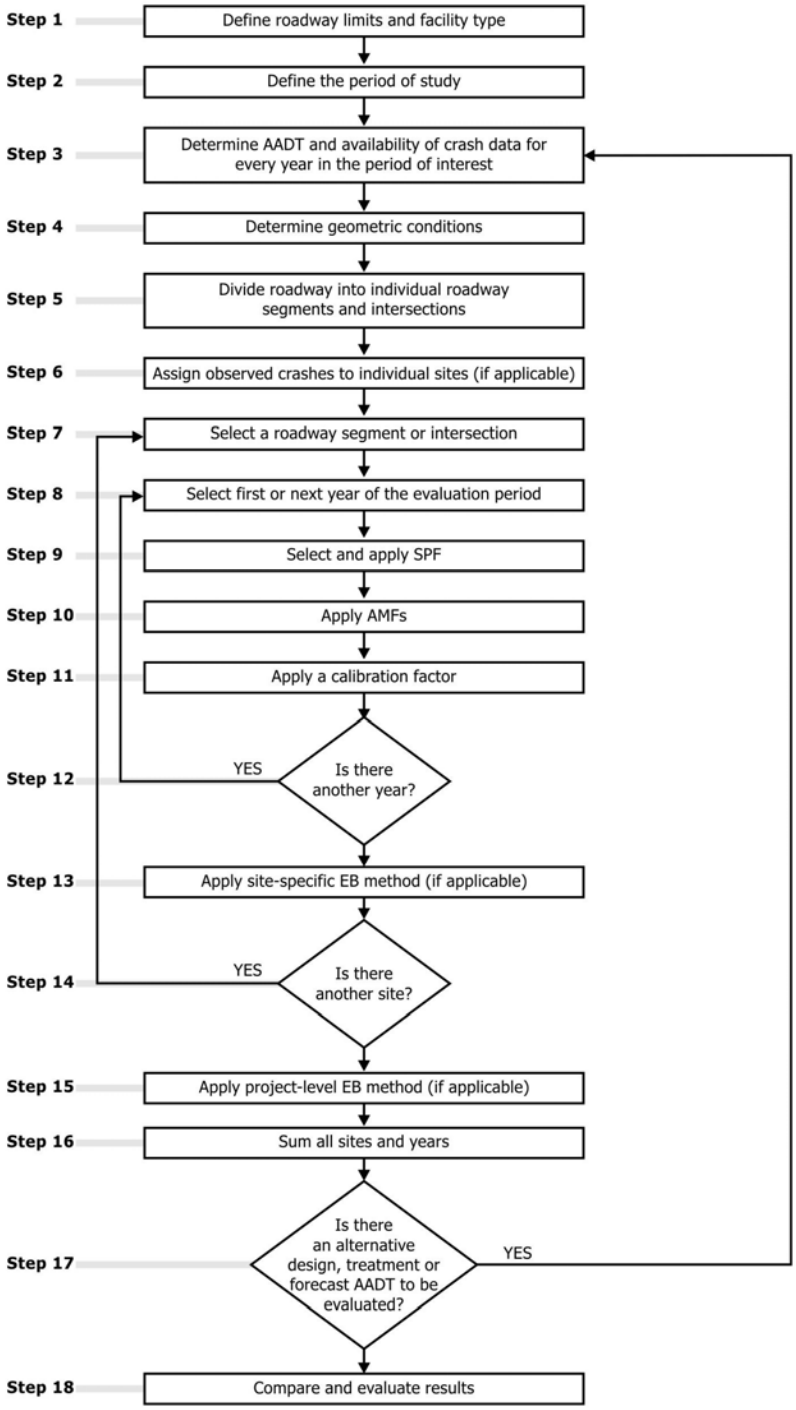
Step 1 - Define the limits of the roadway and facility types in the study network, facility, or site for which the expected average crash frequency, severity, and collision types are to be estimated.

The predictive method can be undertaken for a roadway network, a facility, or a individual site. A site is either an intersection or a homogeneous roadway segment. There are a number of different types of sites, such as signalized and unsignalized intersections. The definitions of a rural two-lane two-way road, an intersection, and a roadway segment and the site types for which SPFs are included in Chapter 10 are provided in Section 10.3.

The predictive method can be applied to an existing roadway, a design alternative for an existing roadway, or a design alternative for new roadway (which may be either unconstructed or yet to experience enough traffic to have observed crash data).

The limits of the roadway of interest will depend on the nature of the study. The study may be limited to only one specific site or a group of contiguous sites. Alternatively, the predictive method can be applied to a long corridor for the purposes of network screening (determining which sites require upgrading to reduce crashes) which is discussed in *Chapter 4*.

Exhibit 10-2: The HSM Predictive Method



Step 2 - Define the period of interest.

The predictive method can be undertaken for either a past period or a future period. All periods are measured in years. Years of interest will be determined by the availability of observed or forecast AADTs, observed crash data, and geometric design data. Whether the predictive method is used for a past or future period depends upon the purpose of the study. The period of study may be:

A past period (based on observed AADTs) for:

- An existing roadway network, facility, or site. If observed crash data are available, the period of study is the period of time for which the observed crash data are available and for which (during that period) the site geometric design features, traffic control features, and traffic volumes are known.
- An existing roadway network, facility, or site for which alternative geometric design features or traffic control features are proposed (for near term conditions).

A future period (based on forecast AADTs) for:

- An existing roadway network, facility, or site for a future period where forecast traffic volumes are available.
- An existing roadway network, facility, or site for which alternative geometric design or traffic control features are proposed for implementation in the future.
- A new roadway network, facility, or site that does not currently exist, but is proposed for construction during some future period.

Step 3 – For the study period, determine the availability of annual average daily traffic volumes and, for an existing roadway network, the availability of observed crash data to determine whether the EB Method is applicable.

Determining Traffic Volumes

The SPFs used in Step 9 (and some AMFs in Step 10), include AADT volumes (vehicles per day) as a variable. For a past period the AADT may be determined by automated recording or estimated from a sample survey. For a future period the AADT may be a forecast estimate based on appropriate land use planning and traffic volume forecasting models, or based on the assumption that current traffic volumes will remain relatively constant.

Roadway segments require two-way AADT.

For each roadway segment, the AADT is the average daily two-way 24 hour traffic volume on that roadway segment in each year of the period to be evaluated selected in Step 8.

Intersections require the major and minor road AADT.

For each intersection, two values are required in each predictive model. These are the AADT of the major street, $AADT_{maj}$; and the two-way AADT of the minor street, $AADT_{min}$.

In Chapter 10, $AADT_{maj}$ and $AADT_{min}$ are determined as follows: if the AADTs on the two major road legs of an intersection differ, the larger of the two AADT values is used for the intersection. For a three-leg intersection, the minor road AADT is the AADT of the single minor road leg. For a four-leg intersection, if the AADTs of the two minor road legs differ, the larger of the two AADTs values is used for the intersection. If AADTs are available for every roadway segment along a facility, the major road AADTs for intersection legs can be determined without additional data.

In many cases, it is expected that AADT data will not be available for all years of the evaluation period. In that case, an estimate of AADT for each year of the evaluation period is interpolated or extrapolated as appropriate. If there is no established procedure for doing this, the following default rules may be applied within the predictive method to estimate the AADTs for years for which data are not available.

- If AADT data are available for only a single year, that same value is assumed to apply to all years of the before period;
- If two or more years of AADT data are available, the AADTs for intervening years are computed by interpolation;
- The AADTs for years before the first year for which data are available are assumed to be equal to the AADT for that first year;
- The AADTs for years after the last year for which data are available are assumed to be equal to the last year.

If the EB Method is used (discussed below), AADT data are needed for each year of the period for which observed crash frequency data are available. If the EB Method will not be used, AADT data for the appropriate time period—past, present, or future—determined in Step 2 are used.

Determining Availability of Observed Crash Data

Where an existing site or alternative conditions to an existing site are being considered, the EB Method is used. The EB Method is only applicable when reliable observed crash data are available for the specific study roadway network, facility, or site. Observed data may be obtained directly from the jurisdiction's accident report system. At least two years of observed crash frequency data are desirable to apply the EB Method. The EB Method and criteria to determine whether the EB Method is applicable are presented in Section A.2.1 in the Appendix to *Part C.*

The EB Method and criteria to determine whether the EB Method is applicable are presented in Section A.2.1 in the Appendix to Part C.

The EB Method can be applied at the site-specific level (i.e., observed crashes are assigned to specific intersections or roadway segments in Step 6) or at the project level (i.e., observed crashes are assigned to a facility as a whole). The site-specific EB Method is applied in Step 13. Alternatively, if observed crash data are available but can not be assigned to individual roadway segments and intersections, the project level EB Method is applied (in Step 15).

If observed crash data are not available, then Steps 6, 13, and 15 of the predictive method are not conducted. In this case, the estimate of expected average crash frequency is limited to using a predictive model (i.e. the predicted average crash frequency).

Step 4 - Determine geometric design features, traffic control features, and site characteristics for all sites in the study network.

In order to determine the relevant data needs and avoid unnecessary data collection, it is necessary to understand the base conditions of the SPFs in Step 9 and the AMFs in Step 10. The base conditions are defined in Section 10.6.1 for roadway segments and in Section 10.6.2 for intersections.

The base conditions for Chapter 10 SPFs are defined in Section 10.6.1 for roadway segments and in Section 10.6.2 for intersections.

The following geometric design and traffic control features are used to select a SPF and to determine whether the site specific conditions vary from the base conditions and, therefore, whether an AMF is applicable:

- Length of segment (miles)
- AADT (vehicles per day)
- Lane width (feet)
- Shoulder width (feet)
- Shoulder type (paved/gravel/composite/turf)
- Presence or absence of horizontal curve (curve/tangent). If the segment has one or more curve:
    - Length of horizontal curve (miles), (this represents the total length of the horizontal curve and includes spiral transition curves, even if the curve extends beyond the limits of the roadway segment being analyzed);.
    - Radius of horizontal curve (feet);
    - Presence or absence of spiral transition curve, (this represents the presence or absence of a spiral transition curve at the beginning and end of the horizontal curve, even if the beginning and/or end of the horizontal curve are beyond the limits of the segment being analyzed); and
    - Superelevation of horizontal curve and the maximum superelevation (e_{max}) used according to policy for the jurisdiction, if available.
- Grade (percent), considering each grade as a straight grade from Point of Vertical Intersection (PVI) to PVI (i.e., ignoring the presence of vertical curves)
- Driveway density (driveways per mile)
- Presence or absence of centerline rumble strips
- Presence or absence of a passing lane
- Presence or absence of a short four-lane section
- Presence or absence of a two-way left-turn lane
- Roadside hazard rating
- Presence or absence of roadway segment lighting
- Presence or absence of automated speed enforcement

For all intersections within the study area, the following geometric design and traffic control features are identified:

- Number of intersection legs (3 or 4)
- Type of traffic control (minor road stop or signal control)
- Intersection skew angle (degrees departure from 90 degrees)

- Number of approaches with intersection left-turn lanes (0, 1, 2, 3, or 4), not including stop-controlled approaches
- Number of approaches with intersection right-turn lanes (0, 1, 2, 3, or 4), not including stop-controlled approaches
- Presence or absence of intersection lighting

Step 5 – Divide the roadway network or facility under consideration into individual homogenous roadway segments and intersections, which are referred to as sites.

The definitions and methodology for dividing the roadway into individual intersections and homogenous roadway segments for use with the Chapter 10 predictive models are provided in Section 10.5.

Using the information from Step 1 and Step 4, the roadway is divided into individual sites, consisting of individual homogenous roadway segments and intersections. The definitions and methodology for dividing the roadway into individual intersections and homogenous roadway segments for use with the Chapter 10 predictive models are provided in Section 10.5. When dividing roadway facilities into small homogenous roadway segments, limiting the segment length to a minimum of 0.10 miles will decrease data collection and management efforts.

Step 6 – Assign observed crashes to the individual sites (if applicable).

Step 6 only applies if it was determined in Step 3 that the site-specific EB Method was applicable. If the site-specific EB Method is not applicable, proceed to Step 7. In Step 3, the availability of observed data and whether the data could be assigned to specific locations was determined. The specific criteria for assigning accidents to individual roadway segments or intersections are presented in Section A.2.3 of the Appendix to *Part C*.

The specific criteria for assigning crashes to individual roadway segments for intersections are presented in Section A.2.3 of the Appendix to Part C.

Crashes that occur at an intersection or on an intersection leg and are related to the presence of an intersection, are assigned to the intersection and used in the EB Method together with the predicted average crash frequency for the intersection. Crashes that occur between intersections and are not related to the presence of an intersection are assigned to the roadway segment on which they occur; such crashes are used in the EB Method together with the predicted average crash frequency for the roadway segment.

Step 7 – Select the first or next individual site in the study network. If there are no more sites to be evaluated, proceed to Step 15.

In Step 5, the roadway network within the study limits is divided into a number of individual homogenous sites (intersections and roadway segments).

The outcome of the HSM predictive method is the expected average crash frequency of the entire study network, which is the sum of the all of the individual sites, for each year in the study. Note that this value will be the total number of crashes expected to occur over all sites during the period of interest. If a crash frequency (crashes per year) is desired, the total can be divided by the number of years in the period of interest.

The estimation for each site (roadway segments or intersection) is conducted one at a time. Steps 8 through 14, described below, are repeated for each site.

Step 8 – For the selected site, select the first or next year in the period of interest. If there are no more years to be evaluated for that site, proceed to Step 15.

Expected average crashes for the study period are calculated for each year of the period.

Steps 8 through 14 are repeated for each site in the study and for each year in the study period.

The individual years of the evaluation period may have to be analyzed one year at a time for any particular roadway segment or intersection because SPFs and some AMFs (e.g., lane and shoulder widths) are dependent on AADT, which may change from year to year.

Step 9 – For the selected site, determine and apply the appropriate Safety Performance Function (SPF) for the site's facility type and traffic control features.

Predictive models for rural two-lane two-way roads are provided in Section 10.3.

Steps 9 through 13 are repeated for each year of the evaluation period as part of the evaluation of any particular roadway segment or intersection. The predictive models in Chapter 10 follow the general form shown in Equation 10-1. Each predictive model consists of an SPF, which is adjusted to site specific conditions using AMFs (in Step 10) and adjusted to local jurisdiction conditions (in Step 11) using a calibration factor (C). The SPFs, AMFs and calibration factor obtained in Steps 9, 10, and 11 are applied to calculate the predicted average crash frequency for the selected year of the selected site. The resultant value is the predicted average crash frequency for the selected year. The SPFs available for rural two-lane two-way highways are presented in Section 10.6.

The SPF (which is a statistical regression model based on observed crash data for a set of similar sites) determines the predicted average crash frequency for a site with the base conditions (i.e., a specific set of geometric design and traffic control features). The base conditions for each SPF are specified in Section 10.6. A detailed explanation and overview of the SPFs in *Part C* is provided in Section C.6.3 of the *Part C Introduction and Applications Guidance*.

The SPFs for specific site types (and base conditions) developed for Chapter 10 are summarized in Exhibit 10-4 in Section 10.6. For the selected site, determine the appropriate SPF for the site type (roadway segment or one of three intersection types). The SPF is calculated using the AADT volume determined in Step 3 (AADT for roadway segments or $AADT_{maj}$ and $AADT_{min}$ for intersections) for the selected year.

Default distributions of crash severity and collision type are presented in Exhibit 10-6 and 10-7 for roadway segments and Exhibit 10-11 and 10-12 for intersections.

Each SPF determined in Step 9 is provided with default distributions of crash severity and collision type. The default distributions are presented in Exhibits 10-6 and 10-7 for roadway segments and in Exhibits 10-11 and 10-12 for intersections. These default distributions can benefit from being updated based on local data as part of the calibration process presented in Appendix A.1.1.

Step 10 – Multiply the result obtained in Step 9 by the appropriate AMFs to adjust the estimated crash frequency for base conditions to the site specific geometric design and traffic control features.

An overview of AMFs and guidance for their use is provided in Section C.6.4 of the Part C Introduction and Applications Guidance

In order to account for differences between the base conditions (Section 10.6) and site specific conditions, AMFs are used to adjust the SPF estimate. An overview of AMFs and guidance for their use is provided in Section C.6.4 of the *Part C Introduction and Applications Guidance*, including the limitations of current knowledge related to the effects of simultaneous application of multiple AMFs. In using multiple AMFs, engineering judgment is required to assess the interrelationships and/or independence of individual elements or treatments being considered for implementation within the same project.

Only the AMFs presented in Section 10.7 may be used as part of the Chapter 10 predictive method.

All AMFs used in Chapter 10 have the same base conditions as the SPFs used in Chapter 10 (i.e., when the specific site has the same condition as the SPF base condition, the AMF value for that condition is 1.00). *Only the AMFs presented in Section 10.7 may be used as part of the Chapter 10 predictive method*. Exhibit 10-13 indicates which AMFs are applicable to the SPFs in Section 10.6.

Step 11 – Multiply the result obtained in Step 10 by the appropriate calibration factor.

The SPFs used in the predictive method have each been developed with data from specific jurisdictions and time periods. Calibration of the SPFs to local conditions will account for differences. A calibration factor (C_r for roadway segments or C_i for intersections) is applied to each SPF in the predictive method. An overview of the use of calibration factors is provided in the *Part C Introduction and Applications Guidance* Section C.6.5. Detailed guidance for the development of calibration factors is included in *Part C* Appendix A.1.1

Detailed guidance for the development of calibration factors is included in Part C Appendix A.1.1.

Steps 9, 10, and 11 together implement the predictive models in Equations 10-2 and 10-3 to determine predicted average crash frequency.

Step 12 – If there is another year to be evaluated in the study period for the selected site, return to Step 8. Otherwise, proceed to Step 13.

This step creates a loop through Steps 8 to 12 that is repeated for each year of the evaluation period for the selected site.

Step 13 – Apply site-specific EB Method (if applicable).

Whether the site-specific EB Method is applicable is determined in Step 3. The site-specific EB Method combines the Chapter 10 predictive model estimate of predicted average crash frequency, $N_{predicted,}$ with the observed crash frequency of the specific site, $N_{observed}$. This provides a more statistically reliable estimate of the expected average crash frequency of the selected site.

In order to apply the site-specific EB Method, in addition to the material in *Part C* Appendix A.2.4, overdispersion parameter, k, for the SPF is also used. The overdispersion parameter provides an indication of the statistical reliability of the SPF. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. This parameter is used in the site-specific EB Method to provide a weighting to $N_{predicted}$ and $N_{observed}$. Overdispersion parameters are provided for each SPF in Section 10.6.

Apply the site-specific EB Method to a future time period, if appropriate.

The estimated expected average crash frequency obtained above applies to the time period in the past for which the observed crash data were obtained. Section A.2.6 in the Appendix to *Part C* provides method to convert the past period estimate of expected average crash frequency into to a future time period.

Step 14 – If there is another site to be evaluated, return to Step 7, otherwise, proceed to Step 15.

This step creates a loop through Steps 7 to 13 that is repeated for each roadway segment or intersection within the facility.

Step 15 – Apply the project level EB Method (if the site-specific EB Method is not applicable).

This step is only applicable to existing conditions when observed crash data are available, but can not be accurately assigned to specific sites (e.g., the crash report may identify crashes as occurring between two intersections, but is not accurate to determine a precise location on the segment). Detailed description of the project level EB Method is provided in *Part C* Appendix A.2.5.

The project level EB Method is described in Part C Appendix A.2.5.

Step 16 – Sum all sites and years in the study to estimate total crash frequency.

The total estimated number of crashes within the network or facility limits during a study period of n years is calculated using Equation 10-4:

$$N_{total} = \sum_{\substack{all \\ roadway \\ segments}} N_{rs} + \sum_{\substack{all \\ intersections}} N_{int} \qquad (10\text{-}4)$$

Where,

N_{total} = total expected number of crashes within the limits of a rural two-lane two-way facility for the period of interest. Or, the sum of the expected average crash frequency for each year for each site within the defined roadway limits within the study period;

N_{rs} = expected average crash frequency for a roadway segment using the predictive method for one specific year;

N_{int} = expected average crash frequency for an intersection using the predictive method for one specific year.

Equation 10-4 represents the total expected number of crashes estimated to occur during the study period. Equation 10-5 is used to estimate the total expected average crash frequency within the network or facility limits during the study period.

$$N_{total\ average} = \frac{N_{total}}{n} \qquad (10\text{-}5)$$

Where,

$N_{total\ average}$ = total expected average crash frequency estimated to occur within the defined network or facility limits during the study period;

n = number of years in the study period.

Step 17 – Determine if there is an alternative design, treatment or forecast AADT to be evaluated.

Steps 3 through 16 of the predictive method are repeated as appropriate for the same roadway limits but for alternative conditions, treatments, periods of interest, or forecast AADTs.

