Appendix A.
Draft Text for the Second Edition of the HSM

Appendix A presents recommended changes for the second edition of the HSM. The recommendations are based on the findings and conclusions of this research. Recommended changes are presented for Chapters 10, 11, 12, and 19 of the first edition and supplement of the HSM. All recommended changes to the text are shown using track changes.

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

10.1. INTRODUCTION

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. (5).

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.
- Crash modification factors (CMFs) 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 signalized and unsignalized 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 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 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, $N_{\text{predicted}}$, are of the general form shown in Equation 10-1.

$$N_{\text{predicted}} = N_{spf\ x} \times \left(CMF_{1x} \times CMF_{2x} \times \ldots \times CMF_{yx} \right) \times C_x \tag{10-1}$$

Where:

$N_{\text{predicted}}$ = 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*;

CMF_{1x} = crash modification factors specific to site type *x* and specific geometric design and traffic control features *y*; and

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, and the predictive models for each of 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-lane, two-way 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 less 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.

Table 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.

Table 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 approach~~es~~) (3ST)
	Unsignalized three-leg (stop control on minor-road approach) where through movement makes turning maneuver (3STT)
	Unsignalized four-leg (stop control on minor-road approaches) (4ST)
	Unsignalized four-leg (all-way stop control) (4aST)
	Signalized three-leg (3SG)
	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.
- *Three-leg intersection with stop control where through movement makes turning maneuver (3STT)*—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, and the major road turns at the intersection. A stop sign with an "Except Right Turn" message may be provided for one of the major road approaches.
- *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 intersection with all-way stop control (4aST)*—an intersection of a rural two-lane, two-way road and two minor roads. A stop sign is provided on all approaches to the intersection.
- *Three-leg signalized intersection (3SG)*—an intersection of a rural two-lane, two-way road and a minor road. Signalized control is provided at the intersection by traffic lights.
- *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 CMFs and a calibration factor.

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

$$N_{\text{predicted } rs} = N_{spf\ rs} \times C_r \times \left(CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{12r}\right) \tag{10-2}$$

Where:

$N_{\text{predicted } rs}$ = 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; and

$CMF_{1r} \ldots CMF_{12r}$ = crash modification factors for rural two-lane, two-way 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).

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

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

Where:

$N_{\text{predicted } int}$ = 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;

$CMF_{1i} \ldots CMF_{4i}$ = crash modification factors for intersections; and

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 CMFs for each of the SPFs are presented in Section 10.7 and summarized in Table 10-7. Only the specific CMFs associated with each SPF are applicable to that SPF (as these CMFs have base conditions which are identical to the base conditions of the SPF). 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 Figure 10-1. 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 A.

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, such as 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 an 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, along with 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.

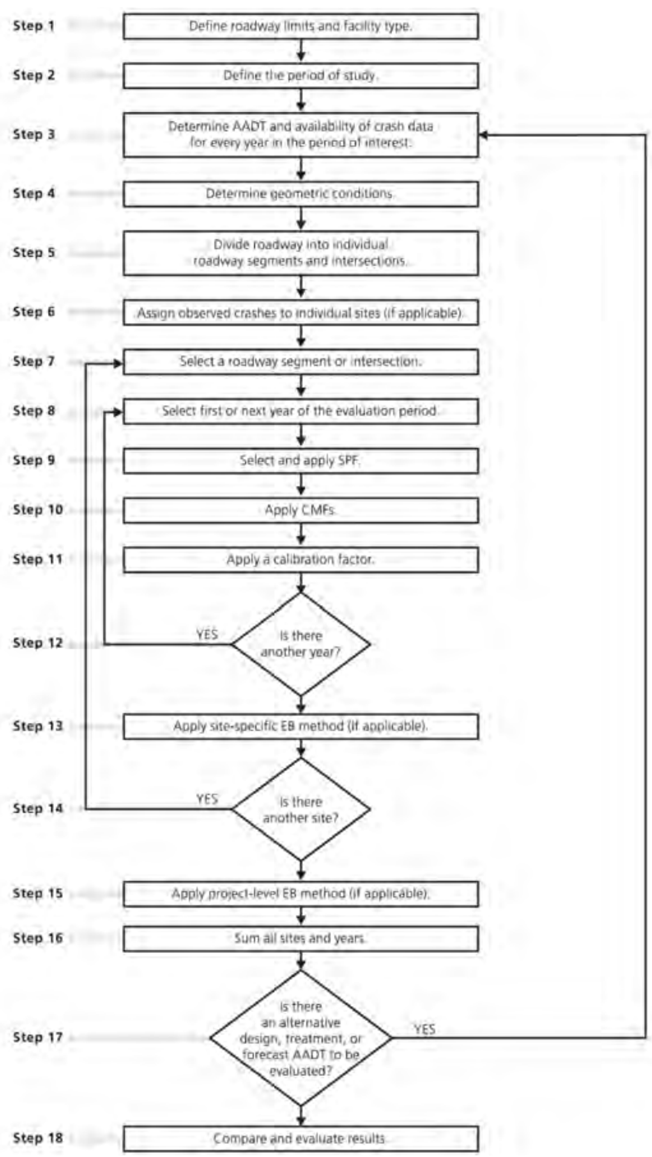

Figure 10-1. The HSM Predictive Method

Step 2—Define the period of interest.

The predictive method can be undertaken for either a past or future period measured in years. Years of interest will be determined by the availability of observed or forecast ~~average annual daily traffic~~annual average daily traffic (AADT) volumes, 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 CMFs 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.

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 evaluation period selected in Step 8.

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. Where needed, $AADT_{total}$ can be estimated as the sum of $AADT_{maj}$ and $AADT_{min}$ and total entering volume (TEV) at the intersection can be estimated as the sum of the two-way AADT for each intersection approach divided by two.

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 crash 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 Part C, Appendix A.2.1.

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 cannot 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 CMFs 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 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 a CMF 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:~~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 a CMF is applicable:

- Number of intersection legs (3 or 4)
- Type of traffic control (minor road stop, all-way stop, or signal control)
- Movements along uncontrolled approaches at three-leg intersection (i.e., straight or turning)
- 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.

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 crashes to individual roadway segments or intersections are presented in Part C, Appendix A.2.3.

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.

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 CMFs (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.

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 CMFs (in Step 10) and adjusted to local jurisdiction conditions (in Step 11) using a calibration factor (C). The SPFs, CMFs, 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.

The SPFs for specific site types (and base conditions) developed for Chapter 10 are summarized in Table 10-2. For the selected site, determine the appropriate SPF for the site type (roadway segment or one of six~~five~~~~three~~ intersection types). The SPF is calculated using the AADT volume determined in Step 3 (AADT for roadway segments or $AADT_{maj}$, ~~and~~ $AADT_{min}$, $AADT_{total}$, or TEV for intersections) for the selected year.