Step 18 – Evaluate and compare results.

The predictive method is used to provide a statistically reliable estimate of the expected average crash frequency within defined network or facility limits over a given period of time, for given geometric design and traffic control features, and known or estimated AADT. In addition to estimating total crashes, the estimate can be made for different crash severity types and different collision types. Default distributions of crash severity and collision type are provided with each SPF in Section 10.6. These default distributions can benefit from being updated based on local data as part of the calibration process presented in *Part C* Appendix A.1.1.

10.5. ROADWAY SEGMENTS AND INTERSECTIONS

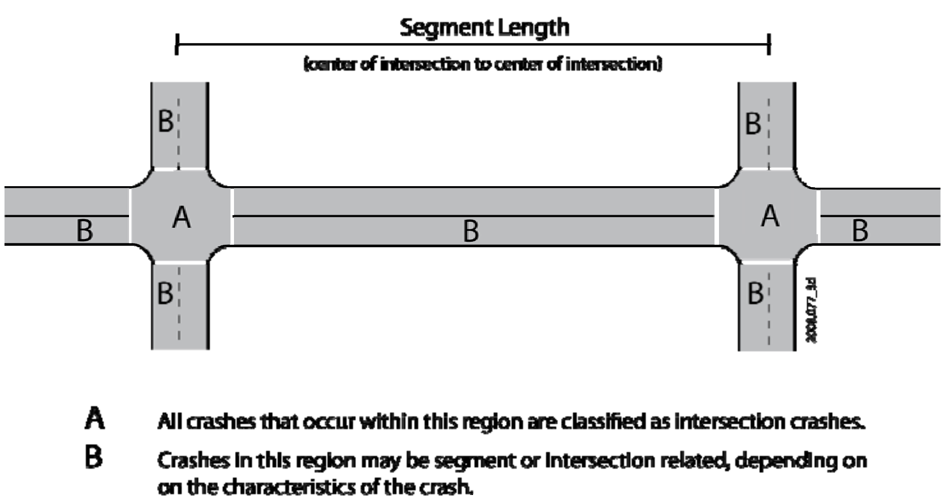
Section 10.4 provides an explanation of the predictive method. Sections 10.5 through 10.8 provide the specific detail necessary to apply the predictive method steps in a rural two-lane two-way road environment. Detail regarding the procedure for determining a calibration factor to apply in Step 11 is provided in the *Part C* Appendix A.1. Detail regarding the EB Method, which is applied in Steps 6, 13, and 15, is provided in the *Part C* Appendix A.2.

In Step 5 of the predictive method, the roadway within the defined roadway limits is divided into individual sites, which are homogenous roadway segments and intersections. A facility consists of a contiguous set of individual intersections and roadway segments, referred to as "sites." A roadway network consists of a number of contiguous facilities. Predictive models have been developed to estimate crash frequencies separately for roadway segments and intersections. The definitions of roadway segments and intersections presented below are the same as those used in the FHWA Interactive Highway Safety Design Model (IHSDM) [(2)].

Roadway segments begin at the center of an intersection and end at either the center of the next intersection, or where there is a change from one homogeneous roadway segment to another homogenous segment. The roadway segment model estimates the frequency of roadway-segment-related crashes which occur in Region B in Exhibit 10-3. When a roadway segment begins or ends at an intersection, the length of the roadway segment is measured from the center of the intersection.

The Chapter 10 predictive method addresses stop controlled (three- and four-leg) and signalized (four-leg) intersections. The intersection models estimate the predicted average frequency of crashes that occur within the limits of an intersection (Region A of Exhibit 10-3) and intersection-related crashes that occur on the intersection legs (Region B in Exhibit 10-3).

Exhibit 10-3: Definition of Segments and Intersections



The roadway segment model estimates the frequency of roadway segment related crashes which occur in Region B in Exhibit 10-3. The intersection models estimate the frequency of all crashes in Region A plus intersection-related crashes that occur in Region B.

The segmentation process produces a set of roadway segments of varying length, each of which is homogeneous with respect to characteristics such as traffic volumes, roadway design characteristics, and traffic control features. Exhibit 10-3 shows the segment length, L, for a single homogenous roadway segment occurring between two intersections. However, it is likely that several homogenous roadway segments will occur between two intersections. A new (unique) homogeneous segment begins at the center of each intersection or at any of the following:

- Beginning or end of a horizontal curve (spiral transitions are considered part of the curve).
- Point of vertical intersection (PVI) for a crest vertical curve, a sag vertical curve, or an angle point at which two different roadway grades meet. Spiral transitions are considered part of the horizontal curve they adjoin and vertical curves are considered part of the grades they adjoin (i.e., grades run from PVI to PVI with no explicit consideration of any vertical curve that may be present).
- Beginning or end of a passing lane or short four-lane section provided for the purpose of increasing passing opportunities.
- Beginning or end of a center two-way left-turn lane.

Also, a new roadway segment starts where there is a change in at least one of the following characteristics of the roadway:

- Average annual daily traffic volume (vehicles per day)
- Lane width

  For lane widths measured to a 0.1-ft level of precision or similar, the following rounded lane widths are recommended before determining "homogeneous" segments:

Measured Lane Width	Rounded Lane Width
9.2-ft or less	9-ft or less
9.3-ft to 9.7-ft	9.5-ft
9.8-ft to 10.2-ft	10-ft
10.3-ft to 10.7-ft	10.5-ft
10.8-ft to 11.2-ft	11-ft
11.3-ft to 11.7-ft	11.5-ft
11.8-ft or more	12-ft or more

- Shoulder width

  For shoulder widths measures to a 0.1-ft level of precision or similar, the following rounded paved shoulder widths are recommended before determining "homogeneous" segments:

Measured Shoulder Width	Rounded Shoulder Width
0.5-ft or less	0-ft
0.6-ft to 1.5-ft	1-ft
1.6-ft to 2.5-ft	2-ft
2.6-ft to 3.5-ft	3-ft
3.6-ft to 4.5-ft	4-ft
4.6-ft to 5.5-ft	5-ft
5.6-ft to 6.5-ft	6-ft
6.6-ft to 7.5-ft	7-ft
7.6-ft or more	8-ft or more

- Shoulder type
- Driveway density (driveways per mile)

  For very short segment lengths (less than 0.5-miles), the use of driveway density for the single segment length may result in an inflated value since driveway density is determined based on length. As a result, the driveway density used for determining homogeneous segments should be for the facility (as defined in Section 10.2) length rather than the segment length.

- Roadside hazard rating

  As described later in Section 10.7.1, the roadside hazard rating (a scale from 1 to 7) will be used to determine a roadside design AMF. Since this rating is a subjective value and can differ marginally based on the opinion of the assessor, it is reasonable to assume that a "homogeneous" segment can have a roadside hazard rating that varies by as much as 2 rating levels. An average of the roadside hazard ratings can be used to compile a "homogeneous" segment as long as the minimum and maximum values are not separated by a value greater than 2. [For example, if the roadside hazard rating ranges from 5 to 7 for a specific road, an average value of 6 can be assumed and this would be considered one homogeneous roadside design condition. If, on the other hand, the roadside hazard ratings ranged from 2 to 5 (a range greater than 2) these would not be considered "homogeneous" roadside conditions and smaller segments may be appropriate.]

- Presence/absence of centerline rumble strip
- Presence/absence of lighting
- Presence/absence of automated speed enforcement

There is no minimum roadway segment length for application of the predictive models for roadway segments. When dividing roadway facilities into small homogenous roadway segments, limiting the segment length to a minimum of 0.10 miles will minimize calculation efforts and not affect results.

In order to apply the site-specific EB Method, observed crashes are assigned to the individual roadway segments and intersections. Observed crashes that occur between intersections are classified as either intersection-related or roadway segment-related. The methodology for assignment of crashes to roadway segments and intersections for use in the site-specific EB Method is presented in Section A.2.3 in the Appendix to *Part C*.

A detailed discussion of SPFs and their use in the HSM is presented in Chapter 3 Section 3.5.2 and the Part C Introduction and Applications Guidance Section C.6.3

10.6. SAFETY PERFORMANCE FUNCTIONS

In Step 9 of the predictive method, the appropriate Safety Performance Functions (SPFs) are used to predict average crash frequency for the selected year for specific base conditions. SPFs are regression models for estimating the predicted average crash frequency of individual roadway segments or intersections. Each SPF in the predictive method was developed with observed crash data for a set of similar sites. The SPFs, like all regression models, estimate the value of a dependent variable as a function of a set of independent variables. In the SPFs developed for the HSM, the dependent variable estimated is the predicted average crash frequency for a roadway segment or intersection under base conditions and the independent variables are the AADTs of the roadway segment or intersection legs (and, for roadway segments, the length of the roadway segment).

The Safety Performance Functions (SPFs) used in Chapter 10 were originally formulated by Vogt and Bared[12,13,14]. A few aspects of the Harwood et al.[4] and Vogt and Bared[12,13,14] work have been updated to match recent changes to the crash prediction module of the FHWA Interactive Highway Safety Design Model[2] software. The SPF coefficients, default crash severity and collision type distributions, and default nighttime crash proportions have been adjusted to a consistent basis by Srinivasan et al[11].

The predicted crash frequencies for base conditions are calculated from the predictive models in Equations 10-2 and 10-3. A detailed discussion of SPFs and their use in the HSM is presented in *Chapter 3* Section 3.5.2 and the *Part C Introduction and Applications Guidance* Section C.6.3.

Each SPF also has an associated overdispersion parameter, k. The overdispersion parameter provides an indication of the statistical reliability of the SPF. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. This parameter is used in the EB Method discussed in the *Part C* Appendix. The SPFs in Chapter 10 are summarized in Exhibit 10-4.

Exhibit 10-4: Safety Performance Functions included in Chapter 10

Chapter 10 SPFs for Rural Two-lane Two-way Roads	SPF Equations and Exhibits
Rural two-lane two-way roadway segments	Equation 10-6 , Exhibit 10-5
Three-leg STOP controlled intersections	Equation 10-8 , Exhibit 10-8
Four-leg STOP controlled intersections	Equation 10-9 , Exhibit 10-9
Four-leg signalized intersections	Equation 10-10 , Exhibit 10-10

Some highway agencies may have performed statistically-sound studies to develop their own jurisdiction-specific SPFs derived from local conditions and crash experience. These models may be substituted for models presented in this chapter. Criteria for the development of SPFs for use in the predictive method are addressed in the calibration procedure presented in the Appendix to *Part C*.

10.6.1. Safety Performance Functions for Rural Two-Lane Two-Way Roadway Segments

The predictive model for predicting average crash frequency for base conditions on a particular rural two-lane two-way roadway segment was presented in Equation 10-2. The effect of traffic volume (AADT) on crash frequency is incorporated through an SPF, while the effects of geometric design and traffic control features are incorporated through the AMFs.

The base conditions for roadway segments on rural two-lane two-way roads are:

▪ Lane width (LW)	12 feet
▪ Shoulder width (SW)	6 feet
▪ Shoulder type	Paved
▪ Roadside hazard rating (RHR)	3
▪ Driveway density (DD)	5 driveways per mile
▪ Horizontal curvature	None
▪ Vertical curvature	None
▪ Centerline rumble strips	None
▪ Passing lanes	None
▪ Two-way left-turn lanes	None
▪ Lighting	None
▪ Automated speed enforcement	None
▪ Grade Level	0% (see note below)

A 0% grade is not allowed by most states and presents issues such as drainage. The SPF uses 0% as a numerical base condition that must always be modified based on the actual grade

The SPF for predicted average crash frequency for rural two-lane two-way roadway segments is shown in Equation 10-6 and presented graphically in Exhibit 10-5:

$$N_{spf\ rs} = AADT \times L \times 365 \times 10^{-6} \times e^{(-0.312)} \qquad (10\text{-}6)$$

Where,

$N_{spf\ rs}$ = predicted total crash frequency for roadway segment base conditions;

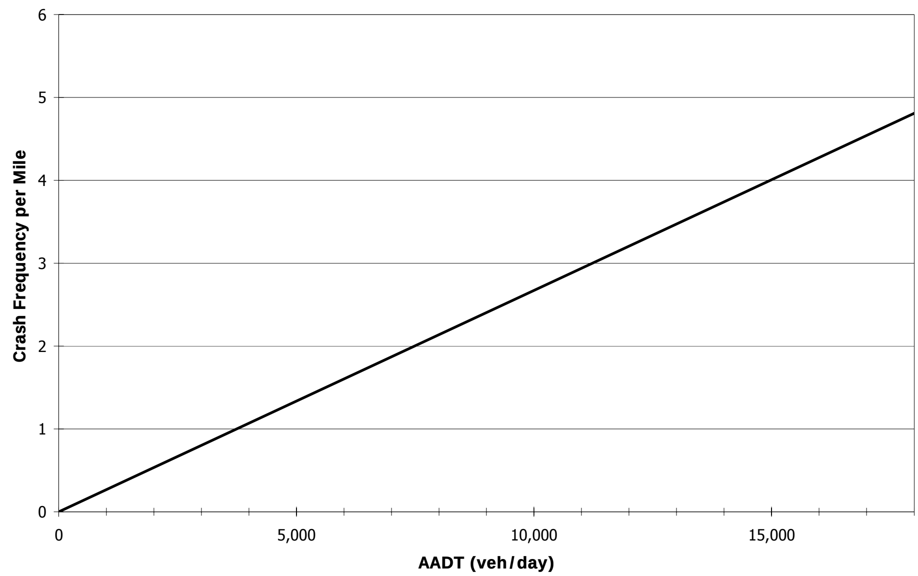
AADT = average annual daily traffic volume (vehicles per day);

L = length of roadway segment (miles).

Guidance on the estimation of traffic volumes for roadway segments for use in the SPFs is presented in Step 3 of the predictive method described in Section 10.4. The SPFs for roadway segments on rural two-lane highways are applicable to the

AADT range from 0 to 17,800 vehicles per day. Application to sites with AADTs substantially outside this range may not provide reliable results.

Exhibit 10-5: Graphical Form of SPF for Rural Two-Lane Two-Way Roadway Segments (Equation 10-6)



The value of the overdispersion parameter associated with the SPF for rural two-lane two-way roadway segments is determined as a function of the roadway segment length using Equation 10-7. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. The value is determined as:

$$k = \frac{0.236}{L} \qquad (10\text{-}7)$$

Where,

k = overdispersion parameter;

L = length of roadway segment (miles).

Exhibits 10-6 and 10-7 provide the default proportions for crash severity and for collision type by crash severity level, respectively. These exhibits may be used to separate the crash frequencies from Equation 10-6 into components by crash severity level and collision type. Exhibits 10-6 and 10-7 are applied sequentially. First, Exhibit 10-6 is used to estimate crash frequencies by crash severity level and then Exhibit 10-7 is used to estimate accident frequencies by collision type for a particular crash severity level. The default proportions for severity levels and collision types shown in Exhibits 10-6 and 10-7 may be updated based on local data for a particular jurisdiction as part of the calibration process described in the Appendix to *Part C*.

Exhibit 10-6: Default Distribution for Crash Severity Level on Rural Two-Lane Two-Way Roadway Segments

Procedures to develop local proportions of crash severity and collision type are provided in the Appendix to Part C.

Crash severity level	Percentage of total roadway segment crashes[a]
Fatal	1.3
Incapacitating Injury	5.4
Nonincapacitating injury	10.9
Possible injury	14.5
Total fatal plus injury	32.1
Property damage only	67.9
TOTAL	100.0

a Based on HSIS data for Washington (2002-2006)

Exhibit 10-7: Default Distribution by Collision Type for Specific Crash Severity Levels on Rural Two-Lane Two-Way Roadway Segments.

Collision type	Percentage of total roadway segment crashes by crash severity level[a]		
	Total fatal and injury	Property damage only	TOTAL (all severity levels combined)
SINGLE-VEHICLE ACCIDENTS			
Collision with animal	3.8	18.4	12.1
Collision with bicycle	0.4	0.1	0.2
Collision with pedestrian	0.7	0.1	0.3
Overturned	3.7	1.5	2.5
Ran off road	54.5	50.5	52.1
Other single-vehicle accident	0.7	2.9	2.1
Total single-vehicle accidents	63.8	73.5	69.3
MULTIPLE-VEHICLE ACCIDENTS			
Angle collision	10.0	7.2	8.5
Head-on collision	3.4	0.3	1.6
Rear-end collision	16.4	12.2	14.2
Sideswipe collision[b]	3.8	3.8	3.7
Other multiple-vehicle collision	2.6	3.0	2.7
Total multiple-vehicle accidents	36.2	26.5	30.7
TOTAL ACCIDENTS	100.0	100.0	100.0

[a]Based on HSIS data for Washington (2002-2006)

[b]Includes approximately 70% opposite-direction sideswipe collisions and 30% same-direction sideswipe collisions

10.6.2. Safety Performance Functions for Intersections

The predictive model for predicting average crash frequency at particular rural two-lane two-way road intersections was presented in Equation 10-3. The effect of the major and minor road traffic volumes (AADTs) on crash frequency is incorporated through SPFs, while the effects of geometric design and traffic control features are incorporated through the AMFs. The SPFs for rural two-lane two-way highway intersections are presented in this section.

SPFs have been developed for three types of intersections on rural two-lane two-way roads. The three types of intersections are:

- Three-leg intersections with minor-road stop control (3ST)
- Four-leg intersections with minor-road stop control (4ST)
- Four-leg signalized intersections (4SG)

SPFs for three-leg signalized intersections on rural two-lane two-way roads are not available. Other types of intersections may be found on rural two-lane two-way highways but are not addressed by these procedures.

The SPFs for each of the intersection types listed above estimates total predicted average crash frequency for intersection-related accidents within the limits of a particular intersection and on the intersection legs. The distinction between roadway segment and intersection crashes is discussed in Section 10.5 and a detailed procedure for distinguishing between roadway-segment-related and intersection-related crashes is presented in Section A.2.3 in the Appendix to *Part C*. These SPFs address intersections that have only two lanes on both the major and minor road legs, not including turn lanes. The SPFs for each of the three intersection types are presented below in Equations 10-8, 10-9, and 10-10. Guidance on the estimation of traffic volumes for the major and minor road legs for use in the SPFs is presented in Section 10.4, Step 3.

The base conditions for the rural two-lane two-way road intersection models are presented here.

The base conditions which apply to the SPFs in Equations 10-8, 10-9, and 10-10 are:

- Intersection skew angle 0°
- Intersection left-turn lanes None on approaches without stop control
- Intersection right-turn lanes None on approaches without stop control
- Lighting None

Three-Leg Stop-Controlled Intersections

The SPF for three-leg stop-controlled intersections is shown in Equation 10-8 and presented graphically in Exhibit 10-8:

$$N_{spf\ 3ST} = exp[-9.86 + 0.79 \times ln(AADT_{maj}) + 0.49 \times ln(AADT_{min})] \qquad (10\text{-}8)$$

Where,

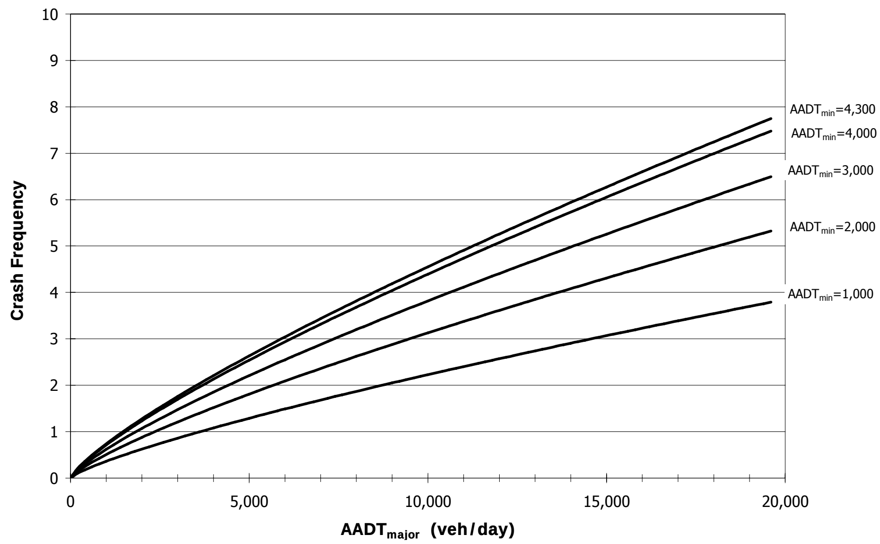
$N_{spf\ 3ST}$ = estimate of intersection-related predicted average crash frequency for base conditions for three-leg stop-controlled intersections;

$AADT_{maj}$ = AADT (vehicles per day) on the major road;

$AADT_{min}$ = AADT (vehicles per day) on the minor road.

The overdispersion parameter (k) for this SPF is 0.54. This SPF is applicable to an $AADT_{maj}$ range from 0 to 19,500 vehicles per day and $AADT_{min}$ range from 0 to 4,300 vehicles per day. Application to sites with AADTs substantially outside these ranges may not provide reliable results.

Exhibit 10-8: Graphical Representation of the SPF for Three-leg STOP-controlled (3ST) Intersections (Equation 10-8)



Four-Leg Stop-Controlled Intersections

The SPF for four-leg stop controlled intersections is shown in Equation 10-9 and presented graphically in Exhibit 10-9:

$$N_{spf\ 4ST} = exp[-8.56 + 0.60 \times ln(AADT_{maj}) + 0.61 \times ln(AADT_{min})] \qquad (10\text{-}9)$$

Where,

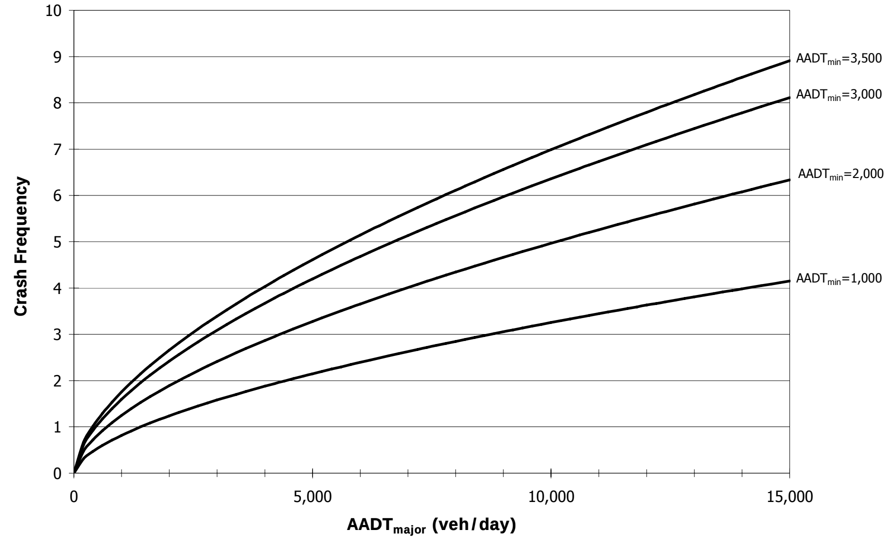
$N_{spf\,4ST}$ = estimate of intersection-related predicted average crash frequency for base conditions for four-leg STOP controlled intersections;

$AADT_{maj}$ = AADT (vehicles per day) on the major road;

$AADT_{min}$ = AADT (vehicles per day) on the minor road.

The overdispersion parameter (k) for this SPF is 0.24. This SPF is applicable to an $AADT_{maj}$ range from 0 to 14,700 vehicles per day and $AADT_{min}$ range from 0 to 3,500 vehicles per day. Application to sites with AADTs substantially outside these ranges may not provide accurate results.

Exhibit 10-9: Graphical Representation of the SPF for Four-leg STOP controlled (4ST) Intersections (Equation 10-9)



Four-Leg Signalized Intersections

The SPF for four-leg signalized intersections is shown below and presented graphically in Exhibit 10-10:

$$N_{spf\ 4SG} = exp[-5.13 + 0.60 \times ln(AADT_{maj}) + 0.20 \times ln(AADT_{min})] \qquad (10\text{-}10)$$

Where,

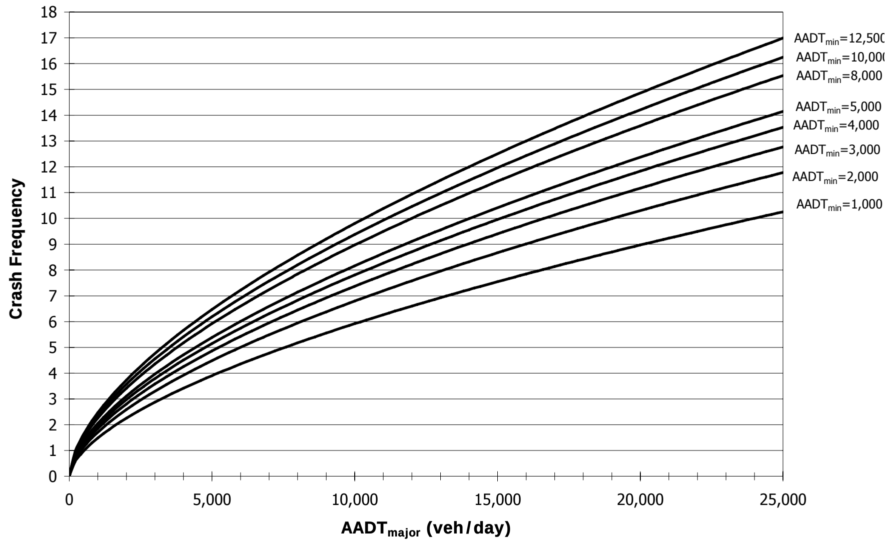
$N_{spf\ 4SG}$ = SPF estimate of intersection-related predicted average crash frequency for base conditions;

$AADT_{maj}$ = AADT (vehicles per day) on the major road;

$AADT_{min}$ = AADT (vehicles per day) on the minor road.

The overdispersion parameter (k) for this SPF is 0.11. This SPF is applicable to an $AADT_{maj}$ range from 0 to 25,200 vehicles per day and $AADT_{min}$ range from 0 to 12,500 vehicles per day. For instances when application is made to sites with AADT substantially outside these ranges, the reliability is unknown.

Exhibit 10-10: Graphical Representation of the SPF for Four-leg Signalized (4SG) Intersections (Equation 10-10)



Exhibits 10-11 and 10-12 provide the default proportions for accident severity levels and collision types, respectively. These exhibits may be used to separate the accident frequencies from Equations 10-8 through 10-10 into components by severity level and collision type. The default proportions for severity levels and collision types shown in Exhibits 10-11 and 10-12 may be updated based on local data for a particular jurisdiction as part of the calibration process described in the Appendix to *Part C*.

Exhibit 10-11: Default Distribution for Crash Severity Level at Rural Two-Lane Two-Way Intersections

Crash severity level	Percentage of total crashes		
	Three-leg stop-controlled intersections	Four-leg stop-controlled intersections	Four-leg signalized intersections
Fatal	1.7	1.8	0.9
Incapacitating Injury	4.0	4.3	2.1
Nonincapacitating injury	16.6	16.2	10.5
Possible injury	19.2	20.8	20.5
Total fatal plus injury	41.5	43.1	34.0
Property damage only	58.5	56.9	66.0
TOTAL	100.0	100.0	100.0

Based on HSIS data for California (2002-2006).

Exhibits 10-11 and 10-12 provide the default proportions for accident severity levels and collision types.

Exhibit 10-12: Default Distribution for Collision Type and Manner of Collision at Rural Two-Way Intersections

Collision Type	Percentage of total crashes by collision type								
	Three-leg stop-controlled intersections			Four-leg stop-controlled intersections			Four-leg signalized intersections		
	Fatal and injury	Property damage only	Total	Fatal and injury	Property damage only	Total	Fatal and injury	Property damage only	Total
SINGLE-VEHICLE ACCIDENTS									
Collision with animal	0.8	2.6	1.9	0.6	1.4	1.0	0.0	0.3	0.2
Collision with bicycle	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Collision with pedestrian	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Overturned	2.2	0.7	1.3	0.6	0.4	0.5	0.3	0.3	0.3
Ran off road	24.0	24.7	24.4	9.4	14.4	12.2	3.2	8.1	6.4
Other single-vehicle accident	1.1	2.0	1.6	0.4	1.0	0.8	0.3	1.8	0.5
Total single-vehicle accidents	28.3	30.2	29.4	11.2	17.4	14.7	4.0	10.7	7.6
MULTIPLE-VEHICLE ACCIDENTS									
Angle collision	27.5	21.0	23.7	53.2	35.4	43.1	33.6	24.2	27.4
Head-on collision	8.1	3.2	5.2	6.0	2.5	4.0	8.0	4.0	5.4
Rear-end collision	26.0	29.2	27.8	21.0	26.6	24.2	40.3	43.8	42.6
Sideswipe collision	5.1	13.1	9.7	4.4	14.4	10.1	5.1	15.3	11.8
Other multiple-vehicle collision	5.0	3.3	4.2	4.2	3.7	3.9	9.0	2.0	5.2
Total multiple-vehicle accidents	71.7	69.8	70.6	88.8	82.6	85.3	96.0	89.3	92.4
TOTAL ACCIDENTS	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

NOTE: Based on HSIS data for California (2002-2006).

10.7. ACCIDENT MODIFICATION FACTORS

In Step 10 of the predictive method shown in Section 10.4, Accident Modification Factors are applied to account for the effects of site-specific geometric design and traffic control features. AMFs are used in the predictive method in Equations 10-2 and 10-3. A general overview of Accident Modification Factors (AMFs) is presented in *Chapter 3* Section 3.5.3. The *Part C Introduction and Applications Guidance* provides further discussion on the relationship of AMFs to the predictive method. This section provides details of the specific AMFs applicable to the Safety Performance Functions presented in Section 10.6.

Accident Modification Factors (AMFs) are used to adjust the SPF estimate of predicted average crash frequency for the effect of individual geometric design and traffic control features, as shown in the general predictive model for Chapter 10 shown in Equation 10-1. The AMF for the SPF base condition of each geometric design or traffic control feature has a value of 1.00. Any feature associated with higher crash frequency than the base condition has an AMF with a value greater than 1.00. Any feature associated with lower crash frequency than the base condition has an AMF with a value less than 1.00.

A general overview of Accident Modification Factors (AMFs) is presented in Chapter 3 Section 3.5.3.

The AMFs used in Chapter 10 are consistent with the AMFs in *Part D*, although they have, in some cases, been expressed in a different form to be applicable to the base conditions. The AMFs presented in Chapter 10 and the specific site types to which they apply are summarized in Exhibit 10-13.

Exhibit 10-13: Summary of Accident Modification Factors (AMFs) in Chapter 10 and the Corresponding Safety Performance Functions (SPFs)

Facility Type	AMF	AMF Description	AMF Equations and Exhibits
Rural Two-Lane Two-Way Roadway Segments	AMF_{1r}	Lane Width	Exhibits 10-14, 10-15, Equation 10-11
	AMF_{2r}	Shoulder Width and Type	Exhibit 10-16, 10-17, 10-18, Equation 10-12
	AMF_{3r}	Horizontal Curves: Length, Radius, and Presence or Absence of Spiral Transitions	Equation 10-13
	AMF_{4r}	Horizontal Curves: Superelevation	Equation 10-14, 10-15, 10-16,
	AMF_{5r}	Grades	Exhibit 10-19
	AMF_{6r}	Driveway Density	Equation 10-17
	AMF_{7r}	Centerline Rumble Strips	See text
	AMF_{8r}	Passing Lanes	See text
	AMF_{9r}	Two-Way Left-Turn Lanes	Equation 10-18, 10-19
	AMF_{10r}	Roadside Design	Equation 10-20
	AMF_{11r}	Lighting	Equation 10-21, Exhibit 10-20
	AMF_{12r}	Automated Speed Enforcement	See text
Three- and four-leg STOP control intersections and four-leg signalized intersections	AMF_{1i}	Intersection Skew Angle	Equation 10-22, 10-23
	AMF_{2i}	Intersection Left-Turn Lanes	Exhibit 10-21
	AMF_{3i}	Intersection Right-Turn Lanes	Exhibit 10-22
	AMF_{4i}	Lighting	Equation 10-24, Exhibit 10-23

10.7.1. Accident Modification Factors for Roadway Segments

Section 10.7.1 provides the AMFs to be used with two-lane rural road segments.

The AMFs for geometric design and traffic control features of rural two-lane two-way roadway segments are presented below. These AMFs are applied in Step 10 of the predictive method and used in Equation 10-2 to adjust the SPF for rural two-lane two-way roadway segments presented in Equation 10-6, to account for differences between the base conditions and the local site conditions.

The first of 12 AMFs for use on rural road segments is an AMF for lane width.

AMF_{1r} - Lane Width

The AMF for lane width on two-lane highway segments is presented in Exhibit 10-14 and illustrated by the graph in Exhibit 10-15. This AMF was developed from the work of Zegeer et al.[(15)] and Griffin and Mak[(3)]. The base value for the lane width AMF is 12-ft. In other words, the roadway segment SPF will predict safety performance of a roadway segment with 12-ft lanes. To predict the safety performance of the actual segment in question (e.g. one with lane widths different than 12 feet), AMFs are used to account for differences between base and actual conditions. Thus, 12-ft lanes are assigned an AMF of 1.00. AMF_{1r} is determined from Exhibit 10-14 based on the applicable lane width and traffic volume range. The relationships shown in Exhibit 10-14 are illustrated in Exhibit 10-15. Lanes greater than 12-ft wide are assigned an AMF equal to that for 12-ft lanes.

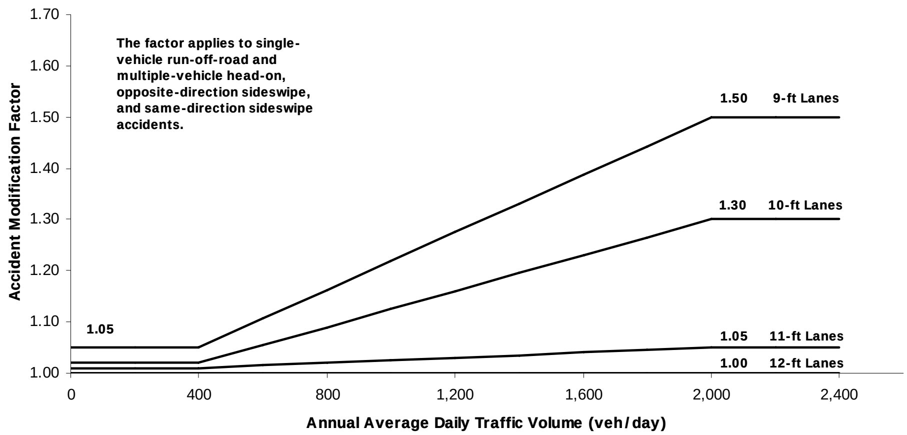
For lane widths with 0.5-ft increments that are not depicted specifically in Exhibit 10-14 or Exhibit 10-15, an AMF value can be interpolated using either of these exhibits since there is a linear transition between the various AADT effects.

Exhibit 10-14: AMF for Lane Width on Roadway Segments (AMF_{ra})

Lane Width	AADT (veh/day)		
	< 400	400 to 2000	> 2000
9-ft or less	1.05	$1.05+2.81\times10^{-4}(AADT-400)$	1.50
10-ft	1.02	$1.02+1.75\times10^{-4}(AADT-400)$	1.30
11-ft	1.01	$1.01+2.5\times10^{-5}(AADT-400)$	1.05
12-ft or more	1.00	1.00	1.00

NOTE: The collision types related to lane width to which this AMF applies include single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents.

Exhibit 10-15: Accident Modification Factor for Lane Width on Roadway Segments



If the lane widths for the two directions of travel on a roadway segment differ, the AMF are determined separately for the lane width in each direction of travel and the resulting AMFs are then be averaged.

The AMFs shown in Exhibits 10-14 and 10-15 apply only to the accident types that are most likely to be affected by lane width: single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents. These are the only accident types assumed to be affected by variation in lane width, and other accident types are assumed to remain unchanged due to the lane width variation. The AMFs expressed on this basis are, therefore, adjusted to total accidents within the predictive method. This is accomplished using Equation 10-11:

$$AMF_{1r} = (AMF_{ra} - 1.0) \times p_{ra} + 1.0 \qquad (10\text{-}11)$$

Where,

AMF_{1r} = Accident Modification Factor for the effect of lane width on total accidents;

AMF_{ra} = Accident Modification Factor for the effect of lane width on related accidents (i.e., single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents), such as the Accident Modification Factor for lane width shown in Exhibit 10-14;

p_{ra} = proportion of total accidents constituted by related accidents.

The proportion of related accidents, p_{ra}, (i.e. single-vehicle run-off-road, and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipes accidents) is estimated as 0.574 (i.e., 57.4%) based on the default distribution of crash types presented in Exhibit 10-7. This default accident type distribution, and therefore the value of p_{ra}, may be updated from local data as part of the calibration process.

***AMF_{2r}* - Shoulder Width and Type**

The second of 12 AMFs for use on two-lane rural road segments is an AMF for shoulder width and type.

The AMF for shoulders has an AMF for shoulder width (AMF_{wra}) and an AMF for shoulder type (AMF_{tra}). The AMFs for both shoulder width and shoulder type are based on the results of Zegeer et al.(15,16) The base value of shoulder width and type is a 6-foot paved shoulder, which is assigned an AMF value of 1.00.

AMF_{wra} for shoulder width on two-lane highway segments is determined from Exhibit 10-16 based on the applicable shoulder width and traffic volume range. The relationships shown in Exhibit 10-16 are illustrated in Exhibit 10-17.

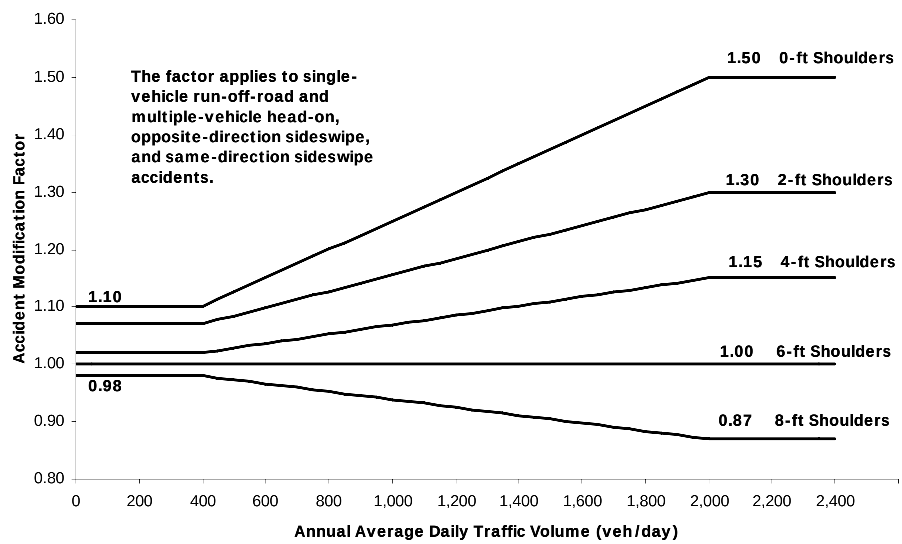
Shoulders over 8-ft wide are assigned an AMF_{wra} equal to that for 8–ft shoulders. The AMFs shown in Exhibits 10-16 and 10-17 apply only to single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents.

Exhibit 10-16: AMF for Shoulder Width on Roadway Segments (AMF_{wra})

Shoulder Width	AADT (vehicles per day)		
	< 400	400 to 2000	> 2000
0-ft	1.10	$1.10 + 2.5 \times 10^{-4}$ (AADT - 400)	1.50
2-ft	1.07	$1.07 + 1.43 \times 10^{-4}$ (AADT - 400)	1.30
4-ft	1.02	$1.02 + 8.125 \times 10^{-5}$ (AADT - 400)	1.15
6-ft	1.00	1.00	1.00
8-ft or more	0.98	$0.98 + 6.875 \times 10^{-5}$ (AADT - 400)	0.87

NOTE: The collision types related to shoulder width to which this AMF applies include single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents.

Exhibit 10-17: Accident Modification Factor for Shoulder Width on Roadway Segments



The base condition for shoulder type is paved. Exhibit 10-18 presents values for AMF_{tra} which adjusts for the safety effects of gravel, turf, and composite shoulders as a function of shoulder width.

Exhibit 10-18: Accident Modification Factors for Shoulder Types and Shoulder Widths on Roadway Segments (AMF_{tra})

Shoulder Type	Shoulder width (ft)						
	0	1	2	3	4	6	8
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06
Turf	1.00	1.01	1.03	1.04	1.05	1.08	1.11

NOTE: The values for composite shoulders in this exhibit represent a shoulder for which 50 percent of the shoulder width is paved and 50 percent of the shoulder width is turf.

If the shoulder types and/or widths for the two directions of a roadway segment differ, the AMF are determined separately for the shoulder type and width in each direction of travel and the resulting AMFs are then be averaged.