Each SPF determined in Step 9 is provided with default distributions of crash severity and collision type. The default distributions are presented in Tables 10-3 and 10-4 for roadway segments and in Tables 10-5 and 10-6 for intersections. 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.

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

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

All CMFs 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 CMF value for that condition is 1.00). *Only the CMFs presented in Section 10.7 may be used as part of the Chapter 10 predictive method.* Table 10-7 indicates which CMFs 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 Section C.6.5. 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, $N_{\text{predicted}}$, 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, overdispersion parameter, *k*, for the SPF is used. This is in addition to the material in Part C, Appendix A.2.4. 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 $N_{\text{predicted}}$ 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. Part C, Appendix A.2.6 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 cannot 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.

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:

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

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; and

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.

$$N_{\text{total average}} = \frac{N_{\text{total}}}{n} \tag{10-5}$$

Where:

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

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, not only for the same roadway limits, but also 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 Part C, Appendix A.1. Detail regarding the EB Method, which is applied in Steps 6, 13, and 15, is provided in 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) (3).

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 Figure 10-2. 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 (three- and four-leg) intersections. The intersection models estimate the predicted average frequency of crashes that occur within the limits of an intersection (Region A of Figure 10-2) and intersection-related crashes that occur on the intersection legs (Region B in Figure 10-2).

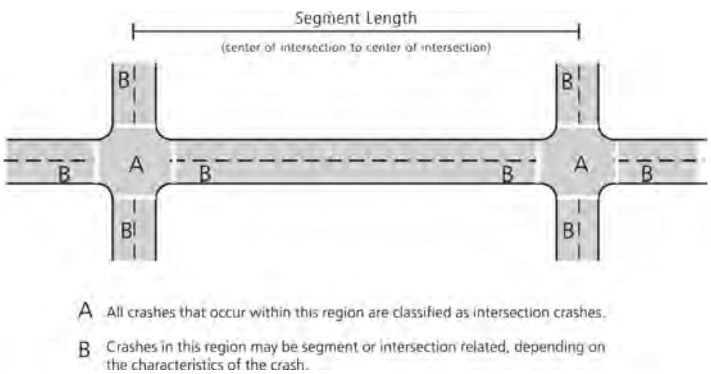

Figure 10-2. Definition of Segments and Intersections

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. Figure 10-2 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~~Annual average 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 CMF. 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 Part C, Appendix A.2.3.

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 SPFs used in Chapter 10 were originally formulated by Vogt and Bared (13, 14, 15). A few aspects of the Harwood et al. (5) and Vogt and Bared (13, 14, 15) work have been updated to match recent changes to the crash prediction module of the FHWA *Interactive Highway Safety Design Model* (3) 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. (12). SPFs, default crash severity and collision type distributions, and default nighttime crash proportions for three-leg stop-controlled turning intersections, four-leg all-way stop-controlled intersections, and three-leg signalized intersections were added to Chapter 10 in the second edition of the *Highway Safety Manual* based on NCHRP Project 17-68 (*20*).

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 Sections 3.5.2, and 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 Part C, Appendix A. The SPFs in Chapter 10 are summarized in Table 10-2.

Table 10-2. Safety Performance Functions included in Chapter 10

Chapter 10 SPFs for Rural Two-Lane, Two-Way Roads	SPF Equations and Figures
Rural two-lane, two-way roadway segments	Equation 10-6, Figure 10-3
Three-leg stop-~~-~~controlled intersections	Equation 10-8, Figure 10-4
Three-leg stop-controlled turning intersections	Equation 10-EC, Figure 10-XC
Four-leg stop-~~-~~controlled intersections	Equation 10-9, Figure 10-5
Four-leg all-way stop-controlled intersections	Equation 10-EA, Figure 10-XA

Three-leg signalized intersections	Equation 10-EB, Figure 10-XB
Four-leg signalized intersections	Equation 10-10, Figure 10-6

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 Part C, Appendix A.

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 CMFs.

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 zero percent grade is not allowed by most states and presents issues such as drainage. The SPF uses zero percent 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 Figure 10-3:

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

Where:

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

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

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

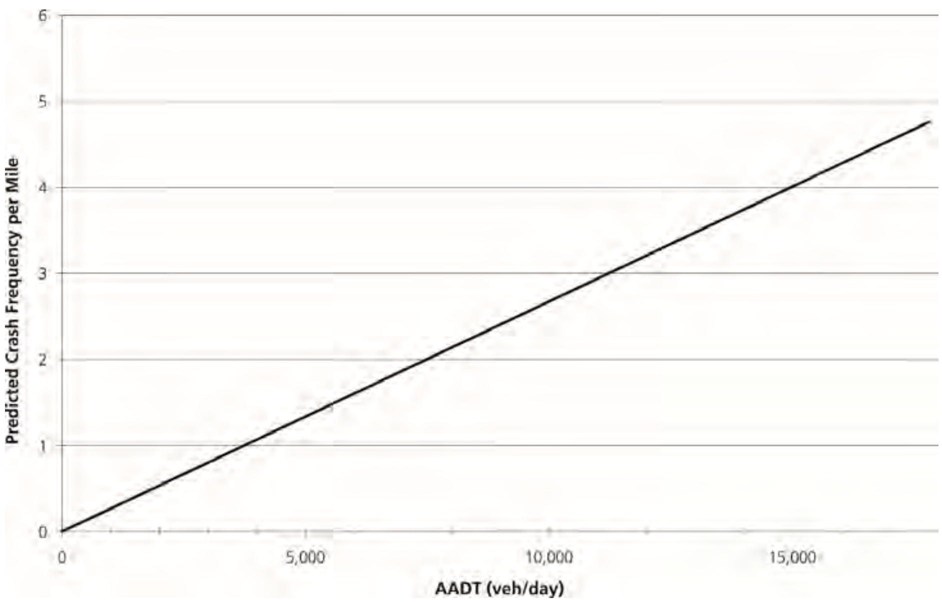

Figure 10-3. Graphical Form of SPF for Rural Two-Lane, Two-Way Roadway Segments (Equation 10-6)

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; and

L = length of roadway segment (miles).

Tables 10-3 and 10-4 provide the default proportions for crash severity and for collision type by crash severity level, respectively. These tables may be used to separate the crash frequencies from Equation 10-6 into components by crash severity level and collision type. Tables 10-3 and 10-4 are applied sequentially. First, Table 10-3 is used to estimate crash frequencies by crash severity level, and then Table 10-4 is used to estimate crash frequencies by collision type for a particular crash severity level. The default proportions for severity levels and collision types shown in Tables 10-3 and 10-4 may be updated based on local data for a particular jurisdiction as part of the calibration process described in Part C, Appendix A.

Table 10-3. Default Distribution for Crash Severity Level on Rural Two-Lane, Two-Way Roadway Segments

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)

Table 10-4. Default Distribution by Collision Type for Specific Crash Severity Levels on Rural Two-Lane, Two-Way Roadway Segments

	Percentage of Total Roadway Segment Crashes by Crash Severity Level[a]		
Collision Type	**Total Fatal and Injury**	**Property Damage Only**	**Total (All Severity Levels Combined)**
SINGLE-VEHICLE CRASHES			
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 crash	0.7	2.9	2.1
Total single-vehicle crashes	63.8	73.5	69.3
MULTIPLE-VEHICLE CRASHES			
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 crashes	36.2	26.5	30.7
Total Crashes	100.0	100.0	100.0

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

[b] Includes approximately 70 percent opposite-direction sideswipe collisions and 30 percent 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 CMFs. The SPFs for rural two-lane, two-way highway intersections are presented in this section.

SPFs have been developed for ~~five~~six~~three~~ types of intersections on rural two-lane, two-way roads. The ~~five~~~~t~~six~~hree~~ types of intersections are:

- Three-leg intersections with minor-road stop control (3ST)
- Three-leg intersections where through movements make~~s~~ turning maneuvers (i.e., turning intersections) (3STT)
- Four-leg intersections with minor-road stop control (4ST)
- Four-leg intersections with all-way stop control (4aST)
- Three-leg signalized intersections (3SG)

- 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 crashes 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 Part C, Appendix A.2.3. 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 six~~three~~ intersection types are presented below in Equations 10-8, 10-EC, 10-9, 10-EA, 10-EB, and ~~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 which apply to the SPFs in Equations 10-8, 10-9, 10-EB, and ~~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 Figure 10-4.

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

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; and

$AADT_{min}$ = 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 zero to 19,500 vehicles per day and $AADT_{min}$ range from zero to 4,300 vehicles per day. Application to sites with AADTs substantially outside these ranges may not provide reliable results.

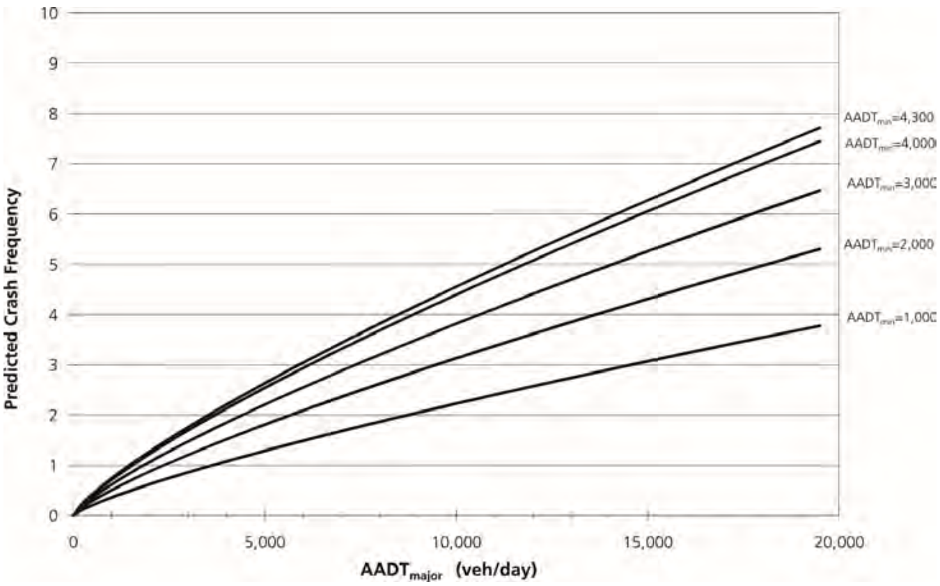

Figure 10-4. Graphical Representation of the SPF for Three-leg Stop-controlled (3ST) Intersections (Equation 10-8)

Three-Leg Stop-Controlled Turning Intersections

The SPF for three-leg stop-controlled intersections where the through movements make turning maneuvers at the intersections is shown in Equation 10-EC and presented graphically in Figure 10-Xi. Base condition for the SPF shown in Equation 10-EC is the absence of lighting.

$$N_{spf\ 3STT} = exp[-6.501 + 0.703 \times \ln(TEV_3)] \quad (10\text{-EC})$$

Where:

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

TEV_3 = total entering volume at a three-leg intersection, see Equation 10-ED (vehicles per day).

$$\mathrm{TEV}_3 = 0.5 \times (\mathrm{AADT}_{maj,1} + \mathrm{AADT}_{maj,2} + \mathrm{AADT}_{min}) \quad (10\text{-ED})$$

$AADT_{maj,1}$ = AADT (vehicles per day) on one major road approach;

$AADT_{maj,2}$ = AADT (vehicles per day) on second major road approach; and

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

The overdispersion parameter (k) for this SPF is 0.24. This SPF is applicable to an AADT$_{maj}$ range from zero to 7,663 vehicles per day and AADT$_{min}$ range from zero to 4,020 vehicles per day. Application to sites with AADTs substantially outside these ranges may not provide reliable results.