The AMFs for shoulder width and type shown in Exhibits 10-16 through 10-18 apply only to the collision types that are most likely to be affected by shoulder width and type: single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents. The AMFs expressed on this basis are, therefore, adjusted to total accidents using Equation 10-12:

$$AMF_{2r} = (AMF_{wra} \times AMF_{tra} - 1.0) \times p_{ra} + 1.0 \qquad (10\text{-}12)$$

Where,

AMF_{2r} = Accident Modification Factor for the effect of shoulder width and type on total accidents;

AMF_{wra} = Accident Modification Factor for related accidents (i.e., single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe accidents), based on shoulder width (from Exhibit 10-16);

AMF_{tra} = Accident Modification Factor for related accidents based on shoulder type (from Exhibit 10-18);

p_{ra} = proportion of total accidents constituted by related accidents.

The proportion of related accidents, p_{ra}, (i.e. single-vehicle run-off-road, and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipes accidents) is estimated as 0.574 (i.e., 57.4%) based on the default distribution of accident types presented in Exhibit 10-7. This default accident type distribution, and therefore the value of p_{ra}, may be updated from local data by a highway agency as part of the calibration process.

AMF_{3r} - Horizontal Curves: Length, Radius, and Presence or Absence of Spiral Transitions

The third of 12 AMFs for use on two-lane rural road segments is an AMF for horizontal curve length, radius, and the presence or absence of spiral transitions.

The base condition for horizontal alignment is a tangent roadway segment. An AMF has been developed to represent the manner in which accident experience on curved alignments differs from that of tangents. This AMF applies to total roadway segment accidents.

The AMF for horizontal curves has been determined from the regression model developed by Zegeer et al[17].

The AMF for horizontal curvature is in the form of an equation and yields a factor similar to the other AMFs in this chapter. The AMF for length, radius, and presence or absence of spiral transitions on horizontal curves is determined using Equation 10-13:

Equation 10-13 is used to determine the AMF for horizontal curve length, radius, and the presence or absence of spiral transitions.

$$AMF_{3r} = \frac{(1.55 \times L_c) + (\frac{80.2}{R}) - (0.012 \times S)}{(1.55 \times L_c)} \quad (10\text{-}13)$$

Where,

AMF_{3r} = Accident Modification Factor for the effect of horizontal alignment on total accidents;

L_c = length of horizontal curve (miles) which includes spiral transitions, if present;

R = radius of curvature (feet);

S = 1 if spiral transition curve is present; 0 if spiral transition curve is not present; 0.5 if a spiral transition curve is present at one but not both ends of the horizontal curve.

Some roadway segments being analyzed may include only a portion of a horizontal curve. In this case, L_c represents the length of the entire horizontal curve, including portions of the horizontal curve that may lie outside the roadway segment of interest.

In applying Equation 10-13, if the radius of curvature (R) is less than 100-ft, R is set to equal to 100-ft. If the length of the horizontal curve (L_c) is less than 100 feet, L_c is set to equal 100ft.

AMF values are computed separately for each horizontal curve in a horizontal curve set (a curve set consists of a series of consecutive curve elements). For each individual curve, the value of L_c used in Equation 10-13 is the total length of the compound curve set and the value of R is the radius of the individual curve.

If the value of AMF_{3r} is less than 1.00, the value of AMF_{3r} is set equal to 1.00.

AMF_{4r} - Horizontal Curves: Superelevation

The fourth of 12 AMFs for two-lane rural road segments is an AMF for the superelevation of a horizontal curve.

The base condition for the AMF for the superelevation of a horizontal curve is the amount of superelevation identified in the AASHTO Green Book[18]. The superelevation in the AASHTO Green Book is determined by taking into account the value of maximum superelevation rate, e_{max}, established by highway agency policies. Policies concerning maximum superelevation rates for horizontal curves vary between highway agencies based on climate and other considerations.

The AMF for superelevation is based on the superelevation variance of a horizontal curve (i.e., the difference between the actual superelevation and the superelevation identified by AASHTO policy). When the actual superelevation meets or exceeds that in the AASHTO policy, the value of the superelevation AMF is 1.00. There is no effect of superelevation variance on crash frequency until the superelevation variance exceeds 0.01. The general functional form of an AMF for superelevation variance is based on the work of Zegeer et al[17,18].

The following relationships present the AMF for superelevation variance:

$$AMF_{4r} = 1.00 \text{ for } SV < 0.01 \tag{10-14}$$

$$AMF_{4r} = 1.00 + 6 \times (SV - 0.01) \text{ for } 0.01 \leq SV < 0.02 \tag{10-15}$$

$$AMF_{4r} = 1.06 + 3 \times (SV - 0.02) \text{ for } SV \geq 0.02 \tag{10-16}$$

Where,

AMF_{4r} = Accident Modification Factor for the effect of superelevation variance on total accidents;

SV = superelevation variance (ft/ft), which represents the superelevation rate contained in the AASHTO Green Book minus the actual superelevation of the curve.

AMF_{4r} applies to total roadway segment accidents for roadway segments located on horizontal curves.

AMF_{5r} - Grades

The fifth of 12 AMFs for two-lane rural road segments is an AMF for grades.

The base condition for grade is a generally level roadway. Exhibit 10-19 presents the AMF for grades based on an analysis of rural two-lane two-way highway grades in Utah conducted by Miaou[7]. The AMFs in Exhibit 10-19 are applied to each individual grade segment on the roadway being evaluated without respect to the sign of the grade. The sign of the grade is irrelevant because each grade on a rural two-lane two-way highway is an upgrade for one direction of travel and a downgrade for the other. The grade factors are applied to the entire grade from one point of vertical intersection (PVI) to the next (i.e., there is no special account taken of vertical curves). The AMFs in Exhibit 10-19 apply to total roadway segment accidents.

Exhibit 10-19: Accident Modification Factors (AMF_{5r}) for Grade of Roadway Segments

Approximate Grade (%)		
Level Grade (≤ 3%)	Moderate Terrain (3%< grade ≤ 6%)	Steep Terrain (> 6%)
1.00	1.10	1.16

The sixth of 12 AMFs for two-lane rural road segments is an AMF for driveway density.

AMF_{6r} - Driveway Density

The base condition for driveway density is five driveways per mile. As with the other AMFs, the model for the base condition was established for roadways with this driveway density. The AMF for driveway density is determined using Equation 10-17, derived from the work of Muskaug[8]:

Equation 10-17 is used to determine the AMF for driveway density.

For DD< 5

AMF = 1.0

$$AMF_{6r} = \frac{0.322 + DD \times [0.05 - 0.005 \times ln(AADT)]}{0.322 + 5 \times [0.05 - 0.005 \times ln(AADT)]} \quad (10\text{-}17)$$

Where,

AMF_{6r} = Accident Modification Factor for the effect of driveway density on total accidents;

AADT = average annual daily traffic volume of the roadway being evaluated (vehicles per day);

DD = driveway density considering driveways on both sides of the highway (driveways/mile).

If driveway density is less than 5 driveways per mile, AMF_{6r} is 1.00. Equation 10-17 can be applied to total roadway accidents of all severity levels.

Driveways serving all types of land use are considered in determining the driveway density. All driveways that are used by traffic on at least a daily basis for entering or leaving the highway are considered. Driveways that receive only occasional use (less than daily), such as field entrancesare not considered.

The seventh of 12 AMFs for two-lane rural road segments is an AMF for centerline rumble strips.

AMF_{7r} - Centerline Rumble Strips

Centerline rumble strips are installed on undivided highways along the centerline of the roadway which divides opposing directions of traffic flow. Centerline rumble strips are incorporated in the roadway surface to alert drivers who unintentionally cross, or begin to cross, the roadway centerline. The base condition for centerline rumble strips is the absence of rumble strips.

The value of AMF_{7r} for the effect of centerline rumble strips for total crashes on rural two-lane two-way highways is derived as 0.94 from the AMF value presented in *Chapter 13* and crash type percentages found in Chapter 10. Details of this derivation are not provided.

The AMF for centerline rumble strips applies only to two-lane undivided highways with no separation other than a centerline marking between the lanes in opposite directions of travel. Otherwise the value of this AMF is 1.00.

AMF_{8r} - Passing Lanes

The base condition for passing lanes is the absence of a lane (i.e., the normal two-lane cross section). The AMF for a conventional passing or climbing lane added in one direction of travel on a rural two-lane two-way highway is 0.75 for total accidents in both directions of travel over the length of the passing lane from the upstream end of the lane addition taper to the downstream end of the lane drop taper. This value assumes that the passing lane is operationally warranted and that the length of the passing lane is appropriate for the operational conditions on the roadway. There may also be some safety benefit on the roadway downstream of a passing lane, but this effect has not been quantified.

The eighth of 12 AMFs for two-lane rural road segments is an AMF for passing lanes.

The AMF for short four-lane sections (i.e., side-by-side passing lanes provided in opposite directions on the same section of roadway) is 0.65 for total accidents over the length of the short four-lane section. This AMF applies to any portion of roadway where the cross section has four lanes and where both added lanes have been provided over a limited distance to increase passing opportunities. This AMF does not apply to extended four-lane highway sections.

The AMF for passing lanes is based primarily on the work of Harwood and St.John[(5)], with consideration also given to the results of Rinde[(10)] and Nettleblad[(9)]. The AMF for short four-lane sections is based on the work of Harwood and St. John [(5)].

AMF_{9r} - Two-Way Left-Turn Lanes

The installation of a center two-way left-turn lane (TWLTL) on a rural two-lane two-way highway to create a three-lane cross-section can reduce accidents related to turning maneuvers at driveways. The base condition for two-way left-turn lanes is the absence of a TWLTL. The AMF for installation of a TWLTL is:

The ninth of 12 AMFs for two-lane rural road segments is an AMF for two-way left-turn lanes.

$$AMF_{9r} = 1.0 - \left(0.7 \times p_{dwy} \times p_{LT/D}\right) \quad (10\text{-}18)$$

Where,

AMF_{9r} = Accident Modification Factor for the effect of two-way left-turn lanes on total accidents;

p_{dwy} = driveway-related accidents as a proportion of total accidents;

$p_{LT/D}$ = left-turn accidents susceptible to correction by a TWLTL as a proportion of driveway-related accidents.

The value of p_{dwy} can be estimated using the following equation[(6)]

$$p_{dwy} = \frac{\left(0.0047 \times DD\right) + \left(0.0024 \times DD^{(2)}\right)}{1.199 + \left(0.0047 \times DD\right) + \left(0.0024 \times DD^{(2)}\right)} \quad (10\text{-}19)$$

Where,

p_{dwy} = driveway-related accidents as a proportion of total accidents;

DD = driveway density considering driveways on both sides of the highway (driveways/mile).

The value of $p_{LT/D}$ is estimated as 0.5.[(6)]

Equation 10-18 provides the best estimate of the AMF for TWLTL installation that can be made without data on the left-turn volumes within the TWLTL.

Realistically, such volumes are seldom available for use in such analyses though Section A.1. of the Appendix to *Part C* describes how to appropriately calibrate this value. This AMF applies to total roadway segment accidents.

The AMF for TWLTL installation is not applied unless the driveway density is greater than or equal to five driveways per mile. If the driveway density is less than five driveways per mile, the AMF for TWLTL installation is 1.00.

The tenth of 12 AMFs for two-lane rural road segments is AMF for roadside design.

AMF_{10r} - Roadside Design

For purposes of the HSM predictive method, the level of roadside design is represented by the roadside hazard rating (1-7 scale) developed by Zegeer et al.[15]. The AMF for roadside design was developed in research by Harwood et al[4]. The base value of roadside hazard rating for roadway segmen ts is 3. The AMF is:

$$AMF_{10r} = \frac{e^{(-0.6869+0.0668\times RHR)}}{e^{(-0.4865)}} \qquad (10\text{-}20)$$

Where,

AMF_{10r} = Accident Modification Factor for the effect of roadside design;

RHR = roadside hazard rating.

This AMF applies to total roadway segment accidents. Photographic examples and quantitative definitions for each roadside hazard rating (1 through 7) as a function of roadside design features such as side slope and clear zone width are presented in *Chapter 13* Appendix A.

AMF_{11r} - Lighting

The eleventh of 12 AMFs for two-lane rural road segments is an AMF for lighting.

The base condition for lighting is the absence of roadway segment lighting. The AMF for lighted roadway segments is determined, based on the work of Elvik and Vaa[1], as:

$$AMF_{11r} = 1.0 - [(1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr}) \times p_{nr}] \qquad (10\text{-}21)$$

Where,

AMF_{11r} = Accident Modification Factor for the effect of lighting on total accidents;

p_{inr} = proportion of total nighttime accidents for unlighted roadway segments that involve a fatality or injury;

p_{pnr} = proportion of total nighttime accidents for unlighted roadway segments that involve property damage only;

p_{nr} = proportion of total accidents for unlighted roadway segments that occur at night.

This AMF applies to total roadway segment accidents. Exhibit 10-20 presents default values for the nighttime accident proportions p_{inr}, p_{pnr}, and p_{nr}. HSM users are encouraged to replace the estimates in Exhibit 10-20 with locally derived values. If lighting installation increases the density of roadside fixed objects, the value of AMF_{10r} is adjusted accordingly.

Exhibit 10-20: Nighttime Accident Proportions for Unlighted Roadway Segments

Roadway Type	Proportion of total nighttime accidents by severity level		Proportion of accidents that occur at night
	Fatal and Injury p_{inr}	PDO p_{pnr}	p_{nr}
2U	0.382	0.618	0.370

NOTE: Based on HSIS data for Washington (2002-2006)

AMF_{12r} - Automated Speed Enforcement

The twelfth of 12 AMFs for two-lane rural road segments is an AMF for automated speed enforcement.

Automated speed enforcement systems use video or photographic identification in conjunction with radar or lasers to detect speeding drivers. These systems automatically record vehicle identification information without the need for police officers at the scene. The base condition for automated speed enforcement is that it is absent.

The value of AMF_{12r} for the effect of automated speed enforcement for total crashes on rural two-lane two-way highways is derived as 0.93 from the AMF value presented in *Chapter 17* and crash type percentages found in Chapter 10. Details of this derivation are not provided.

10.7.2. Accident Modification Factors for Intersections

Section 10.7.2 presents AMFs for intersections on two-lane rural roads.

The effects of individual geometric design and traffic control features of intersections are represented in the predictive models by AMFs. The AMFs for intersection skew angle, left-turn lanes, right-turn lanes and lighting are presented below. Each of the AMFs applies to total crashes.

AMF_{1i} - Intersection Skew Angle

The first of four AMFs for intersections on two-lane rural roads is an AMF for intersection skew angle.

The base condition for intersection skew angle is 0 degrees of skew (i.e., an intersection angle of 90 degrees). The skew angle for an intersection was defined as the absolute value of the deviation from an intersection angle of 90 degrees. The absolute value is used in the definition of skew angle because positive and negative skew angles are considered to have similar detrimental effect(4). This is illustrated in *Chapter 14* Section 14.6.2.

Three-Leg Intersections with Stop-Control on the Minor Approach

The AMF for intersection angle at three-leg intersections with stop-control on the minor approach is:

$$AMF_{1i} = e^{(0.004 \times SKEW)} \qquad (10\text{-}22)$$

Where,

AMF_{1i} = Accident Modification Factor for the effect of intersection skew on total accidents;

SKEW = intersection skew angle (in degrees); the absolute value of the difference between 90 degrees and the actual intersection angle.

This AMF applies to total intersection accidents.

Four-Leg Intersections with Stop-Control on the Minor Approaches

The AMF for intersection angle at four-leg intersection with stop-control on the minor approaches is:

$$AMF_{1i} = e^{(0.0054 \times SKEW)} \qquad (10\text{-}23)$$

Where,

AMF_{1i} = Accident Modification Factor for the effect of intersection skew on total accidents;

SKEW = intersection skew angle (in degrees); the absolute value of the difference between 90 degrees and the actual intersection angle.

This AMF applies to total intersection accidents.

If the skew angle differs for the two minor road legs at a four-leg stop-controlled intersection, values of AMF_{1i} is computed separately for each minor road leg and then averaged.

Four-leg Signalized Intersections

Since the traffic signal separates most movements from conflicting approaches, the risk of collisions related to the skew angle between the intersecting approaches is limited at a signalized intersection. Therefore, the AMF for skew angle at four-leg signalized intersections is 1.00 for all cases.

The second of four AMFs for intersections on two-lane rural roads is an AMF for intersection left-turn lanes.

AMF_{2i} - Intersection Left-Turn Lanes

The base condition for intersection left-turn lanes is the absence of left-turn lanes on the intersection approaches. The AMFs for the presence of left-turn lanes are presented in Exhibit 10-21. These AMFs apply to installation of left-turn lanes on any approach to a signalized intersection, but only on uncontrolled major road approaches to a stop-controlled intersection. The AMFs for installation of left-turn lanes on multiple approaches to an intersection are equal to the corresponding AMF for the installation of a left-turn lane on one approach raised to a power equal to the number of approaches with left-turn lanes. There is no indication of any safety effect of providing a left-turn lane on an approach controlled by a stop sign, so the presence of a left-turn lane on a stop-controlled approach is not considered in applying Exhibit 10-21. The AMFs for installation of left-turn lanes are based on research by Harwood et al.[(4)] and are consistent with the AMFs presented in *Chapter 14*. An AMF of 1.00 is always be used when no left-turn lanes are present.

Exhibit 10-21: Accident Modification Factors (AMF_{2i}) for Installation of Left-Turn Lanes on Intersection Approaches.

Intersection type	Intersection traffic control	Number of approaches with left-turn lanes [a]			
		One approach	Two approaches	Three approaches	Four approaches
Three-leg intersection	Minor road stop control[b]	0.56	0.31	—	—
Four-leg intersection	Minor road stop control[b]	0.72	0.52	—	—
	Traffic signal	0.82	0.67	0.55	0.45

NOTE: [a] Stop-controlled approaches are not considered in determining the number of approaches with left-turn lanes
[b] Stop signs present on minor road approaches only.

AMF_{3i} - Intersection Right-Turn Lanes

The third of four AMFs for intersections on two-lane rural roads is an AMF for intersection right-turn lanes.

The base condition for intersection right-turn lanes is the absence of right-turn lanes on the intersection approaches. The AMF for the presence of right-turn lanes is based on research by Harwood et al.[(4)] and is consistent with the AMFs in *Chapter 14*. These AMFs apply to installation of right-turn lanes on any approach to a signalized intersection, but only on uncontrolled major road approaches to stop-controlled intersections. The AMFs for installation of right-turn lanes on multiple approaches to an intersection are equal to the corresponding AMF for installation of a right-turn lane on one approach raised to a power equal to the number of approaches with right-turn lanes. There is no indication of any safety effect for providing a right-turn lane on an approach controlled by a stop sign, so the presence of a right-turn lane on a stop-controlled approach is not considered in applying Exhibit 10-22. The AMFs in the exhibit apply to total intersection accidents. An AMF value of 1.00 is always be used when no right-turn lanes are present. This AMF applies only to right-turn lanes that are identified by marking or signing. The AMF is not applicable to long tapers, flares, or paved shoulders that may be used informally by right-turn traffic.

Exhibit 10-22: Accident Modification Factors (AMF_{3i}) for Right-Turn Lanes on Approaches to an Intersection on Rural Two-Lane Two-Way Highways.

Intersection type	Intersection traffic control	Number of approaches with right-turn lanes [a]			
		One approach	Two approaches	Three approaches	Four approaches
Three-leg intersection	Minor road stop control[b]	0.86	0.74	–	–
Four-leg intersection	Minor road stop control[b]	0.86	0.74	—	—
	Traffic signal	0.96	0.92	0.88	0.85

NOTE: [a] Stop-controlled approaches are not considered in determining the number of approaches with right-turn lanes.
[b] Stop signs present on minor road approaches only.

The fourth of four AMFs for intersections on two-lane rural roads is an AMF for lighting.

AMF_{4i} - Lighting

The base condition for lighting is the absence of intersection lighting. The AMF for lighted intersections is adapted from the work of Elvik and Vaa [1], as:

$$AMF_{4i} = 1 - 0.38 \times p_{ni} \qquad (10\text{-}24)$$

Where,

AMF_{4i} = Accident Modification Factor for the effect of lighting on total accidents;

p_{ni} = proportion of total accidents for unlighted intersections that occur at night.

This AMF applies to total intersection accidents. Exhibit 10-23 presents default values for the nighttime accident proportion p_{ni}. HSM users are encouraged to replace the estimates in Exhibit 10-23 with locally derived values.

Exhibit 10-23: Nighttime Accident Proportions for Unlighted Intersections

Intersection Type	Proportion of accidents that occur at night p_{ni}
3ST	0.260
4ST	0.244
4SG	0.286

Based on HSIS data for California (2002-2006)

10.8. CALIBRATION OF THE SPFS TO LOCAL CONDITIONS

In Step 10 of the predictive method, presented in Section 10.4, the predictive model is calibrated to local state or geographic conditions. Accident frequencies, even for nominally similar roadway segments or intersections, can vary widely from one jurisdiction to another. Geographic regions differ markedly in climate, animal population, driver populations, accident reporting threshold, and accident reporting practices. These variations may result in some jurisdictions experiencing a different number of reported traffic accidents on rural two-lane two-way roads than others. Calibration factors are included in the methodology to allow highway agencies to adjust the SPFs to match actual local conditions.

The calibration procedures are presented in the Appendix to Part C.

The calibration factors for roadway segments and intersections (defined as C_r and C_i, respectively) will have values greater than 1.0 for roadways that, on average, experience more accidents than the roadways used in the development of the SPFs. The calibration factors for roadways that experience fewer accidents on average than the roadways used in the development of the SPFs will have values less than 1.0. The calibration procedures are presented in the Appendix to *Part C*.

Calibration factors provide one method of incorporating local data to improve estimated accident frequencies for individual agencies or locations. Several other default values used in the predictive method, such as collision type distribution, can also be replaced with locally derived values. The derivation of values for these parameters is addressed in the calibration procedure in the Appendix to *Part C*.

10.9. LIMITATIONS OF PREDICTIVE METHOD IN CHAPTER 10

This section discusses limitations of the specific predictive models and the application of the predictive method in Chapter 10.

Limitations of the predictive method which apply generally across all of the Part C chapters are discussed in Section C.14 of the Part C Introduction and Applications Guidance chapter.

Where rural two-lane two-way roads intersect access-controlled facilities (i.e., freeways), the grade-separated interchange facility, including the two-lane road within the interchange area, cannot be addressed with the predictive method for rural two-lane two-way roads.

The SPFs developed for Chapter 10 do not include signalized three-leg intersection models. Such intersections are occasionally found on rural two-lane two-way roads.

10.10. APPLICATION OF CHAPTER 10 PREDICTIVE METHOD

The predictive method presented in Chapter 10 applies to rural two-lane two-way roads. The predictive method is applied to a rural two-lane two-way facility by following the 18 steps presented in Section 10.4. Appendix A provides a series of worksheets for applying the predictive method and the predictive models detailed in this chapter. All computations within these worksheets are conducted with values expressed to three decimal places. This level of precision is needed for consistency in computations. In the last stage of computations, rounding the final estimate of expected average crash frequency to one decimal place is appropriate.

10.11. SUMMARY

The predictive method can be used to estimate the expected average crash frequency for a series of contiguous sites (entire rural two-lane two-way facility), or a single individual site. A rural two-lane two-way facility is defined in Section 10.3, and consists of a two-lane two-way undivided road which does not have access control and is outside of cities or towns with a population greater than 5,000 persons. Two-lane two-way undivided roads that have occasional added lanes to provide additional passing opportunities can also be addressed with the Chapter 10 predictive method.

The predictive method for rural two-lane two-way roads is applied by following the 18 steps of the predictive method presented in Section 10.4. Predictive models, developed for rural two-lane two-way facilities, are applied in Steps 9, 10, and 11 of the method. These predictive models have been developed to estimate the predicted average crash frequency of an individual site which is an intersection or homogenous roadway segment. The facility is divided into these individual sites in Step 5 of the predictive method.

Each predictive model in Chapter 10 consists of a Safety Performance Function (SPF), Accident Modification Factors (AMFs), and a calibration factor. The SPF is selected in Step 9, and is used to estimate the predicted average crash frequency for a site with base conditions. The estimate can be for total crashes, or by crash severity or collision type distribution. In order to account for differences between the base conditions and the specific conditions of the site, AMFs are applied in Step 10, which adjust the prediction to account for the geometric design and traffic control features of the site. Calibration factors are also used to adjust the prediction to local conditions in the jurisdiction where the site is located. The process for determining calibration factors for the predictive models is described in the *Part C* Appendix A.1.

Section 10.12 presents 6 sample problems which detail the application of the predictive method. Appendix A contains worksheets which can be used in the calculations for the predictive method steps.

10.12. SAMPLE PROBLEMS

In this section, six sample problems are presented using the predictive method for rural two-lane two-way roads. Sample Problems 1 and 2 illustrate how to calculate the predicted average crash frequency for rural two-lane roadway segments. Sample Problem 3 illustrates how to calculate the predicted average crash frequency for a stop-controlled intersection. Sample Problem 4 illustrates a similar calculation for a signalized intersection. Sample Problem 5 illustrates how to combine the results from Sample Problems 1 through 3 in a case where site-specific observed crash data are available (i.e. using the site-specific EB Method). Sample Problem 6 illustrates how to combine the results from Sample Problems 1 through 3 in a case where site-specific observed crash data are not available but project-level observed crash data are available (i.e. using the project-level EB Method).

Exhibit 10-24: List of Sample Problems in Chapter 10

Problem No.	Page No.	Description
1	10-44	Predicted average crash frequency for a tangent roadway segment
2	10-53	Predicted average crash frequency for a curved roadway segment
3	10-62	Predicted average crash frequency for a three-leg stop-controlled intersection
4	10-70	Predicted average crash frequency for a four-leg signalized intersection
5	10-77	Expected average crash frequency for a facility when site-specific observed crash data are available
6	10-81	Expected average crash frequency for a facility when site-specific observed crash data are not available

10.12.1. Sample Problem 1

The Site/Facility

A rural two-lane tangent roadway segment.

The Question

What is the predicted average crash frequency of the roadway segment for a particular year?

The Facts

- 1.5-mi length
- Tangent roadway segment
- 10,000 veh/day
- 2% grade
- 6 driveways per mi
- 10-ft lane width
- 4-ft gravel shoulder
- Roadside hazard rating = 4

Assumptions

- Collision type distributions used are the default values presented in Exhibit 10-7.
- The calibration factor is assumed to be 1.10.

Results

Using the predictive method steps as outlined below, the predicted average crash frequency for the roadway segment in Sample Problem 1 is determined to be 6.1 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8

To determine the predicted average crash frequency of the roadway segment in Sample Problem 1, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year, and the EB Method is not applied.

Step 9 – For the selected site, determine and apply the appropriate Safety Performance Function (SPF) for the site's facility type and traffic control features.

The SPF for a single roadway segment can be calculated from Equation 10-6 as follows:

$$N_{spr\ rf} = AADT \times L \times 365 \times 10^{-6} \times e^{(-0.312)}$$

$$= 10{,}000 \times 1.5 \times 365 \times 10^{-6} \times e^{(-0.312)}$$

$$= 4.008 \text{ crashes/year}$$

Step 10 – Multiply the result obtained in Step 9 by the appropriate AMFs to adjust the estimated crash frequency for base conditions to the site-specific geometric design and traffic control features.

Each AMF used in the calculation of the predicted average crash frequency of the roadway segment is calculated below:

Lane Width (AMF_{1r})

AMF_{1r} can be calculated from Equation 10-11 as follows:

$$AMF_{1r} = (AMF_{ra} - 1.0) \times p_{ra} + 1.0$$

For a 10-ft lane width and AADT of 10,000, AMF_{ra} = 1.30 (see Exhibit 10-14).

The proportion of related crashes, p_{ra}, is 0.574 (see discussion below Equation 10-11).

$$AMF_{1r} = (1.3 - 1.0) \times 0.574 + 1.0$$

$$= 1.17$$

Shoulder Width and Type (AMF_{2r})

AMF_{2r} can be calculated from Equation 10-12, using values from Exhibit 10-16, Exhibit 10-18 and Exhibit 10-7 as follows:

$$AMF_{2r} = (AMF_{wra} \times AMF_{ra} - 1.0) \times p_{ra} + 1.0$$

For 4-ft shoulders and AADT of 10,000, AMF_{wra} = 1.15 (see Exhibit 10-16).

For 4-ft gravel shoulders, AMF_{tra} = 1.01 (see Exhibit 10-18).

The proportion of related crashes, p_{ra}, is 0.574 (see discussion below Equation 10-12).

$$AMF_{2r} = (1.15 \times 1.01 - 1.0) \times 0.574. + 1.0$$

$$= 1.09$$

Horizontal Curves: Length, Radius, and Presence or Absence of Spiral Transitions (AMF_{3r})

Since the roadway segment in Sample Problem 1 is a tangent, AMF_{3r} = 1.00 (i.e. the base condition for AMF_{3r} is no curve).

Horizontal Curves: Superelevation (AMF_{4r})

Since the roadway segment in Sample Problem 1 is a tangent, and therefore has no superelevation, AMF_{4r} = 1.00.

Grade (AMF_{5r})

From Exhibit 10-19, for a 2% grade, AMF_{5r} = 1.00

Driveway Density (AMF_{6r})

The driveway density, DD, is 6 driveways per mile. AMF_{6r} can be calculated using Equation 10-17 as follows:

$$AMF_{6r} = \frac{0.322 + DD \times [0.05 - 0.005 \times ln(AADT)]}{0.322 + 5 \times [0.05 - 0.005 \times ln(AADT)]}$$

$$= \frac{0.322 + 6 \times [0.05 - 0.005 \times ln(10{,}000)]}{0.322 + 5 \times [0.05 - 0.005 \times ln(10{,}000)]}$$

$$= 1.01$$

Centerline Rumble Strips (AMF_{7r})

Since there are no centerline rumble strips in Sample Problem 1, AMF_{7r} = 1.00 (i.e. the base condition for AMF_{7r} is no centerline rumble strips).

Passing Lanes (AMF_{8r})

Since there are no passing lanes in Sample Problem 1, AMF_{8r} = 1.00 (i.e. the base condition for AMF_{8r} is the absence of a passing lane).

Two-Way Left-Turn Lanes (AMF_{9r})

Since there are no two-way left-turn lanes in Sample Problem 1, AMF_{9r} = 1.00 (i.e. the base condition for AMF_{9r} is the absence of a two-way left-turn lane).

Roadside Design (AMF_{10r})

The roadside hazard rating, RHR, in Sample Problem 1 is 4. AMF_{10r} can be calculated from Equation 10-20 as follows:

$$AMF_{10r} = \frac{e^{(-0.6869+0.0668\times RHR)}}{e^{(-0.4865)}}$$

$$= \frac{e^{(-0.6869+0.0668\times 4)}}{e^{(-0.4865)}}$$

$$= 1.07$$

Lighting (AMF_{11r})

Since there is no lighting in Sample Problem 1, AMF_{11r} = 1.00 (i.e. the base condition for AMF_{11r} is the absence of roadway lighting).

Automated Speed Enforcement (AMF_{12r})

Since there is no automated speed enforcement in Sample Problem 1, AMF_{12r} = 1.00 (i.e. the base condition for AMF_{12r} is the absence of automated speed enforcement).

The combined AMF value for Sample Problem 1 is calculated below.

$$AMF_{COMB} = 1.17 \times 1.09 \times 1.01 \times 1.07$$

$$= 1.38$$

Step 11 – Multiply the result obtained in Step 10 by the appropriate calibration factor.

It is assumed a calibration factor, C_r, of 1.10 has been determined for local conditions. See *Part C* Appendix A.1 for further discussion on calibration of the predictive models.

Calculation of Predicted Average Crash Frequency

The predicted average crash frequency is calculated using Equation 10-2 based on the results obtained in Steps 9 through 11 as follows:

$$N_{predicted\ rs} = N_{spf\ rs} \times C_r \times (AMF_{1r} \times AMF_{2r} \times \ldots \times AMF_{12r})$$

$$= 4.008 \times 1.10 \times (1.38)$$

$$= 6.084 \text{ crashes/year}$$

Worksheets

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for a roadway segment. To apply the predictive method steps to multiple segments, a series of five worksheets are provided for determining predicted average crash frequency. The five worksheets include:

- Worksheet 1A – General Information and Input Data for Rural Two-Lane Two-Way Roadway Segments
- Worksheet 1B – Accident Modification Factors for Rural Two-Lane Two-Way Roadway Segments

- Worksheet 1C – Roadway Segment Crashes for Rural Two-Lane Two-Way Roadway Segments
- Worksheet 1D – Crashes by Severity Level and Collision Type for Rural Two-Lane Two-Way Roadway Segments
- Worksheet 1E – Summary Results for Rural Two-Lane Two-Way Roadway Segments

Details of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 10 Appendix A.

Worksheet 1A – General Information and Input Data for Rural Two-Lane Two-Way Roadway Segments

Worksheet 1A is a summary of general information about the roadway segment, analysis, input data (i.e., "The Facts") and assumptions for Sample Problem 1.

Worksheet 1A – General Information and Input Data for Rural Two-Lane Two-Way Roadway Segments

General Information		**Location Information**	
Analyst		Roadway	
Agency or Company		Roadway Section	
Date Performed		Jurisdiction	
		Analysis Year	

Input Data	**Base Conditions**	**Site Conditions**
Length of segment, L (mi)	-	1.5
AADT (veh/day)	-	10,000
Lane width (ft)	12	10
Shoulder width (ft)	6	4
Shoulder type	paved	Gravel
Length of horizontal curve (mi)	0	not present
Radius of curvature (ft)	0	not present
Spiral transition curve (present/not present)	not present	not present
Superelevation variance (ft/ft)	<0.01	not present
Grade (%)	0	2
Driveway density (driveways/mile)	5	6
Centerline rumble strips (present/not present)	not present	not present
Passing lanes (present/not present)	not present	not present
Two-way left-turn lane (present/not present)	not present	not present
Roadside hazard rating (1-7 scale)	3	4
Segment lighting (present/not present)	not present	not present
Auto speed enforcement (present/not present)	not present	not present
Calibration Factor, C_r	1.0	1.1

Worksheet 1B – Accident Modification Factors for Rural Two-Lane Two-Way Roadway Segments

In Step 10 of the predictive method, Accident Modification Factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 10.7 presents the tables and equations necessary for determining AMF values. Once the value for each AMF has been determined, all of the AMFs are multiplied together in Column 13 of Worksheet 1B which indicates the combined AMF value.

Worksheet 1B – Accident Modification Factors for Rural Two-Lane Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
AMF for Lane Width	AMF for Shoulder Width and Type	AMF for Horizontal Curves	AMF for Superelevation	AMF for Grades	AMF for Driveway Density	AMF for Centerline Rumble Strips	AMF for Passing Lanes	AMF for Two-Way Left-Turn Lane	AMF for Roadside Design	AMF for Lighting	AMF for Automated Speed Enforcement	Combined AMF
AMF_{1r}	AMF_{2r}	AMF_{3r}	AMF_{4r}	AMF_{5r}	AMF_{6r}	AMF_{7r}	AMF_{8r}	AMF_{9r}	AMF_{10r}	AMF_{11r}	AMF_{12r}	AMF_{COMB}
from Equation 10-11	from Equation 10-12	from Equation 10-13	from Equations 10-14, 10-15, or 10-16	from Exhibit 10-19	from Equation 10-17	from Section 10.7.1	from Section 10.7.1	from Equation 10-18	from Equation 10-20	from Equation 10-21	from Section 10.7.1	(1)*(2)*… *(11)*(12)
1.17	1.09	1.00	1.00	1.00	1.01	1.00	1.00	1.00	1.07	1.00	1.00	1.38

Worksheet 1C – Roadway Segment Crashes for Rural Two-Lane Two-Way Roadway Segments

The SPF for the roadway segment in Sample Problem 1 is calculated using Equation 10-6 and entered into Column 2 of Worksheet 1C. The overdispersion parameter associated with the SPF can be entered into Column 3; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized). Column 4 of the worksheet presents the default proportions for crash severity levels from Exhibit 10-6. These proportions may be used to separate the SPF (from Column 2) into components by crash severity level, as illustrated in Column 5. Column 6 represents the combined AMF (from Column 13 in Worksheet 1B), and Column 7 represents the calibration factor. Column 8 calculates the predicted average crash frequency using the values in Column 5, the combined AMF in Column 6, and the calibration factor in Column 7.

Worksheet 1C – Roadway Segment Crashes for Rural Two-Lane Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	**$N_{spf\ rs}$**	**Overdispersion Parameter, k**	**Crash Severity Distribution**	**$N_{spf\ rs}$ by Severity Distribution**	**Combined AMFs**	**Calibration Factor, C_r**	**Predicted average crash frequency, $N_{predicted\ rs}$**
	from Equation 10-6	from Equation 10-7	from Exhibit 10-6	$(2)_{TOTAL}$ * (4)	(13) from Worksheet 1B		(5)*(6)*(7)
Total	4.008	0.16	1.000	4.008	1.38	1.10	6.084
Fatal and Injury (FI)	-	-	0.321	1.287	1.38	1.10	1.954
Property Damage Only (PDO)	-	-	0.679	2.721	1.38	1.10	4.131

Worksheet 1D – Crashes by Severity Level and Collision for Rural Two-Lane Two-Way Roadway Segments

Worksheet 1D presents the default proportions for collision type (from Exhibit 10-7) by crash severity level as follows:

- Total crashes (Column 2)
- Fatal and injury crashes (Column 4)
- Property damage only crashes (Column 6)

Using the default proportions, the predicted average crash frequency by collision type is presented in Columns 3 (Total), 5 (Fatal and Injury, FI) and 7 (Property Damage Only, PDO).

These proportions may be used to separate the predicted average crash frequency (from Column 8, Worksheet 1C) by crash severity and collision type.

Worksheet 1D – Crashes by Severity Level and Collision Type for Rural Two-Lane Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Collision Type	**Proportion of Collision Type (TOTAL)**	**$N_{predicted\ rs\ (TOTAL)}$ (crashes/year)**	**Proportion of Collision Type (FI)**	**$N_{predicted\ rs\ (FI)}$ (crashes/year)**	**Proportion of Collision Type (PDO)**	**$N_{predicted\ rs\ (PDO)}$ (crashes/year)**
	from Exhibit 10-7	$(8)_{TOTAL}$ from Worksheet 1C	from Exhibit 10-7	$(8)_{FI}$ from Worksheet 1C	from Exhibit 10-7	$(8)_{PDO}$ from Worksheet 1C
Total	1.000	6.084	1.000	1.954	1.000	4.131
		$(2)*(3)_{TOTAL}$		$(4)*(5)_{FI}$		$(6)*(7)_{PDO}$
SINGLE-VEHICLE						
Collision with animal	0.121	0.736	0.038	0.074	0.184	0.760
Collision with bicycle	0.002	0.012	0.004	0.008	0.001	0.004
Collision with pedestrian	0.003	0.018	0.007	0.014	0.001	0.004
Overturned	0.025	0.152	0.037	0.072	0.015	0.062
Ran off road	0.521	3.170	0.545	1.065	0.505	2.086
Other single-vehicle collision	0.021	0.128	0.007	0.014	0.029	0.120
Total single-vehicle crashes	0.693	4.216	0.638	1.247	0.735	3.036
MULTIPLE-VEHICLE						
Angle collision	0.085	0.517	0.100	0.195	0.072	0.297
Head-on collision	0.016	0.097	0.034	0.066	0.003	0.012
Rear-end collision	0.142	0.864	0.164	0.320	0.122	0.504
Sideswipe collision	0.037	0.225	0.038	0.074	0.038	0.157
Other multiple-vehicle collision	0.027	0.164	0.026	0.051	0.030	0.124
Total multiple-vehicle crashes	0.307	1.868	0.362	0.707	0.265	1.095

Worksheet 1E – Summary Results or Rural Two-Lane Two-Way Roadway Segments

Worksheet 1E presents a summary of the results. Using the roadway segment length, the worksheet presents the crash rate in miles per year (Column 5).

Worksheet 1E – Summary Results for Rural Two-Lane Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)
Crash severity level	**Crash Severity Distribution**	**Predicted average crash frequency (crashes/year)**	**Roadway segment length (mi)**	**Crash rate (crashes/mi/year)**
	(4) from Worksheet 1C	(8) from Worksheet 1C		(3)/(4)
Total	1.000	6.084	1.5	4.1
Fatal and Injury (FI)	0.321	1.954	1.5	1.3
Property Damage Only (PDO)	0.679	4.131	1.5	2.8

10.12.2. Sample Problem 2

The Site/Facility

A rural two-lane curved roadway segment.

The Question

What is the predicted average crash frequency of the roadway segment for a particular year?

The Facts

- 0.1-mi length
- Curved roadway segment
- 8,000 veh/day
- 1% grade
- 1,200-ft horizontal curve radius
- No spiral transition
- 0 driveways per mi
- 11-ft lane width
- 2-ft gravel shoulder
- Roadside hazard rating = 5
- 0.1-mi horizontal curve length
- 0.04 superelevation rate

Assumptions

- Collision type distributions have been adapted to local experience. The percentage of total crashes representing single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes is 78%.
- The calibration factor is assumed to be 1.10.
- Design speed = 60 mph
- Maximum superelevation rate, e_{max} = 6%

Results

Using the predictive method steps as outlined below, the predicted average crash frequency for the roadway segment in Sample Problem 2 is determined to be 0.5 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8

To determine the predicted average crash frequency of the roadway segment in Sample Problem 2, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year, and the EB Method is not applied.