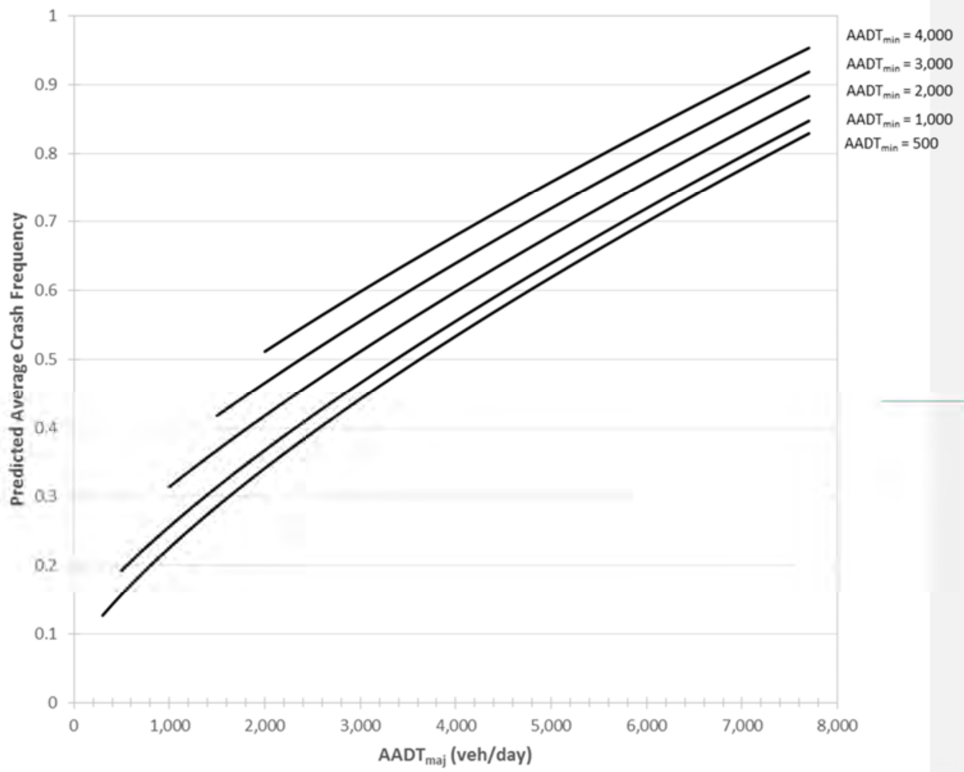

Figure 10-Xi. Graphical Representation of the SPF for Three-leg Stop-Controlled Turning (3STT) Intersections (Equation 10-EC)

Four-Leg Stop-Controlled Intersections

The SPF for four-leg stop controlled intersections is shown in Equation 10-9 and presented graphically in Figure 10-5.

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

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; and

$AADT_{min}$ = 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 zero to 14,700 vehicles per day and $AADT_{min}$ range from zero to 3,500 vehicles per day. Application to sites with AADTs substantially outside these ranges may not provide accurate results.

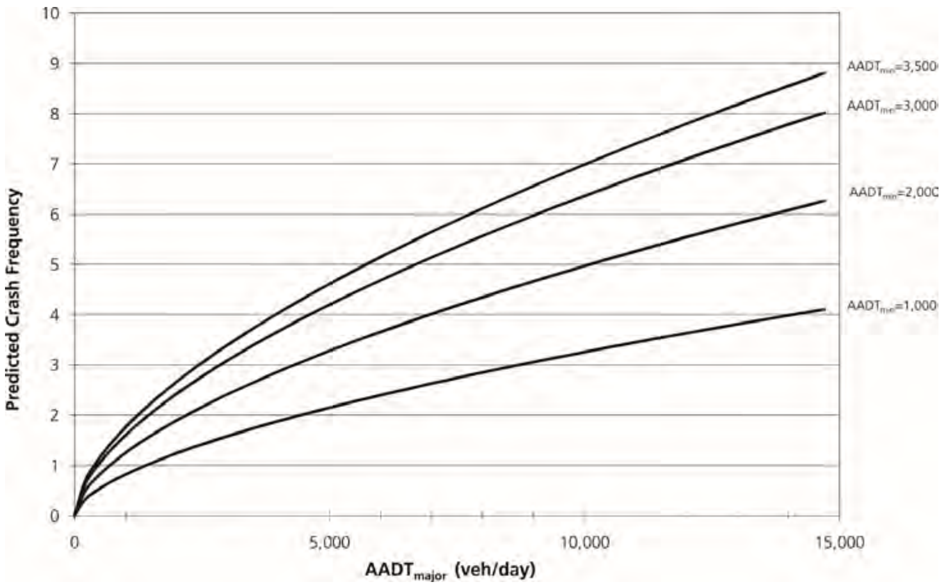

Figure 10-5. Graphical Representation of the SPF for Four-leg, Stop-controlled (4ST) Intersections (Equation 10-9)

Four-Leg All-Way Stop-Controlled Intersections

The SPF for four-leg all-way stop-controlled intersections is shown in Equation 10-EA and presented graphically in Figure 10-XA. Base condition for the SPF shown in Equation 10-EA is the absence of lighting.

$$N_{spf\ 4aST} = exp[-9.67 + 1.12 \times ln(AADT_{total})] \quad (10\text{-EA})$$

Where:

$N_{spf\ 4aST}$ = estimate of intersection-related predicted average crash frequency for base conditions for four-leg all-way stop-controlled intersections; and

$AADT_{total}$ = AADT (vehicles per day) for major- and minor-road approaches combined.

The overdispersion parameter (k) for this SPF is 0.39. This SPF is applicable to an $AADT_{maj}$ range from zero to 12,983 vehicles per day and an $AADT_{min}$ range from zero to 9,985 vehicles per day. Application to sites with AADTs substantially outside these ranges may not provide accurate results.

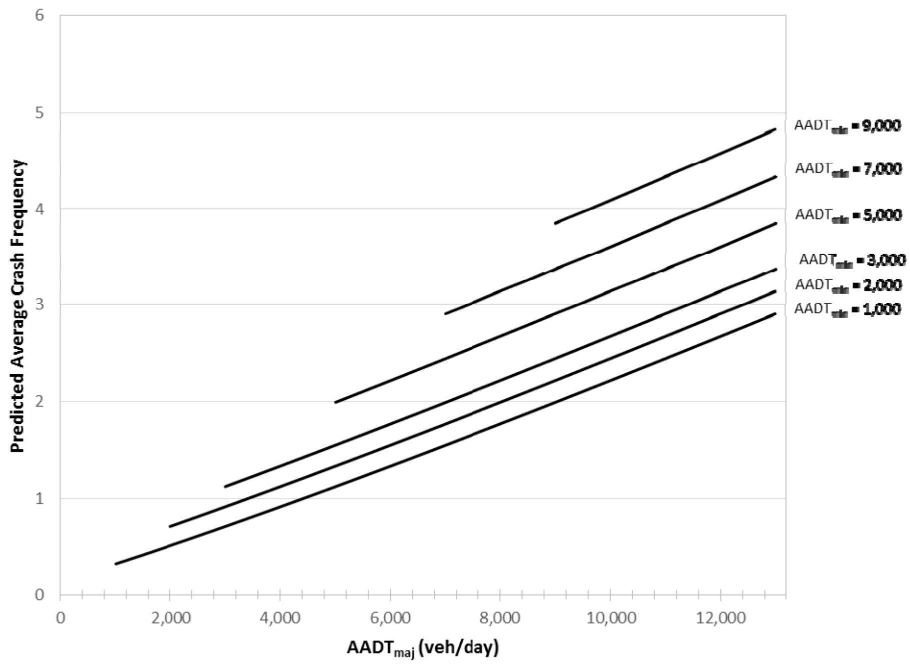

Figure 10-XA. Graphical Representation of the SPF for Four-leg All-way Stop-Controlled (4aST) Intersections (Equation 10-EA)

Three-Leg Signalized Intersections

The SPF for three-leg signalized intersections is shown in Equation 10-EB and presented graphically in Figure 10-XB.

$$N_{spf\ 3SG} = exp[-5.88 + 0.54 \times ln(AADT_{maj}) + 0.23 \times ln(AADT_{min})] \quad (10\text{-}EB)$$

Where:

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

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

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

The overdispersion parameter (k) for this SPF is 0.31. This SPF is applicable to an $AADT_{maj}$ range from zero to 23,591 vehicles per day and $AADT_{min}$ range from zero to 23,320 vehicles per day. Application to sites with AADTs substantially outside these ranges may not provide accurate results.