Step 9 – For the selected site, determine and apply the appropriate Safety Performance Function (SPF) for the site's facility type and traffic control features.

The SPF for a single roadway segment can be calculated from Equation 10-6 as follows:

$$N_{spf\ rs} = AADT \times L \times 365 \times 10^{-6} \times e^{(-0.312)}$$
$$= 8{,}000 \times 0.1 \times 365 \times 10^{-6} \times e^{(-0.312)}$$
$$= 0.214 \text{ crashes/year}$$

Step 10 – Multiply the result obtained in Step 9 by the appropriate AMFs to adjust the estimated crash frequency for base conditions to the site specific geometric design and traffic control features.

Each AMF used in the calculation of the predicted average crash frequency of the roadway segment is calculated below:

Lane Width (AMF_{1r})

AMF_{1r} can be calculated from Equation 10-11 as follows:

$$AMF_{1r} = (AMF_{ra} - 1.0) \times p_{ra} + 1.0$$

For an 11-ft lane width and AADT of 8,000 veh/day, AMF_{ra} = 1.05 (see Exhibit 10-14)

The proportion of related crashes, p_{ra}, is 0.78 (see assumptions)

$$AMF_{1r} = (1.05 - 1.0) \times 0.78 + 1.0$$
$$= 1.04$$

Shoulder Width and Type (AMF_{2r})

AMF_{2r} can be calculated from Equation 10-12, using values from Exhibit 10-16, Exhibit 10-18 and local data (p_{ra} = 0.78) as follows:

$$AMF_{2r} = (AMF_{wra} \times AMF_{ra} - 1.0) \times p_{ra} + 1.0$$

For 2-ft shoulders and AADT of 8,000 veh/day, AMF_{wra} = 1.30 (see Exhibit 10-16)

For 2-ft gravel shoulders, AMF_{tra} = 1.01 (see Exhibit 10-18)

The proportion of related crashes, p_{ra}, is 0.78 (see assumptions)

$$AMF_{2r} = (1.30 \times 1.01 - 1.0) \times 0.78 + 1.0$$
$$= 1.24$$

Horizontal Curves: Length, Radius, and Presence or Absence of Spiral Transitions (AMF_{3r})

For a 0.1 mile horizontal curve with a 1,200 ft radius and no spiral transition, AMF_{3r} can be calculated from Equation 10-13 as follows:

$$AMF_{3r} = \frac{(1.55 \times L_c) + (\frac{80.2}{R}) - (0.012 \times S)}{(1.55 \times L_c)}$$

$$= \frac{(1.55 \times 0.1) + (\frac{80.2}{1200}) - (0.012 \times 0)}{(1.55 \times 0.1)}$$

$$= 1.43$$

Horizontal Curves: Superelevation (AMF_{4r})

AMF_{4r} can be calculated from Equation 10-16 as follows:

$$AMF_{4r} = 1.06 + 3 \times (SV - 0.02)$$

For a roadway segment with an assumed design speed of 60 mph and an assumed maximum superelevation (e_{max}) of 6%, AASHTO *Green Book* provides for a 0.06 superelevation rate. Since the superelevation in Sample Problem 2 is 0.04, the superelevation variance is 0.02 (0.06 - 0.04).

$$AMF_{4r} = 1.06 + 3 \times (0.02 - 0.02)$$

$$= 1.06$$

Grade (AMF_{5r})

From Exhibit 10-19, for a 1% grade, AMF_{5r} = 1.00.

Driveway Density (AMF_{6r})

Since the driveway density, DD, in Sample Problem 2 is less than 5 driveways per mile, AMF_{6r} = 1.00 (i.e. the base condition for AMF_{6r} is five driveways per mile. If driveway density is less than five driveways per mile, AMF_{6r} is 1.00).

Centerline Rumble Strips (AMF_{7r})

Since there are no centerline rumble strips in Sample Problem 2, AMF_{7r} = 1.00 (i.e. the base condition for AMF_{7r} is no centerline rumble strips).

Passing Lanes (AMF_{8r})

Since there are no passing lanes in Sample Problem 2, AMF_{8r} = 1.00 (i.e. the base condition for AMF_{8r} is the absence of a passing lane).

Two-Way Left-Turn Lanes (AMF_{9r})

Since there are no two-way left-turn lanes in Sample Problem 2, AMF_{9r} = 1.00 (i.e. the base condition for AMF_{9r} is the absence of a two-way left-turn lane).

Roadside Design (AMF_{10r})

The roadside hazard rating, RHR, is 5. Therefore, AMF_{10r} can be calculated from Equation 10-20 as follows:

$$AMF_{10r} = \frac{e^{(-0.6869+0.0668 \times RHR)}}{e^{(-0.4865)}}$$

$$= \frac{e^{(-0.6869+0.0668 \times 5)}}{e^{(-0.4865)}}$$

$$= 1.14$$

Lighting (AMF_{11r})

Since there is no lighting in Sample Problem 2, AMF_{11r} = 1.00 (i.e. the base condition for AMF_{11r} is the absence of roadway lighting).

Automated Speed Enforcement (AMF_{12r})

Since there is no automated speed enforcement in Sample Problem 2, AMF_{12r} = 1.00 (i.e. the base condition for AMF_{12r} is the absence of automated speed enforcement).

The combined AMF value for Sample Problem 2 is calculated below.

$$AMF_{COMB} = 1.04 \times 1.24 \times 1.43 \times 1.06 \times 1.14$$

$$= 2.23$$

Step 11 – Multiply the result obtained in Step 10 by the appropriate calibration factor.

It is assumed that a calibration factor, C_r, of 1.10 has been determined for local conditions. See *Part C* Appendix A.1 for further discussion on calibration of the predictive models.

Calculation of Predicted Average Crash Frequency

The predicted average crash frequency is calculated using Equation 10-2 based on the results obtained in Steps 9 through 11 as follows:

$$N_{predicted\ rs} = N_{spf\ rs} \times C_r \times (AMF_{1r} \times AMF_{2r} \times \ldots \times AMF_{12r})$$

$$= 0.214 \times 1.10 \times (2.23)$$

$$= 0.525 \text{ crashes/year}$$

Worksheets

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for a roadway segment. To apply the predictive method steps to multiple segments, a series of five worksheets are provided for determining predicted average crash frequency. The five worksheets include:

- Worksheet 1A – General Information and Input Data for Rural Two-Lane Two-Way Roadway Segments
- Worksheet 1B – Accident Modification Factors for Rural Two-Lane Two-Way Roadway Segments
- Worksheet 1C – Roadway Segment Crashes for Rural Two-Lane Two-Way Roadway Segments

- Worksheet 1D – Crashes by Severity Level and Collision Type for Rural Two-Lane Two-Way Roadway Segments
- Worksheet 1E – Summary Results for Rural Two-Lane Two-Way Roadway Segments

Details of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 10 Appendix A.

Worksheet 1A – General Information and Input Data for Rural Two-Lane Two-Way Roadway Segments

Worksheet 1A is a summary of general information about the roadway segment, analysis, input data (i.e., "The Facts") and assumptions for Sample Problem 2.

Worksheet 1A – General Information and Input Data for Rural Two-Lane Two-Way Roadway Segments

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Roadway Section	
Date Performed		Jurisdiction	
		Analysis Year	

Input Data	Base Conditions	Site Conditions
Length of segment, L (mi)	-	0.1
AADT (veh/day)	-	8,000
Lane width (ft)	12	11
Shoulder width (ft)	6	2
Shoulder type	paved	gravel
Length of horizontal curve (mi)	0	0.1
Radius of curvature (ft)	0	1,200
Spiral transition curve (present/not present)	not present	not present
Superelevation variance (ft/ft)	<0.01	0.02 (0.06-0.04)
Grade (%)	0	1
Driveway density (driveways/mile)	5	0
Centerline rumble strips (present/not present)	not present	not present
Passing lanes (present/not present)	not present	not present
Two-way left-turn lane (present/not present)	not present	not present
Roadside hazard rating (1-7 scale)	3	5
Segment lighting (present/not present)	not present	not present
Auto speed enforcement (present/not present)	not present	not present
Calibration Factor, C_r	1.0	1.1

Worksheet 1B – Accident Modification Factors for Rural Two-Lane Two-Way Roadway Segments

In Step 10 of the predictive method, Accident Modification Factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 10.7 presents the tables and equations necessary for determining AMF values. Once the value for each AMF has been determined, all of the AMFs are multiplied together in Column 13 of Worksheet 1B which indicates the combined AMF value.

Worksheet 1B – Accident Modification Factors for Rural Two-Lane Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
AMF for Lane Width	AMF for Shoulder Width and Type	AMF for Horizontal Curves	AMF for Superelevation	AMF for Grades	AMF for Driveway Density	AMF for Centerline Rumble Strips	AMF for Passing Lanes	AMF for Two-Way Left-Turn Lane	AMF for Roadside Design	AMF for Lighting	AMF for Automated Speed Enforcement	Combined AMF
AMF_{1r}	AMF_{2r}	AMF_{3r}	AMF_{4r}	AMF_{5r}	AMF_{6r}	AMF_{7r}	AMF_{8r}	AMF_{9r}	AMF_{10r}	AMF_{11r}	AMF_{12r}	AMF_{COMB}
from Equation 10-11	from Equation 10-12	from Equation 10-13	from Equations 10-14, 10-15, or 10-16	from Exhibit 10-19	from Equation 10-17	from Section 10.7.1	from Section 10.7.1	from Equation 10-18	from Equation 10-20	from Equation 10-21	from Section 10.7.1	(1)*(2)*... *(11)*(12)
1.04	1.24	1.43	1.06	1.00	1.00	1.00	1.00	1.00	1.14	1.00	1.00	2.23

Worksheet 1C – Roadway Segment Crashes for Rural Two-Lane Two-Way Roadway Segments

The SPF for the roadway segment in Sample Problem 2 is calculated using Equation 10-6 and entered into Column 2 of Worksheet 1C. The overdispersion parameter associated with the SPF can be entered into Column 3; however, the overdispersion parameter is not needed for Sample Problem 2. Column 4 of the worksheet presents the default proportions for crash severity levels from Exhibit 10-6 (as the EB Method is not utilized). These proportions may be used to separate the SPF (from Column 2) into components by crash severity level, as illustrated in Column 5. Column 6 represents the combined AMF (from Column 13 in Worksheet 1B), and Column 7 represents the calibration factor. Column 8 calculates the predicted average crash frequency using the values in Column 5, the combined AMF in Column 6, and the calibration factor in Column 7.

Worksheet 1C – Roadway Segment Crashes for Rural Two-Lane Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	**$N_{spf\ rs}$**	**Overdispersion Parameter, k**	**Crash Severity Distribution**	**$N_{spf\ rs}$ by Severity Distribution**	**Combined AMFs**	**Calibration Factor, C_r**	**Predicted average crash frequency, $N_{predicted\ rs}$**
	from Equation 10-6	from Equation 10-7	from Exhibit 10-6	$(2)_{TOTAL}$ * (4)	(13) from Worksheet 1B		(5)*(6)*(7)
Total	0.214	2.36	1.000	0.214	2.23	1.10	0.525
Fatal and Injury (FI)	-	-	0.321	0.069	2.23	1.10	0.169
Property Damage Only (PDO)	-	-	0.679	0.145	2.23	1.10	0.356

Worksheet 1D – Crashes by Severity Level and Collision for Rural Two-Lane Two-Way Roadway Segments

Worksheet 1D presents the default proportions for collision type (from Exhibit 10-6) by crash severity level as follows:

- Total crashes (Column 2)
- Fatal and injury crashes (Column 4)
- Property damage only crashes (Column 6)

Using the default proportions, the predicted average crash frequency by collision type is presented in Columns 3 (Total), 5 (Fatal and Injury, FI), and 7 (Property Damage Only, PDO).

These proportions may be used to separate the predicted average crash frequency (from Column 8, Worksheet 1C) by crash severity and collision type.

Worksheet 1D – Crashes by Severity Level and Collision Type for Rural Two-Lane Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Collision Type	**Proportion of Collision Type (TOTAL)**	**$N_{predicted\ rs\ (TOTAL)}$ (crashes/year)**	**Proportion of Collision Type (FI)**	**$N_{predicted\ rs\ (FI)}$ (crashes/year)**	**Proportion of Collision Type (PDO)**	**$N_{predicted\ rs\ (PDO)}$ (crashes/year)**
	from Exhibit 10-7	$(8)_{TOTAL}$ from Worksheet 1C	from Exhibit 10-7	$(8)_{FI}$ from Worksheet 1C	from Exhibit 10-7	$(8)_{PDO}$ from Worksheet 1C
Total	1.000	0.525	1.000	0.169	1.000	0.356
		$(2)*(3)_{TOTAL}$		$(4)*(5)_{FI}$		$(6)*(7)_{PDO}$
SINGLE-VEHICLE						
Collision with animal	0.121	0.064	0.038	0.006	0.184	0.066
Collision with bicycle	0.002	0.001	0.004	0.001	0.001	0.000
Collision with pedestrian	0.003	0.002	0.007	0.001	0.001	0.000
Overturned	0.025	0.013	0.037	0.006	0.015	0.005
Ran off road	0.521	0.274	0.545	0.092	0.505	0.180
Other single-vehicle collision	0.021	0.011	0.007	0.001	0.029	0.010
Total single-vehicle crashes	0.693	0.364	0.638	0.108	0.735	0.262
MULTIPLE-VEHICLE						
Angle collision	0.085	0.045	0.100	0.017	0.072	0.026
Head-on collision	0.016	0.008	0.034	0.006	0.003	0.001
Rear-end collision	0.142	0.075	0.164	0.028	0.122	0.043
Sideswipe collision	0.037	0.019	0.038	0.006	0.038	0.014
Other multiple-vehicle collision	0.027	0.014	0.026	0.004	0.030	0.011
Total multiple-vehicle crashes	0.307	0.161	0.362	0.061	0.265	0.094

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Worksheet 1E – Summary Results for Rural Two-Lane Two-Way Roadway Segments

Worksheet 1E presents a summary of the results. Using the roadway segment length, the worksheet presents the crash rate in miles per year (Column 5).

Worksheet 1E – Summary Results for Rural Two-Lane Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)
Crash severity level	**Crash Severity Distribution**	**Predicted average crash frequency (crashes/year)**	**Roadway segment length (mi)**	**Crash rate (crashes/mi/year)**
	(4) from Worksheet 1C	(8) from Worksheet 1C		(3)/(4)
Total	1.000	0.525	0.1	5.3
Fatal and Injury (FI)	0.321	0.169	0.1	1.7
Property Damage Only (PDO)	0.679	0.356	0.1	3.6

10.12.3. Sample Problem 3

The Site/Facility

A three-leg stop-controlled intersection located on a rural two-lane roadway.

The Question

What is the predicted average crash frequency of the stop-controlled intersection for a particular year?

The Facts

- 3 legs
- Minor-road stop control
- No right-turn lanes on major road
- No left-turn lanes on major road
- 30-degree skew angle
- AADT of major road = 8,000 veh/day
- AADT of minor road = 1,000 veh/day
- Intersection lighting is present

Assumptions

- Collision type distributions used are the default values from Exhibit 10-12.
- The proportion of crashes that occur at night are not known, so the default proportion for nighttime crashes is assumed.
- The calibration factor is assumed to be 1.50.

Results

Using the predictive method steps as outlined below, the predicted average crash frequency for the intersection in Sample Problem 3 is determined to be 2.9 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8

To determine the predicted average crash frequency of the intersection in Sample Problem 3, only Steps 9 through 11 are conducted. No other steps are necessary because only one intersection is analyzed for one year, and the EB Method is not applied.

Step 9 – For the selected site, determine and apply the appropriate Safety Performance Function (SPF) for the site's facility type and traffic control features.

The SPF for a single three-leg stop-controlled intersection can be calculated from Equation 10-8 as follows:

$$N_{spf\ 3ST} = exp[-9.86 + 0.79 \times ln(AADT_{maj}) + 0.49 \times ln(AADT_{min})]$$

$$= exp[-9.86 + 0.79 \times ln(8{,}000) + 0.49 \times ln(1{,}000)]$$

$$= 1.867 \text{ crashes/year}$$

Step 10 – Multiply the result obtained in Step 9 by the appropriate AMFs to adjust the estimated crash frequency for base conditions to the site specific geometric design and traffic control features.

Each AMF used in the calculation of the predicted average crash frequency of the intersection is calculated below:

Intersection Skew Angle (AMF_{1i})

AMF_{1i} can be calculated from Equation 10-22 as follows:

$$AMF_{1i} = e^{(0.004 \times SKEW)}$$

The intersection skew angle for Sample Problem 3 is 30 degrees.

$$AMF_{1i} = e^{(0.004 \times 30)}$$

$$= 1.13$$

Intersection Left-Turn Lanes (AMF_{2i})

Since no left-turn lanes are present in Sample Problem 3, AMF_{2i} = 1.00 (i.e. the base condition for AMF_{2i} is the absence of left-turn lanes on the intersection approaches).

Intersection Right-Turn Lanes (AMF_{3i})

Since no right-turn lanes are present, AMF_{3i} = 1.00 (i.e. the base condition for AMF_{3i} is the absence of right-turn lanes on the intersection approaches).

Lighting (AMF_{4i})

AMF_{4i} can be calculated from Equation 10-24 using Exhibit 10-23.

$$AMF_{4i} = 1 - 0.38 \times p_{ni}$$

From Exhibit 10-23, for a three-leg stop-controlled intersection, the proportion of total accidents that occur at night (see assumption), p_{ni}, is 0.26.

$$AMF_{4i} = 1 - 0.38 \times 0.26$$

$$= 0.90$$

The combined AMF value for Sample Problem 3 is calculated below.

$$AMF_{COMB} = 1.13 \times 0.90$$

$$= 1.02$$

Step 11 – Multiply the result obtained in Step 10 by the appropriate calibration factor.

It is assumed that a calibration factor, C_i, of 1.50 has been determined for local conditions. See *Part C* Appendix A.1 for further discussion on calibration of the predictive models.

Calculation of Predicted Average Crash Frequency

The predicted average crash frequency is calculated using Equation 10-3 based on the results obtained in Steps 9 through 11 as follows:

$$N_{predicted\ int} = N_{spf\ int} \times C_i \times (AMF_{1i} \times AMF_{2i} \times \ldots \times AMF_{4i})$$

$$= 1.867 \times 1.50 \times (1.02)$$

$$= 2.857 \text{ crashes/year}$$

Worksheets

The step-by-step instructions above are the predictive method for calculating the predicted average crash frequency for an intersection. To apply the predictive method steps to multiple intersections, a series of five worksheets are provided for determining predicted average crash frequency. The five worksheets include:

- Worksheet 2A – General Information and Input Data for Rural Two-Lane Two-Way Road Intersections
- Worksheet 2B – Accident Modification Factors for Rural Two-Lane Two-Way Road Intersections
- Worksheet 2C – Intersection Crashes for Rural Two-Lane Two-Way Road Intersections
- Worksheet 2D – Crashes by Severity Level and Collision Type for Rural Two-Lane Two-Way Road Intersections
- Worksheet 2E – Summary Results for Rural Two-Lane Two-Way Road Intersections

Details of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 10 Appendix A.

Worksheet 2A – General Information and Input Data for Rural Two-Lane Two-Way Road Intersections

Worksheet 2A is a summary of general information about the intersection, analysis, input data (i.e., "The Facts") and assumptions for Sample Problem 3.

Worksheet 2A – General Information and Input Data for Rural Two-Lane Two-Way Road Intersections

General Information		**Location Information**	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	

Input Data	**Base Conditions**	**Site Conditions**
Intersection type (3ST, 4ST, 4SG)	-	3ST
$AADT_{major}$ (veh/day)	-	8,000
$AADT_{minor}$ (veh/day)	-	1,000
Intersection skew angle (degrees)	0	30
Number of signalized or uncontrolled approaches with a left turn lane (0,1,2,3,4)	0	0
Number of signalized or uncontrolled approaches with a right turn lane (0,1,2,3,4)	0	0
Intersection lighting (present/not present)	not present	present
Calibration Factor, C_i	1.0	1.50

Worksheet 2B – Accident Modification Factors for Rural Two-Lane Two-Way Road Intersections

In Step 10 of the predictive method, Accident Modification Factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 10.7 presents the tables and equations necessary for determining AMF values. Once the value for each AMF has been determined, all of the AMFs are multiplied together in Column 5 of Worksheet 2B which indicates the combined AMF value.

Worksheet 2B – Accident Modification Factors for Rural Two-Lane Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)
AMF for Intersection Skew Angle	AMF for Left-Turn Lanes	AMF for Right-Turn Lanes	AMF for Lighting	Combined AMF
AMF_{1i}	AMF_{2i}	AMF_{3i}	AMF_{4i}	AMF_{COMB}
from Equations 10-22 or 10-23	from Exhibit 10-21	from Exhibit 10-22	from Equation 10-24	(1)*(2)*(3)*(4)
1.13	1.00	1.00	0.90	1.02

Worksheet 2C – Intersection Crashes for Rural Two-Lane Two-Way Road Intersections

The SPF for the intersection in Sample Problem 3 is calculated using Equation 10-8 and entered into Column 2 of Worksheet 2C. The overdispersion parameter associated with the SPF can be entered into Column 3; however, the overdispersion parameter is not needed for Sample Problem 3 (as the EB Method is not utilized). Column 4 of the worksheet presents the default proportions for crash severity levels from Exhibit 10-11. These proportions may be used to separate the SPF (from Column 2) into components by crash severity level, as illustrated in Column 5. Column 6 represents the combined AMF (from Column 13 in Worksheet 2B), and Column 7 represents the calibration factor. Column 8 calculates the predicted average crash frequency using the values in Column 5, the combined AMF in Column 6, and the calibration factor in Column 7.

Worksheet 2C – Intersection Crashes for Rural Two-Lane Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	$N_{spf\ 3ST,4ST\ or\ 4SG}$	**Overdispersion Parameter, k**	**Crash Severity Distribution**	$N_{spf\ 3ST,4ST\ or\ 4SG}$ **by Severity Distribution**	**Combined AMFs**	**Calibration Factor, C_i**	**Predicted average crash frequency, $N_{predicted\ int}$**
	from Equations 10-8, 10-9, or 10-10	from Section 10.6.2	from Exhibit 10-11	$(2)_{TOTAL}$ * (4)	from (5) of Worksheet 2B		(5)*(6)*(7)
Total	1.867	0.54	1.000	1.867	1.02	1.50	2.857
Fatal and Injury (FI)	-	-	0.415	0.775	1.02	1.50	1.186
Property Damage Only (PDO)	-	-	0.585	1.092	1.02	1.50	1.671

Worksheet 2D – Crashes by Severity Level and Collision for Rural Two-Lane Two-Way Road Intersections

Worksheet 2D presents the default proportions for collision type (from Exhibit 10-12) by crash severity level as follows:

- Total crashes (Column 2)
- Fatal and injury crashes (Column 4)
- Property damage only crashes (Column 6)

Using the default proportions, the predicted average crash frequency by collision type is presented in Columns 3 (Total), 5 (Fatal and Injury, FI), and 7 (Property Damage Only, PDO).

These proportions may be used to separate the predicted average crash frequency (from Column 8, Worksheet 2C) by crash severity and collision type.

Worksheet 2D – Crashes by Severity Level and Collision Type for Rural Two-Lane Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Collision Type	**Proportion of Collision Type $_{(TOTAL)}$**	**$N_{predicted\ int\ (TOTAL)}$ (crashes/year)**	**Proportion of Collision Type $_{(FI)}$**	**$N_{predicted\ int\ (FI)}$ (crashes/year)**	**Proportion of Collision Type $_{(PDO)}$**	**$N_{predicted\ int\ (PDO)}$ (crashes/year)**
	from Exhibit 10-12	$(8)_{TOTAL}$ from Worksheet 2C	from Exhibit 10-12	$(8)_{FI}$ from Worksheet 2C	from Exhibit 10-12	$(8)_{PDO}$ from Worksheet 2C
Total	1.000	2.857	1.000	1.186	1.000	1.671
		$(2)*(3)_{TOTAL}$		$(4)*(5)_{FI}$		$(6)*(7)_{PDO}$
SINGLE-VEHICLE						
Collision with animal	0.019	0.054	0.008	0.009	0.026	0.043
Collision with bicycle	0.001	0.003	0.001	0.001	0.001	0.002
Collision with pedestrian	0.001	0.003	0.001	0.001	0.001	0.002
Overturned	0.013	0.037	0.022	0.026	0.007	0.012
Ran off road	0.244	0.697	0.240	0.285	0.247	0.413
Other single-vehicle collision	0.016	0.046	0.011	0.013	0.020	0.033
Total single-vehicle crashes	0.294	0.840	0.283	0.336	0.302	0.505
MULTIPLE-VEHICLE						
Angle collision	0.237	0.677	0.275	0.326	0.210	0.351
Head-on collision	0.052	0.149	0.081	0.096	0.032	0.053
Rear-end collision	0.278	0.794	0.260	0.308	0.292	0.488
Sideswipe collision	0.097	0.277	0.051	0.060	0.131	0.219
Other multiple-vehicle collision	0.042	0.120	0.050	0.059	0.033	0.055
Total multiple-vehicle crashes	0.706	2.017	0.717	0.850	0.698	1.166

Worksheet 2E –Summary Results for Rural Two-Lane Two-Way Road Intersections

Worksheet 2E presents a summary of the results.

Worksheet 2E – Summary Results for Rural Two-Lane Two-Way Road Intersections

(1)	(2)	(3)
Crash severity level	**Crash Severity Distribution**	**Predicted average crash frequency (crashes/year)**
	(4) from Worksheet 2C	(8) from Worksheet 2C
Total	1.000	2.857
Fatal and Injury (FI)	0.415	1.186
Property Damage Only (PDO)	0.585	1.671

10.12.4. Sample Problem 4

A four-leg signalized intersection located on a rural two-lane roadway.

The Question

What is the predicted average crash frequency of the signalized intersection for a particular year?

The Facts

- 4 legs
- 1 right-turn lane on one approach
- Signalized intersection
- 90-degree intersection angle
- No lighting present
- AADT of major road = 10,000 veh/day
- AADT of minor road = 2,000 veh/day
- 1 left-turn lane on each of two approaches

Assumptions

- Collision type distributions used are the default values from Exhibit 10-12.
- The calibration factor is assumed to be 1.30.

Results

Using the predictive method steps as outlined below, the predicted average crash frequency for the intersection in Sample Problem 4 is determined to be 5.7 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8

To determine the predicted average crash frequency of the intersection in Sample Problem 4, only Steps 9 through 11 are conducted. No other steps are necessary because only one intersection is analyzed for one year, and the EB Method is not applied.

Step 9 – For the selected site, determine and apply the appropriate Safety Performance Function (SPF) for the site's facility type and traffic control features.

The SPF for a signalized intersection can be calculated from Equation 10-10 as follows:

$$N_{spf\,4SG} = exp[-5.13 + 0.60 \times ln(AADT_{maj}) + 0.20 \times ln(AADT_{min})]$$
$$= exp[-5.13 + 0.60 \times ln(10{,}000) + 0.20 \times ln(2{,}000)]$$
$$= 6.796 \text{ crashes/year}$$

Step 10 – Multiply the result obtained in Step 9 by the appropriate AMFs to adjust the estimated crash frequency for base conditions to the site specific geometric design and traffic control features.

Each AMF used in the calculation of the predicted average crash frequency of the intersection is calculated below:

Intersection Skew Angle (AMF_{1i})

The AMF for skew angle at four-leg signalized intersections is 1.00 for all cases.

Intersection Left-Turn Lanes (AMF_{2i})

From Exhibit 10-21 for a signalized intersection with left-turn lanes on two approaches, AMF_{2i} = 0.67.

Intersection Right-Turn Lanes (AMF_{3i})

From Exhibit 10-22 for a signalized intersection with a right-turn lane on one approach, AMF_{3i} = 0.96.

Lighting (AMF_{4i})

Since there is no intersection lighting present in Sample Problem 4, AMF_{4i} = 1.00 (i.e. the base condition for AMF_{4i} is the absence of intersection lighting).

The combined AMF value for Sample Problem 4 is calculated below.

$$AMF_{COMB} = 0.67 \times 0.96$$
$$= 0.64$$

Step 11 – Multiply the result obtained in Step 10 by the appropriate calibration factor.

It is assumed that a calibration factor, C_i, of 1.30 has been determined for local conditions. See *Part C* Appendix A.1 for further discussion on calibration of the predictive models.

Calculation of Predicted Average Crash Frequency

The predicted average crash frequency is calculated using the results obtained in Steps 9 through 11 as follows:

$$N_{predicted\ int} = N_{spf\ int} \times C_i \times (AMF_{1i} \times AMF_{2i} \times \ldots \times AMF_{4i})$$
$$= 6.796 \times 1.30 \times (0.64)$$
$$= 5.654 \text{ crashes/year}$$

Worksheets

The step-by-step instructions above are the predictive method for calculating the predicted average crash frequency for an intersection. To apply the predictive method steps to multiple intersections, a series of five worksheets are provided for determining predicted average crash frequency. The five worksheets include:

- Worksheet 2A – General Information and Input Data for Rural Two-Lane Two-Way Road Intersections
- Worksheet 2B – Accident Modification Factors for Rural Two-Lane Two-Way Road Intersections
- Worksheet 2C – Intersection Crashes for Rural Two-Lane Two-Way Road Intersections
- Worksheet 2D – Crashes by Severity Level and Collision for Rural Two-Lane Two-Way Road Intersections
- Worksheet 2E – Summary Results for Rural Two-Lane Two-Way Road Intersections

Details of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 10 Appendix A.

Worksheet 2A – General Information and Input Data for Rural Two-Lane Two-Way Road Intersections

Worksheet 2A is a summary of general information about the intersection, analysis, input data (i.e., "The Facts") and assumptions for Sample Problem 4.

Worksheet 2A – General Information and Input Data for Rural Two-Lane Two-Way Road Intersections			
General Information		**Location Information**	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		**Base Conditions**	**Site Conditions**
Intersection type (3ST, 4ST, 4SG)		-	4SG
$AADT_{major}$ (veh/day)		-	10,000
$AADT_{minor}$ (veh/day)		-	2,000
Intersection skew angle (degrees)		0	0
Number of signalized or uncontrolled approaches with a left turn lane (0,1,2,3,4)		0	2
Number of signalized or uncontrolled approaches with a right turn lane (0,1,2,3,4)		0	1
Intersection lighting (present/not present)		not present	not present
Calibration Factor, C_i		1.0	1.3

Worksheet 2B – Accident Modification Factors for Rural Two-Lane Two-Way Road Intersections

In Step 10 of the predictive method, Accident Modification Factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 10.7 presents the tables and equations necessary for determining AMF values. Once the value for each AMF has been determined, all of the AMFs are multiplied together in Column 5 of Worksheet 2B which indicates the combined AMF value.

Worksheet 2B – Accident Modification Factors for Rural Two-Lane Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)
AMF for Intersection Skew Angle	AMF for Left-Turn Lanes	AMF for Right-Turn Lanes	AMF for Lighting	Combined AMF
AMF_{1i}	AMF_{2i}	AMF_{3i}	AMF_{4i}	AMF_{COMB}
from Equations 10-22 or10-23	from Exhibit 10-21	from Exhibit 10-22	from Equation 10-24	(1)*(2)*(3)*(4)
1.00	0.67	0.96	1.00	0.64

Worksheet 2C – Intersection Crashes for Rural Two-Lane Two-Way Road Intersections

The SPF the intersection in Sample Problem 4 is calculated using Equation 10-8 and entered into Column 2 of Worksheet 2C. The overdispersion parameter associated with the SPF can be entered into Column 3; however, the overdispersion parameter is not needed for Sample Problem 4 (as the EB Method is not utilized). Column 4 of the worksheet presents the default proportions for crash severity levels from Exhibit 10-11. These proportions may be used to separate the SPF (from Column 2) into components by crash severity level, as illustrated in Column 5. Column 6 represents the combined AMF (from Column 13 in Worksheet 2B), and Column 7 represents the calibration factor. Column 8 calculates the predicted average crash frequency using the values in Column 5, the combined AMF in Column 6, and the calibration factor in Column 7.

Worksheet 2C – Intersection Crashes for Rural Two-Lane Two-Way Road Intersections							
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	**$N_{spf\ 3ST,4ST\ or\ 4SG}$**	**Overdispersion Parameter, k**	**Crash Severity Distribution**	**$N_{spf\ 3ST,4ST\ or\ 4SG}$ by Severity Distribution**	**Combined AMFs**	**Calibration Factor, C_i**	**Predicted average crash frequency, $N_{predicted\ int}$**
	from Equations 10-8, 10-9, or 10-10	from Section 10.6.2	from Exhibit 10-11	$(2)_{TOTAL}$ * (4)	from (5) of Worksheet 2B		(5)*(6)*(7)
Total	6.796	0.11	1.000	6.796	0.64	1.30	5.654
Fatal and Injury (FI)	-	-	0.340	2.311	0.64	1.30	1.923
Property Damage Only (PDO)	-	-	0.660	4.485	0.64	1.30	3.732

Worksheet 2D – Crashes by Severity Level and Collision for Rural Two-Lane Two-Way Road Intersections

Worksheet 2D presents the default proportions for collision type (from Exhibit 10-12) by crash severity level as follows:

- Total crashes (Column 2)
- Fatal and injury crashes (Column 4)
- Property damage only crashes (Column 6)

Using the default proportions, the predicted average crash frequency by collision type is presented in Columns 3 (Total), 5 (Fatal and Injury, FI), and 7 (Property Damage Only, PDO).

These proportions may be used to separate the predicted average crash frequency (from Column 8, Worksheet 2C) by crash severity and collision type.

Worksheet 2D – Crashes by Severity Level and Collision Type for Rural Two-Lane Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Collision Type	**Proportion of Collision Type (TOTAL)**	$N_{predicted\ int\ (TOTAL)}$ **(crashes/year)**	**Proportion of Collision Type (FI)**	$N_{predicted\ int\ (FI)}$ **(crashes/year)**	**Proportion of Collision Type (PDO)**	$N_{predicted\ int\ (PDO)}$ **(crashes/year)**
	from Exhibit 10-12	$(8)_{TOTAL}$ from Worksheet 2C	from Exhibit 10-12	$(8)_{FI}$ from Worksheet 2C	from Exhibit 10-12	$(8)_{PDO}$ from Worksheet 2C
Total	1.000	5.654	1.000	1.923	1.000	3.732
		$(2)*(3)_{TOTAL}$		$(4)*(5)_{FI}$		$(6)*(7)_{PDO}$
SINGLE-VEHICLE						
Collision with animal	0.002	0.011	0.000	0.000	0.003	0.011
Collision with bicycle	0.001	0.006	0.001	0.002	0.001	0.004
Collision with pedestrian	0.001	0.006	0.001	0.002	0.001	0.004
Overturned	0.003	0.017	0.003	0.006	0.003	0.011
Ran off road	0.064	0.362	0.032	0.062	0.081	0.302
Other single-vehicle collision	0.005	0.028	0.003	0.006	0.018	0.067
Total single-vehicle crashes	0.076	0.430	0.040	0.077	0.107	0.399
MULTIPLE-VEHICLE						
Angle collision	0.274	1.549	0.336	0.646	0.242	0.903
Head-on collision	0.054	0.305	0.080	0.154	0.040	0.149
Rear-end collision	0.426	2.409	0.403	0.775	0.438	1.635
Sideswipe collision	0.118	0.667	0.051	0.098	0.153	0.571
Other multiple-vehicle collision	0.052	0.294	0.090	0.173	0.020	0.075
Total multiple-vehicle crashes	0.924	5.224	0.960	1.846	0.893	3.333

Worksheet 2E –Summary Results for Rural Two-Lane Two-Way Road Intersections

Worksheet 2E presents a summary of the results.

Worksheet 2E – Summary Results for Rural Two-Lane Two-Way Road Intersections

(1)	(2)	(3)
Crash severity level	**Crash Severity Distribution**	**Predicted average crash frequency (crashes/year)**
	(4) from Worksheet 2C	(8) from Worksheet 2C
Total	1.000	5.654
Fatal and injury (FI)	0.340	1.923
Property Damage Only (PDO)	0.660	3.732

10.12.5. Sample Problem 5

The Project

A project of interest consists of three sites: a rural two-lane tangent segment; a rural two-lane curved segment; and a three-leg intersection with minor-road stop control. (This project is a compilation of roadway segments and intersections from Sample Problems 1, 2 and 3.)

The Question

What is the expected average crash frequency of the project for a particular year incorporating both the predicted average crash frequencies from Sample Problems 1, 2 and 3 and the observed crash frequencies using the **site-specific EB Method**?

The Facts

- 2 roadway segments (2U tangent segment, 2U curved segment)
- 1 intersection (3ST intersection)
- 15 observed crashes (2U tangent segment: 10 crashes; 2U curved segment: 2 crashes; 3ST intersection: 3 crashes)

Outline of Solution

To calculate the expected average crash frequency, site-specific observed crash frequencies are combined with predicted average crash frequencies for the project using the site-specific EB Method (i.e. observed crashes are assigned to specific intersections or roadway segments) presented in Section A.2.4 of *Part C* Appendix.

Results

The expected average crash frequency for the project is 12.3 crashes per year (rounded to one decimal place).

Worksheets

To apply the site-specific EB Method to multiple roadway segments and intersections on a rural two-lane two-way road combined, two worksheets are provided for determining the expected average crash frequency. The two worksheets include:

- Worksheet 3A – Predicted and Observed Crashes by Severity and Site Type Using the Site-Specific EB Method for Rural Two-Lane Two-Way Roads and Multilane Highways
- Worksheet 3B – Site-Specific EB Method Summary Results for Rural Two-Lane Two-Way Roads and Multilane Highways

Details of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 10 Appendix A.

Worksheets 3A – Predicted and Observed Crashes by Severity and Site Type Using the Site-Specific EB Method for Rural Two-Lane Two-Way Roads and Multilane Highways

The predicted average crash frequencies by severity type determined in Sample Problems 1 through 3 are entered into Columns 2 through 4 of Worksheet 3A. Column 5 presents the observed crash frequencies by site type, and Column 6 presents the overdispersion parameters. The expected average crash frequency is calculated by applying the site-specific EB Method which considers both the predicted model estimate and observed crash frequencies for each roadway segment and intersection. Equation A-5 from *Part C* Appendix is used to calculate the weighted adjustment and entered into Column 7. The expected average crash frequency is calculated using Equation A-4 and entered into Column 8. Detailed calculation of Columns 7 and 8 are provided below.

Worksheet 3A – Predicted and Observed Crashes by Severity and Site Type Using the Site-Specific EB Method for Rural Two-Lane Two-Way Roads and Multilane Highways

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Site type	**Predicted average crash frequency (crashes/year)**			**Observed crashes, $N_{observed}$ (crashes/year)**	**Overdispersion parameter, k**	**Weighted adjustment, w**	**Expected average crash frequency, $N_{expected}$**
	$N_{predicted\ (TOTAL)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$			Equation A-5 from Part C Appendix	Equation A-4 from Part C Appendix
ROADWAY SEGMENTS							
Segment 1	6.084	1.954	4.131	10	0.16	0.507	8.015
Segment 2	0.525	0.169	0.356	2	2.36	0.447	1.341
INTERSECTIONS							
Intersection 1	2.857	1.186	1.671	3	0.54	0.393	2.944
COMBINED (sum of column)	9.466	3.309	6.158	15	-	-	12.300

Column 7 - Weighted Adjustment

The weighted adjustment, w, to be placed on the predictive model estimate is calculated using Equation A-5 from *Part C* Appendix as follows:

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

Segment 1 $$w = \frac{1}{1 + 0.16 \times (6.084)}$$

$$= 0.507$$

Segment 2 $$w = \frac{1}{1 + 2.36 \times (0.525)}$$

$$= 0.447$$

Intersection 1 $$w = \frac{1}{1 + 0.54 \times (2.857)}$$

$$= 0.393$$

Column 8 - Expected Average Crash Frequency

The estimate of expected average crash frequency, $N_{expected}$, is calculated using Equation A-4 from *Part C* Appendix as follows:

$$N_{expected} = w \times N_{predicted} + (1 - w) \times N_{observed}$$

Segment 1 $$N_{expected} = 0.507 \times 6.084 + (1 - 0.507) \times 10$$

$$= 8.015$$

Segment 2 $$N_{expected} = 0.447 \times 0.525 + (1 - 0.447) \times 2$$

$$= 1.341$$

Intersection 1 $$N_{expected} = 0.393 \times 2.857 + (1 - 0.393) \times 3$$

$$= 2.944$$

Worksheet 3B – Site-Specific EB Method Summary Results for Rural Two-Lane Two-Way Roads and Multilane Highways

Worksheet 3B presents a summary of the results. The expected average crash frequency by severity level is calculated by applying the proportion of predicted average crash frequency by severity level to the total expected average crash frequency (Column 3).