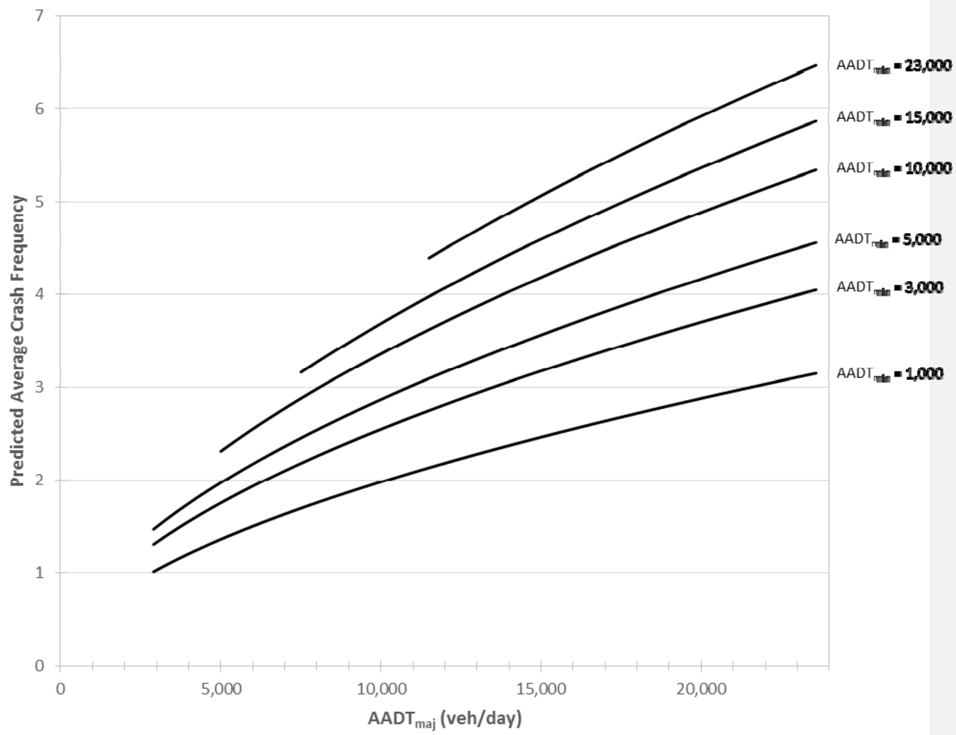

Figure 10-XB. Graphical Representation of the SPF for Three-leg Signalized (3SG) Intersections (Equation 10-EB)

Four-Leg Signalized Intersections

The SPF for four-leg signalized intersections is shown in Equation 10-10 and presented graphically in Figure 10-6.

$$N_{spf\,4SG} = exp\left[-5.13 + 0.60 \times 1n\left(AADT_{maj}\right) + 0.20 \times ln\left(AADT_{min}\right)\right] \quad (10\text{-}10)$$

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; and

$AADT_{min}$ = 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 zero to 25,200 vehicles per day and $AADT_{min}$ range from zero to 12,500 vehicles per day. For instances when application is made to sites with AADT substantially outside these ranges, the reliability is unknown.

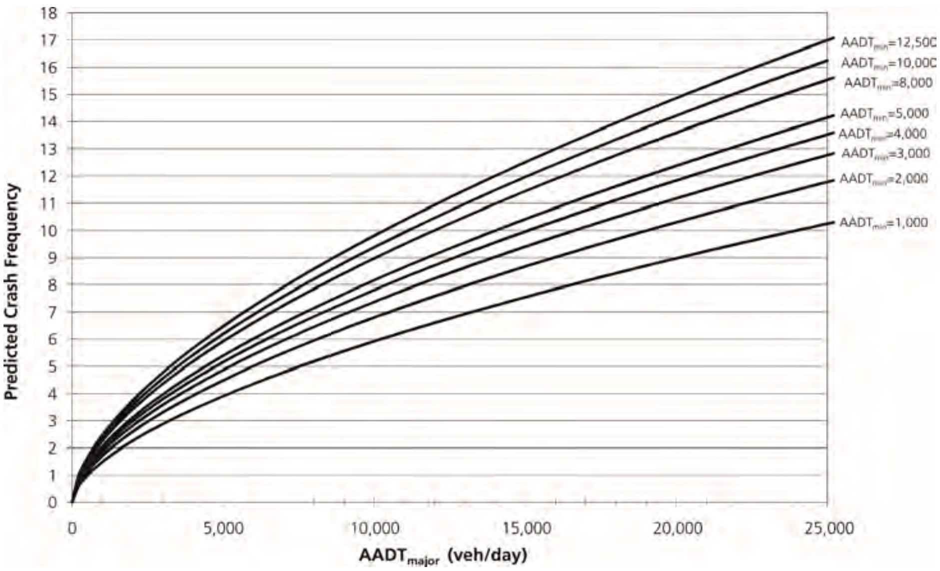

Figure 10-6. Graphical Representation of the SPF for Four-leg Signalized (4SG) Intersections (Equation 10-10)

Tables 10-5 and 10-6 provide the default proportions for crash severity levels and collision types, respectively. These tables may be used to separate the crash 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 Tables 10-5 and 10-6 may be updated based on local data for a particular jurisdiction as part of the calibration process described in Part C, Appendix A.

Table 10-5. 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[a]	Three-Leg Stop-Controlled Turning Intersections[b]	Four-Leg Stop-Controlled Intersections[a]	Four-Leg All-Way Stop-Controlled Intersections[b]	Three-Leg Signalized Intersections[b]	Four-Leg Signalized Intersections[a]
Fatal	1.7	0.3	1.8	0.3	0.1	0.9
Incapacitating Injury	4.0	6.0	4.3	3.6	2.4	2.1
Nonincapacitating injury	16.6	17.3	16.2	11.2	14.3	10.5
Possible injury	19.2	12.4	20.8	12.4	20.5	20.5
Total fatal plus injury	41.5	36.0	43.1	27.5	37.3	34.0
Property damage only	58.5	64.0	56.9	72.5	62.7	66.0
Total	100.0	100.0	100.0	100.0	100.0	100.0

Note: [a] Based on HSIS data for California (2002–2006). [b] Based on data from NCHRP Project 17-68.

Table 10-6. 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[a]			Three-Leg Stop-Controlled Turning Intersections[b]			Four-Leg Stop-Controlled Intersections[a]		
	Fatal and Injury	Property Damage Only	Total	Fatal and Injury	Property Damage Only	Total	Fatal and Injury	Property Damage Only	Total
SINGLE-VEHICLE CRASHES									
Collision with animal	0.8	2.6	1.9	0.0	11.2	7.1	0.6	1.4	1.0
Collision with bicycle	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1
Collision with pedestrian	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0.1	0.1
Overturned	2.2	0.7	1.3	6.9	2.1	3.8	0.6	0.4	0.5
Ran off road	24.0	24.7	24.4	61.1	54.9	57.1	9.4	14.4	12.2
Other single-vehicle crash	1.1	2.0	1.6	3.8	3.9	3.9	0.4	1.0	0.8
Total single-vehicle crashes	28.3	30.2	29.4	71.8	72.1	71.9	11.2	17.4	14.7
MULTIPLE-VEHICLE CRASHES									
Angle collision	27.5	21.0	23.7	19.8	17.2	18.1	49.8	44.2	45.7
Head-on collision	8.1	3.2	5.2	3.8	2.1	2.8	1.5	1.4	1.4
Rear-end collision	26.0	29.2	27.8	1.5	2.6	2.2	29.7	29.0	29.2
Sideswipe collision	5.1	13.1	9.7	2.3	4.7	3.9	2.6	7.5	6.2
Other multiple-vehicle collision	5.0	3.3	4.2	0.8	1.3	1.1	2.9	5.3	4.6
Total multiple-vehicle crashes	71.7	69.8	70.6	28.2	27.9	28.1	86.4	87.3	87.1
Total Crashes	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Note: [a] Based on HSIS data for California (2002–2006). [b] Based on data from NCHRP Project 17-68.

Table 10-6. Default Distribution for Collision Type and Manner of Collision at Rural Two-Way Intersections (Continued)

Collision Type	Four-Leg All-Way Stop-Controlled Intersections[b] Fatal and Injury	Four-Leg All-Way Stop-Controlled Intersections[b] Property Damage Only	Four-Leg All-Way Stop-Controlled Intersections[b] Total	Three-Leg Signalized Intersections[b] Fatal and Injury	Three-Leg Signalized Intersections[b] Property Damage Only	Three-Leg Signalized Intersections[b] Total	Four-Leg Signalized Intersections[a] Fatal and Injury	Four-Leg Signalized Intersections[a] Property Damage Only	Four-Leg Signalized Intersections[a] Total
	Percentage of Total Crashes by Collision Type								
SINGLE-VEHICLE CRASHES									
Collision with animal	0.7	0.4	0.5	0.0	3.4	1.8	0.0	0.3	0.2
Collision with bicycle	1.5	0.0	0.4	0.7	0.2	0.3	0.1	0.1	0.1
Collision with pedestrian	0.4	0.0	0.1	0.0	0.0	0.0	0.1	0.1	0.1
Overturned	1.8	0.1	0.6	4.6	0.6	1.8	0.3	0.3	0.3
Ran off road	--	--	--	0.0	0.2	0.1	3.2	8.1	6.4
Other single-vehicle crash	9.2	12.1	11.3	12.4	18.9	15.4	0.3	1.8	0.5
Total single-vehicle crashes	13.6	12.7	12.9	17.7	23.3	19.4	4.0	10.7	7.6
MULTIPLE-VEHICLE CRASHES									
Angle collision	49.8	44.2	45.7	26.2	15.8	19.3	33.6	24.2	27.4
Head-on collision	1.5	1.4	1.4	5.7	1.7	2.7	8.0	4.0	5.4
Rear-end collision	29.7	29.0	29.2	42.6	46.3	46.0	40.3	43.8	42.6
Sideswipe collision	2.6	7.5	6.2	2.5	4.6	4.8	5.1	15.3	11.8
Other multiple-vehicle collision	2.9	5.3	4.6	5.3	8.2	7.7	9.0	2.0	5.2
Total multiple-vehicle crashes	86.4	87.3	87.1	82.3	76.6	80.5	96.0	89.3	92.4
Total Crashes	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Note: [a] Based on HSIS data for California (2002–2006). [b] Based on data from NCHRP Project 17-68.

10.7. CRASH MODIFICATION FACTORS

In Step 10 of the predictive method shown in Section 10.4, crash modification factors (CMFs) are applied to account for the effects of site-specific geometric design and traffic control features. CMFs are used in the predictive method in Equations 10-2 and 10-3. A general overview of crash modification factors (CMFs) is presented in Section 3.5.3. The Part C—Introduction and Applications Guidance provides further discussion on the relationship of CMFs to the predictive method. This section provides details of the specific CMFs applicable to the safety performance functions presented in Section 10.6.

Crash modification factors (CMFs) 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 CMF 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 a CMF with a value greater than 1.00. Any feature associated with lower crash frequency than the base condition has a CMF with a value less than 1.00.

The CMFs used in Chapter 10 are consistent with the CMFs in Part D, although they have, in some cases, been expressed in a different form to be applicable to the base conditions. The CMFs presented in Chapter 10 and the specific site types to which they apply are summarized in Table 10-7.

Table 10-7. Summary of Crash Modification Factors (CMFs) in Chapter 10 and the Corresponding Safety Performance Functions (SPFs)

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

[a] Only CMF applicable to this intersection type is CMF_{4i} (Lighting). CMFs for intersection skew angle (CMF_{1i}), left-turn lanes (CMF_{2i}), and right-turn lanes (CMF_{3i}) are not applicable to three-leg stop control turning intersections and four-leg all-way stop-controlled intersections.

10.7.1. Crash Modification Factors for Roadway Segments

The CMFs for geometric design and traffic control features of rural two-lane, two-way roadway segments are presented below. These CMFs 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.

CMF_{1r}—Lane Width

The CMF for lane width on two-lane highway segments is presented in Table 10-8 and illustrated by the graph in Figure 10-7. This CMF was developed from the work of Zegeer et al. (16) and Griffin and Mak (4). The base value for the lane width CMF 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 ft), CMFs are used to account for differences between base and actual conditions. Thus, 12-ft lanes are assigned a CMF of 1.00. CMF_{1r} is determined from Table 10-8 based on the applicable lane width and traffic volume range. The relationships shown in Table 10-8 are illustrated in Figure 10-7. Lanes with widths greater than 12 ft are assigned a CMF equal to that for 12-ft lanes.

For lane widths with 0.5-ft increments that are not depicted specifically in Table 10-8 or Figure 10-7, a CMF value can be interpolated using either of these exhibits since there is a linear transition between the various AADT effects.