Worksheet 3B – Site-Specific EB Method Summary Results for Rural Two-Lane Two-Way Roads and Multilane Highways

(1)	(2)	(3)
Crash severity level	$N_{predicted}$	$N_{expected}$
Total	$(2)_{COMB}$ from Worksheet 3A	$(8)_{COMB}$ from Worksheet 3A
	9.466	12.3
Fatal and injury (FI)	$(3)_{COMB}$ from Worksheet 3A	$(3)_{TOTAL}*(2)_{FI}/(2)_{TOTAL}$
	3.309	4.3
Property damage only (PDO)	$(4)_{COMB}$ from Worksheet 3A	$(3)_{TOTAL}*(2)_{PDO}/(2)_{TOTAL}$
	6.158	8.0

10.12.6. Sample Problem 6

The Project

A project of interest consists of three sites: a rural two-lane tangent segment; a rural two-lane curved segment; and a three-leg intersection with minor-road stop control. (This project is a compilation of roadway segments and intersections from Sample Problems 1, 2 and 3.)

The Question

What is the expected average crash frequency of the project for a particular year incorporating both the predicted average crash frequencies from Sample Problems 1, 2 and 3 and the observed crash frequencies using the **project-level EB Method**?

The Facts

- 2 roadway segments (2U tangent segment, 2U curved segment)
- 1 intersection (3ST intersection)
- 15 observed crashes (but no information is available to attribute specific crashes to specific sites within the project)

Outline of Solution

Observed crash frequencies for the project as a whole are combined with predicted average crash frequencies for the project as a whole using the project-level EB Method (i.e. observed crash data for individual roadway segments and intersections are not available, but observed crashes are assigned to a facility as a whole) presented in Section A.2.5 of *Part C* Appendix.

Results

The expected average crash frequency for the project is 11.7 crashes per year (rounded to one decimal place).

Worksheets

To apply the project-level EB Method to multiple roadway segments and intersections on a rural two-lane two-way road combined, two worksheets are provided for determining the expected average crash frequency. The two worksheets include:

- Worksheet 4A – Predicted and Observed Crashes by Severity and Site Type Using the Project-Level EB Method for Rural Two-Lane Two-Way Roads and Multilane Highways
- Worksheet 4B – Project-Level EB Method Summary Results for Rural Two-Lane Two-Way Roads and Multilane Highways

Details of these worksheets are provided below. Blank versions of worksheets used in the Sample Problems are provided in Chapter 10 Appendix A.

Worksheets 4A – Predicted and Observed Crashes by Severity and Site Type Using the Project-Level EB Method for Rural Two-Lane Two-Way Roads and Multilane Highways

The predicted average crash frequencies by severity type determined in Sample Problems 1 through 3 are entered in Columns 2 through 4 of Worksheet 4A. Column 5 presents the total observed crash frequencies combined for all sites, and Column 6 presents the overdispersion parameters. The expected average crash frequency is calculated by applying the project-level EB Method which considers both the predicted model estimate for each roadway segment and intersection and the project observed crashes. Column 7 calculates N_{w0} and Column 8 N_{w1}. Equations A-10 through A-14 from *Part C* Appendix are used to calculate the expected average crash frequency of combined sites. The results obtained from each equation are presented in Columns 9 through 14. Section A.2.5 in *Part C* Appendix defines all the variables used in this worksheet. Detailed calculations of Columns 9 through 13 are provided below.

Worksheet 4A – Predicted and Observed Crashes by Severity and Site Type Using the Project-Level EB Method for Rural Two-Lane Two-Way Roads and Multilane Highways

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Site type	**Predicted average crash frequency (crashes/year)**			**Observed crashes, $N_{observed}$ (crashes/year)**	**Overdispersion Parameter, k**	**$N_{predicted\ w0}$**	**$N_{predicted\ w1}$**	**w_0**	**N_0**	**w_1**	**N_1**	**$N_{expected/comb}$**
	$N_{predicted}$ (TOTAL)	$N_{predicted}$ (FI)	$N_{predicted}$ (PDO)			Equation A-8 (6)* (2)^2	Equation A-9 sqrt((6)*(2))	Equation A-10	Equation A-11	Equation A-12	Equation A-13	Equation A-14
ROADWAY SEGMENTS												
Segment 1	6.084	1.954	4.131	-	0.16	5.922	0.987	-	-	-	-	-
Segment 2	0.525	0.169	0.356	-	2.36	0.651	1.113	-	-	-	-	-
INTERSECTIONS												
Intersection 1	2.857	1.186	1.671	-	0.54	4.408	1.242	-	-	-	-	-
COMBINED (sum of column)	9.466	3.309	6.158	15	-	10.981	3.342	0.463	12.438	0.739	10.910	11.674

NOTE: $N_{predicted\ w0}$ = Predicted number of total accidents assuming that accidents frequencies are statistically independent

$$N_{predicted\ w0} = \sum_{j=1}^{5} k_{rmj}\ N_{rmj}^2 + \sum_{j=1}^{5} k_{rsj}\ N_{rsj}^2 + \sum_{j=1}^{5} k_{rdj}\ N_{rdj}^2 + \sum_{j=1}^{4} k_{imj}\ N_{imj}^2 + \sum_{j=1}^{4} k_{isj}\ N_{isj}^2 \quad \text{(A-8)}$$

$N_{predicted\ w1}$ = Predicted number of total accidents assuming that accidents frequencies are perfectly correlated

$$N_{predicted\ w1} = \sum_{j=1}^{5} \sqrt{k_{rmj}\ N_{rmj}} + \sum_{j=1}^{5} \sqrt{k_{rsj}\ N_{isj}} + \sum_{j=1}^{5} \sqrt{k_{rdj}\ N_{rdj}} + \sum_{j=1}^{4} \sqrt{k_{imj}\ N_{imj}} + \sum_{j=1}^{4} \sqrt{k_{isj}\ N_{isj}} \quad \text{(A-9)}$$

Column 9 – w_0

The weight placed on predicted crash frequency under the assumption that accidents frequencies for different roadway elements are statistically independent, w_0, is calculated using Equation A-10 from *Part C* Appendix as follows:

$$w_0 = \frac{1}{1 + \frac{N_{predicted\ w0}}{N_{predicted\ (TOTAL)}}}$$

$$= \frac{1}{1 + \frac{10.981}{9.466}}$$

$$= 0.463$$

Column 10 – N_0

The expected crash frequency based on the assumption that different roadway elements are statistically independent, N_0, is calculated using Equation A-11 from *Part C* Appendix as follows:

$$N_0 = w_0\ N_{predicted\ (TOTAL)} + (1 - w_0)\ N_{observed\ (TOTAL)}$$

$$= 0.463 \times 9.466 + (1 - 0.463) \times 15$$

$$= 12.438$$

Column 11 – w_1

The weight placed on predicted crash frequency under the assumption that accidents frequencies for different roadway elements are perfectly correlated, w_1, is calculated using Equation A-12 from *Part C* Appendix as follows:

$$w_1 = \frac{1}{1 + \frac{N_{predicted\ w1}}{N_{predicted\ (TOTAL)}}}$$

$$= \frac{1}{1 + \frac{3.342}{9.466}}$$

$$= 0.739$$

Column 12 – N_1

The expected crash frequency based on the assumption that different roadway elements are perfectly correlated, N_1, is calculated using Equation A-13 from *Part C* Appendix as follows:

$$N_1 = w_1\ N_{predicted\ (TOTAL)} + (1 - w_1)\ N_{observed\ (TOTAL)}$$

$$= 0.739 \times 9.466 + (1 - 0.739) \times 15$$

$$= 10.910$$

Column 13 – $N_{expected/comb}$

The expected average crash frequency based of combined sites, $N_{p/comb}$, is calculated using Equation A-14 from *Part C* Appendix as follows:

$$N_{expected/comb} = \frac{N_0 + N_1}{2}$$

$$= \frac{12.438 + 10.910}{2}$$

$$= 11.674$$

Worksheet 4B – Project-Level EB Method Summary Results for Rural Two-Lane Two-Way Roads and Multilane Highways

Worksheet 4B presents a summary of the results. The expected average crash frequency by severity level is calculated by applying the proportion of predicted average crash frequency by severity level to the total expected average crash frequency (Column 3).

Worksheet 4B – Project-Level EB Method Summary Results for Rural Two-Lane Two-Way Roads and Multilane Highways

(1)	(2)	(3)
Crash severity level	**$N_{predicted}$**	**$N_{expected/comb}$**
Total	$(2)_{COMB}$ from Worksheet 4A	$(13)_{COMB}$ from Worksheet 4A
	9.466	11.7
Fatal and injury (FI)	$(3)_{COMB}$ from Worksheet 4A	$(3)_{TOTAL}*(2)_{FI}/(2)_{TOTAL}$
	3.309	4.1
Property damage only (PDO)	$(4)_{COMB}$ from Worksheet 4A	$(3)_{TOTAL}*(2)_{PDO}/(2)_{TOTAL}$
	6.158	7.6

10.13. REFERENCES

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A.1 Appendix A – Worksheets for Predictive Method for Rural Two-Lane Two-Way Roads

Worksheet 1A – General Information and Input Data for Rural Two-Lane Two-Way Roadway Segments			
General Information		**Location Information**	
Analyst		Roadway	
Agency or Company		Roadway Section	
Date Performed		Jurisdiction	
		Analysis Year	

Input Data	**Base Conditions**	**Site Conditions**
Length of segment, L (mi)	-	
AADT (veh/day)	-	
Lane width (ft)	12	
Shoulder width (ft)	6	
Shoulder type	paved	
Length of horizontal curve (mi)	0	
Radius of curvature (ft)	0	
Spiral transition curve (present/not present)	not present	
Superelevation variance (ft/ft)	<0.01	
Grade (%)	0	
Driveway density (driveways/mile)	5	
Centerline rumble strips (present/not present)	not present	
Passing lanes (present/not present)	not present	
Two-way left-turn lane (present/not present)	not present	
Roadside hazard rating (1-7 scale)	3	
Segment lighting (present/not present)	not present	
Auto speed enforcement (present/not present)	not present	
Calibration Factor, C_r	1.0	

Worksheet 1B – Accident Modification Factors for Rural Two-Lane Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
AMF for Lane Width	AMF for Shoulder Width and Type	AMF for Horizontal Curves	AMF for Superelevation	AMF for Grades	AMF for Driveway Density	AMF for Centerline Rumble Strips	AMF for Passing Lanes	AMF for Two-Way Left-Turn Lane	AMF for Roadside Design	AMF for Lighting	AMF for Automated Speed Enforcement	Combined AMF
AMF_{1r}	AMF_{2r}	AMF_{3r}	AMF_{4r}	AMF_{5r}	AMF_{6r}	AMF_{7r}	AMF_{8r}	AMF_{9r}	AMF_{10r}	AMF_{11r}	AMF_{12r}	AMF_{COMB}
from Equation 10-11	from Equation 10-12	from Equation 10-13	from Equations 10-14, 10-15, or 10-16	from Exhibit 10-19	from Equation 10-17	from Section 10.7.1	from Section 10.7.1	from Equation 10-18	from Equation 10-20	from Equation 10-21	from Section 10.7.1	(1)*(2)*… *(11)*(12)

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Worksheet 1C – Roadway Segment Crashes for Rural Two-Lane Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	**$N_{spf\ rs}$**	**Overdispersion Parameter, k**	**Crash Severity Distribution**	**$N_{spf\ rs}$ by Severity Distribution**	**Combined AMFs**	**Calibration Factor, C_r**	**Predicted average crash frequency, $N_{predicted\ rs}$**
	from Equation 10-6	from Equation 10-7	from Exhibit 10-6	$(2)_{TOTAL}$ * (4)	(13) from Worksheet 1B		(5)*(6)*(7)
Total			1.000				
Fatal and Injury (FI)	-	-	0.321				
Property Damage Only (PDO)	-	-	0.679				

Worksheet 1D – Crashes by Severity Level and Collision Type for Rural Two-Lane Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Collision Type	**Proportion of Collision Type (TOTAL)**	**$N_{predicted\ rs\ (TOTAL)}$ (crashes/year)**	**Proportion of Collision Type (FI)**	**$N_{predicted\ rs\ (FI)}$ (crashes/year)**	**Proportion of Collision Type (PDO)**	**$N_{predicted\ rs\ (PDO)}$ (crashes/year)**
	from Exhibit 10-7	$(8)_{TOTAL}$ from Worksheet 1C	from Exhibit 10-7	$(8)_{FI}$ from Worksheet 1C	from Exhibit 10-7	$(8)_{PDO}$ from Worksheet 1C
Total	1.000		1.000		1.000	
		$(2)*(3)_{TOTAL}$		$(4)*(5)_{FI}$		$(6)*(7)_{PDO}$
SINGLE-VEHICLE						
Collision with animal	0.121		0.038		0.184	
Collision with bicycle	0.002		0.004		0.001	
Collision with pedestrian	0.003		0.007		0.001	
Overturned	0.025		0.037		0.015	
Ran off road	0.521		0.545		0.505	
Other single-vehicle collision	0.021		0.007		0.029	
Total single-vehicle crashes	0.693		0.638		0.735	
MULTIPLE-VEHICLE						
Angle collision	0.085		0.100		0.072	
Head-on collision	0.016		0.034		0.003	
Rear-end collision	0.142		0.164		0.122	
Sideswipe collision	0.037		0.038		0.038	
Other multiple-vehicle collision	0.027		0.026		0.03	
Total multiple-vehicle crashes	0.307		0.362		0.265	

Worksheet 1E – Summary Results for Rural Two-Lane Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)
Crash severity level	**Crash Severity Distribution**	**Predicted average crash frequency (crashes/year)**	**Roadway segment length (mi)**	**Crash rate (crashes/mi/year)**
	(4) from Worksheet 1C	(8) from Worksheet 1C		(3)/(4)
Total				
Fatal and Injury (FI)				
Property Damage Only (PDO)				

Worksheet 2A – General Information and Input Data for Rural Two-Lane Two-Way Road Intersections

General Information		**Location Information**	
Analyst		Roadway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	

Input Data	**Base Conditions**	**Site Conditions**
Intersection type (3ST, 4ST, 4SG)	-	
$AADT_{major}$ (veh/day)	-	
$AADT_{minor}$ (veh/day)	-	
Intersection skew angle (degrees)	0	
Number of signalized or uncontrolled approaches with a left turn lane (0,1,2,3,4)	0	
Number of signalized or uncontrolled approaches with a right turn lane (0,1,2,3,4)	0	
Intersection lighting (present/not present)	not present	
Calibration Factor, C_i	1.0	

Worksheet 2B – Accident Modification Factors for Rural Two-Lane Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)
AMF for Intersection Skew Angle	AMF for Left-Turn Lanes	AMF for Right-Turn Lanes	AMF for Lighting	Combined AMF
AMF_{1i}	AMF_{2i}	AMF_{3i}	AMF_{4i}	AMF_{COMB}
from Equations 10-22 or10-23	from Exhibit 10-21	from Exhibit 10-22	from Equation 10-24	(1)*(2)*(3)*(4)

Worksheet 2C – Intersection Crashes for Rural Two-Lane Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	**$N_{spf\ 3ST,4ST\ or\ 4SG}$**	**Overdispersion Parameter, k**	**Crash Severity Distribution**	**$N_{spf\ 3ST,4ST\ or\ 4SG}$ by Severity Distribution**	**Combined AMFs**	**Calibration Factor, C_i**	**Predicted average crash frequency, $N_{predicted\ int}$**
	from Equations 10-8, 10-9, or 10-10	from Section 10.6.2	from Exhibit 10-11	$(2)_{TOTAL}$ * (4)	from (5) of Worksheet 2B		(5)*(6)*(7)
Total							
Fatal and Injury (FI)	-	-					
Property Damage Only (PDO)	-	-					

Worksheet 2D – Crashes by Severity Level and Collision Type for Rural Two-Lane Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Collision Type	**Proportion of Collision Type (TOTAL)**	**$N_{predicted\ int\ (TOTAL)}$ (crashes/year)**	**Proportion of Collision Type (FI)**	**$N_{predicted\ int\ (FI)}$ (crashes/year)**	**Proportion of Collision Type (PDO)**	**$N_{predicted\ int\ (PDO)}$ (crashes/year)**
	from Exhibit 10-12	$(8)_{TOTAL}$ from Worksheet 2C	from Exhibit 10-12	$(8)_{FI}$ from Worksheet 2C	from Exhibit 10-12	$(8)_{PDO}$ from Worksheet 2C
Total	1.000		1.000		1.000	
		$(2)*(3)_{TOTAL}$		$(4)*(5)_{FI}$		$(6)*(7)_{PDO}$
SINGLE-VEHICLE						
Collision with animal						
Collision with bicycle						
Collision with pedestrian						
Overturned						
Ran off road						
Other single-vehicle collision						
Total single-vehicle crashes						
MULTIPLE-VEHICLE						
Angle collision						
Head-on collision						
Rear-end collision						
Sideswipe collision						
Other multiple-vehicle collision						
Total multiple-vehicle crashes						

Worksheet 2E – Summary Results for Rural Two-Lane Two-Way Road Intersections

(1)	(2)	(3)
Crash severity level	**Crash Severity Distribution**	**Predicted average crash frequency (crashes/year)**
	(4) from Worksheet 2C	(8) from Worksheet 2C
Total		
Fatal and injury (FI)		
Property Damage Only (PDO)		

Worksheet 3A – Predicted and Observed Crashes by Severity and Site Type Using the Site-Specific EB Method for Rural Two-Lane Two-Way Roads and Multilane Highways

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Site type	**Predicted average crash frequency (crashes/year)**			**Observed crashes, $N_{observed}$ (crashes/year)**	**Overdispersion parameter, k**	**Weighted adjustment, w**	**Expected average crash frequency, $N_{expected}$**
	$N_{predicted}$ (TOTAL)	$N_{predicted}$ (FI)	$N_{predicted}$ (PDO)			Equation A-5 from Part C Appendix	Equation A-4 from Part C Appendix
ROADWAY SEGMENTS							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
Segment 5							
Segment 6							
Segment 7							
Segment 8							
INTERSECTIONS							
Intersection 1							
Intersection 2							
Intersection 3							
Intersection 4							
Intersection 5							
Intersection 6							
Intersection 7							
Intersection 8							
COMBINED (sum of column)					-	-	

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Worksheet 3B – Site-Specific EB Method Summary Results for Rural Two-Lane Two-Way Roads and Multilane Highways		
(1)	(2)	(3)
Crash severity level	$N_{predicted}$	$N_{expected}$
Total	$(2)_{COMB}$ from Worksheet 3A	$(8)_{COMB}$ from Worksheet 3A
Fatal and injury (FI)	$(3)_{COMB}$ from Worksheet 3A	$(3)_{TOTAL}*(2)_{FI}/(2)_{TOTAL}$
Property damage only (PDO)	$(4)_{COMB}$ from Worksheet 3A	$(3)_{TOTAL}*(2)_{PDO}/(2)_{TOTAL}$

Worksheet 4A – Predicted and Observed Crashes by Severity and Site Type Using the Project-Level EB Method for Rural Two-Lane Two-Way Roads and Multilane Highways

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Site type	**Predicted average crash frequency (crashes/year)**			**Observed crashes, $N_{observed}$ (crashes/year)**	**Overdispersion Parameter, k**	$N_{predicted\ w0}$	$N_{predicted\ w1}$	W_0	N_0	w_1	N_1	$N_{expected/comb}$
	$N_{predicted}$ (TOTAL)	$N_{predicted}$ (FI)	$N_{predicted}$ (PDO)			Equation A-8 $(6)*(2)^2$	Equation A-9 sqrt((6)*(2))	Equation A-10	Equation A-11	Equation A-12	Equation A-13	Equation A-14
ROADWAY SEGMENTS												
Segment 1				-				-	-	-	-	-
Segment 2				-				-	-	-	-	-
Segment 3				-				-	-	-	-	-
Segment 4				-				-	-	-	-	-
Segment 5				-				-	-	-	-	-
Segment 6				-				-	-	-	-	-
Segment 7				-				-	-	-	-	-
Segment 8				-				-	-	-	-	-
INTERSECTIONS												
Intersection 1				-				-	-	-	-	-
Intersection 2				-				-	-	-	-	-
Intersection 3				-				-	-	-	-	-
Intersection 4				-				-	-	-	-	-
Intersection 5				-				-	-	-	-	-
Intersection 6				-				-	-	-	-	-
Intersection 7				-				-	-	-	-	-
Intersection 8				-				-	-	-	-	-
COMBINED (sum of column)					-							

Worksheet 4B – Project-Level EB Method Summary Results for Rural Two-Lane Two-Way Roads and Multilane Highways		
(1)	(2)	(3)
Crash severity level	$\mathbf{N}_{predicted}$	$\mathbf{N}_{expected/comb}$
Total	$(2)_{COMB}$ from Worksheet 4A	$(13)_{COMB}$ from Worksheet 4A
Fatal and injury (FI)	$(3)_{COMB}$ from Worksheet 4A	$(3)_{TOTAL}*(2)_{FI}/(2)_{TOTAL}$
Property damage only (PDO)	$(4)_{COMB}$ from Worksheet 4A	$(3)_{TOTAL}*(2)_{PDO}/(2)_{TOTAL}$