Table 10-8. CMF for Lane Width on Roadway Segments (CMF_{ra})

	AADT (vehicles per day)		
Lane Width	**< 400**	**400 to 2000**	**> 2000**
9 ft or less	1.05	$1.05 + 2.81 \times 10^{-4}$ (AADT − 400)	1.50
10 ft	1.02	$1.02 + 1.75 \times 10^{-4}$ (AADT − 400)	1.30
11 ft	1.01	$1.01 + 2.5 \times 10^{-5}$ (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 CMF applies include single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes.

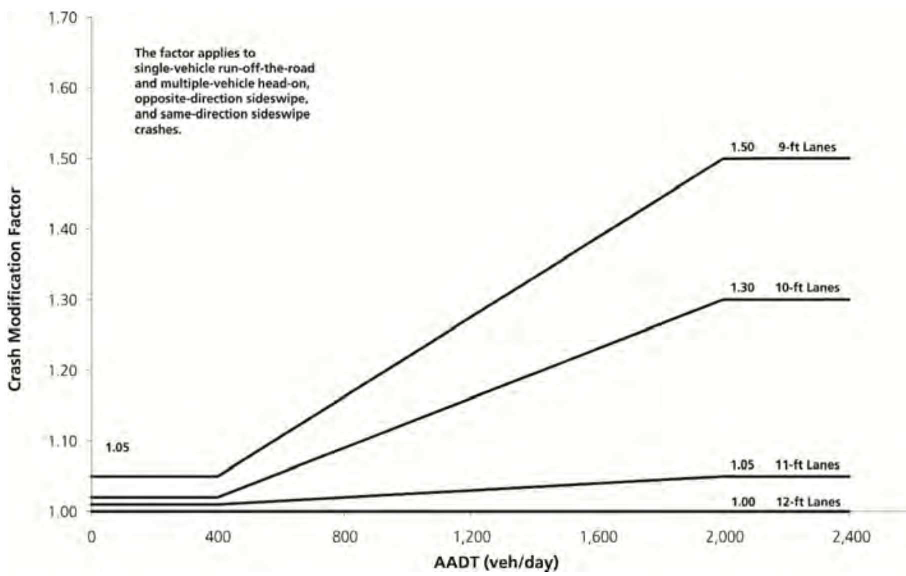

Figure 10-7. Crash Modification Factor for Lane Width on Roadway Segments

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

The CMFs shown in Table 10-8 and Figure 10-7 apply only to the crash 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 crashes. These are the only crash types assumed to be affected by variation in lane width, and other crash types are assumed to remain unchanged due to the lane width variation. The CMFs expressed on this basis are, therefore, adjusted to total crashes within the predictive method. This is accomplished using Equation 10-11:

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

Where:

CMF_{1r} = crash modification factor for the effect of lane width on total crashes;

CMF_{ra} = crash modification factor for the effect of lane width on related crashes (i.e., single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes), such as the crash modification factor for lane width shown in Table 10-8; and

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

The proportion of related crashes, p_{ra}, (i.e., single-vehicle run-off-the-road, and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipes crashes) is estimated as 0.574 (i.e., 57.4 percent) based on the default distribution of crash types presented in Table 10-4. This default crash type distribution, and therefore the value of p_{ra}, may be updated from local data as part of the calibration process.

CMF_{2r}—Shoulder Width and Type

The CMF for shoulders has a CMF for shoulder width (CMF_{wra}) and a CMF for shoulder type (CMF_{tra}). The CMFs for both shoulder width and shoulder type are based on the results of Zegeer et al. (16, 17). The base value of shoulder width and type is a 6-foot paved shoulder, which is assigned a CMF value of 1.00.

CMF_{wra} for shoulder width on two-lane highway segments is determined from Table 10-9 based on the applicable shoulder width and traffic volume range. The relationships shown in Table 10-9 are illustrated in Figure 10-8.

Shoulders over 8-ft wide are assigned a CMF_{wra} equal to that for 8-ft shoulders. The CMFs shown in Table 10-9 and Figure 10-8 apply only to single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes.

Table 10-9. CMF for Shoulder Width on Roadway Segments (CMF_{wra})

	AADT (vehicles per day)		
Shoulder Width	**< 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 CMF applies include single-vehicle run-off the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes.

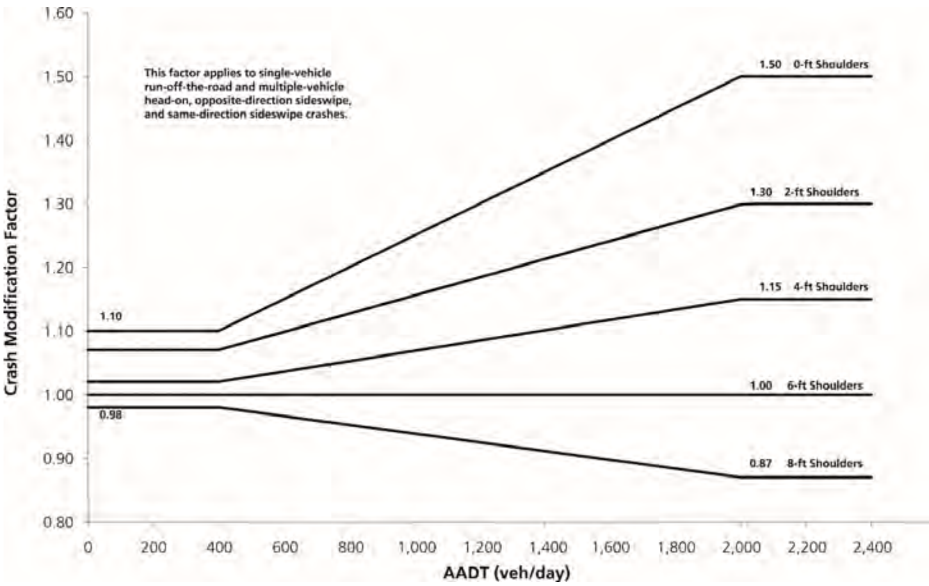

Figure 10-8. Crash Modification Factor for Shoulder Width on Roadway Segments

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

Table 10-10. Crash Modification Factors for Shoulder Types and Shoulder Widths on Roadway Segments (CMF_{tra})

	Shoulder Width (ft)						
Shoulder Type	**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 table 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 CMF are determined separately for the shoulder type and width in each direction of travel and the resulting CMFs are then be averaged.

The CMFs for shoulder width and type shown in Tables 10-9 and 10-10, and Figure 10-8 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 crashes. The CMFs expressed on this basis are, therefore, adjusted to total crashes using Equation 10-12.

$$CMF_{2r} = (CMF_{wra} \times CMF_{tra} - 1.0) \times p_{ra} + 1.0 \tag{10-12}$$

Where:

CMF_{2r} = crash modification factor for the effect of shoulder width and type on total crashes;

CMF_{wra} = crash modification factor for related crashes (i.e., single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes), based on shoulder width (from Table 10-9);

CMF_{tra} = crash modification factor for related crashes based on shoulder type (from Table 10-10); and

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

The proportion of related crashes, p_{ra}, (i.e., single-vehicle run-off-the-road, and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipes crashes) is estimated as 0.574 (i.e., 57.4 percent) based on the default distribution of crash types presented in Table 10-4. This default crash 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.

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

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

The CMF for horizontal curves has been determined from the regression model developed by Zegeer et al. (18).

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

$$CMF_{3r} = \frac{(1.55 \times L_c) + \left(\frac{80.2}{R}\right) - (0.012 \times S)}{(1.55 \times L_c)} \tag{10-13}$$

Where:

CMF_{3r} = crash modification factor for the effect of horizontal alignment on total crashes;

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

R = radius of curvature (feet); and

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 100 ft.

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

CMF_{4r}—Horizontal Curves: Superelevation

The base condition for the CMF for the superelevation of a horizontal curve is the amount of superelevation identified in *A Policy on Geometric Design of Highways and Streets*—also called the AASHTO Green Book (1). 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 CMF 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 CMF 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 a CMF for superelevation variance is based on the work of Zegeer et al. (18, 19).

The following relationships present the CMF for superelevation variance:

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

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

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

Where:

CMF_{4r} = crash modification factor for the effect of superelevation variance on total crashes; and

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

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

CMF_{5r}—Grades

The base condition for grade is a generally level roadway. Table 10-11 presents the CMF for grades based on an analysis of rural two-lane, two-way highway grades in Utah conducted by Miaou (8). The CMFs in Table 10-11 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 CMFs in Table 10-11 apply to total roadway segment crashes.

Table 10-11. Crash Modification Factors (CMF_{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

*CMF*6r—*Driveway Density*

The base condition for driveway density is five driveways per mile. As with the other CMFs, the model for the base condition was established for roadways with this driveway density. The CMF for driveway density is determined using Equation 10-17, derived from the work of Muskaug (9).

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

Where:

CMF6r = crash modification factor for the effect of driveway density on total crashes;

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

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

If driveway density is less than 5 driveways per mile, CMF_{6r} is 1.00. Equation 10-17 can be applied to total roadway crashes 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 entrances are not considered.

CMF7r—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 CMF_{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 CMF value presented in Chapter 13 and crash type percentages found in Chapter 10. Details of this derivation are not provided.

The CMF 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 CMF is 1.00.

CMF8r—Passing Lanes

The base condition for passing lanes is the absence of a lane (i.e., the normal two-lane cross section). The CMF 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 crashes 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 CMF 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 crashes over the length of the short four-lane section. This CMF 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 CMF does not apply to extended four-lane highway sections.

The CMF for passing lanes is based primarily on the work of Harwood and St.John (6), with consideration also given to the results of Rinde (11) and Nettelblad (10). The CMF for short four-lane sections is based on the work of Harwood and St. John (6).

CMF_{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 crashes related to turning maneuvers at driveways. The base condition for two-way left-turn lanes is the absence of a TWLTL. The CMF for installation of a TWLTL is:

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

Where:

CMF_{9r} = crash modification factor for the effect of two-way left-turn lanes on total crashes;

P_{dwy} = driveway-related crashes as a proportion of total crashes; and

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

The value of p_{dwy} can be estimated using Equation 10-19 (6).

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

Where:

P_{dwy} = driveway-related crashes as a proportion of total crashes; and

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 CMF 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 Part C, Appendix A.1 describes how to appropriately calibrate this value. This CMF applies to total roadway segment crashes.

The CMF 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 CMF for TWLTL installation is 1.00.

CMF_{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. (16). The CMF for roadside design was developed in research by Harwood et al. (5). The base value of roadside hazard rating for roadway segments is 3. The CMF is:

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

Where:

CMF_{10r} = crash modification factor for the effect of roadside design; and

RHR = roadside hazard rating.

This CMF applies to total roadway segment crashes. Photographic examples and quantitative definitions for each roadside hazard rating (1–7) as a function of roadside design features such as sideslope and clear zone width are presented in Appendix 13A.

CMF_{11r}—Lighting

The base condition for lighting is the absence of roadway segment lighting. The CMF for lighted roadway segments is determined, based on the work of Elvik and Vaa (2), as:

$$CMF_{11r} = 1.0 - \left[\left(1.0 - 0.72\times p_{inr} - 0.83\times p_{pnr}\right)\times p_{nr}\right] \tag{10-21}$$

Where:

CMF_{11r} = crash modification factor for the effect of lighting on total crashes;

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

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

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

This CMF applies to total roadway segment crashes. Table 10-12 presents default values for the nighttime crash proportions p_{inr}, p_{pnr}, and p_{nr}. HSM users are encouraged to replace the estimates in Table 10-12 with locally derived values. If lighting installation increases the density of roadside fixed objects, the value of CMF_{10r} is adjusted accordingly.

Table 10-12. Nighttime Crash Proportions for Unlighted Roadway Segments

	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occur at Night
Roadway Type	**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)

CMF_{12r}—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 CMF_{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 CMF value presented in Chapter 17 and crash type percentages found in Chapter 10. Details of this derivation are not provided.

10.7.2. Crash Modification Factors for Intersections

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

CMF_{1i}—Intersection Skew Angle

The base condition for intersection skew angle is zero 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 Section 14.6.2.

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

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

$$CMF_{1i} = e^{(0.004 \times skew)} \tag{10-22}$$

Where:

CMF_{1i} = crash modification factor for the effect of intersection skew on total crashes; and

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

This CMF applies to total intersection crashes.

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

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

$$CMF_{1i} = e^{(0.0054 \times skew)} \tag{10-23}$$

Where:

CMF_{1i} = crash modification factor for the effect of intersection skew on total crashes; and

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

This CMF applies to total intersection crashes.

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

Four-Leg All-Way Stop-Controlled and Three- and Four-Leg Signalized Intersections

Since the traffic ~~signal~~control at all-way stop-controlled and signalized intersections separates most movements from conflicting approaches, the risk of collisions related to the skew angle between the intersecting approaches is limited at all-way stop-controlled and~~a~~ signalized intersections. Therefore, the CMF for skew angle at four-leg all-way stop-controlled and three- and four-leg signalized intersections is 1.00 for all cases.

Three-Leg Stop-Controlled Turning Intersections

Since the traffic control and vehicle maneuvers at three-leg stop-controlled turning intersections are unique compared to the conventional three-leg stop-controlled intersections, the base conditions for the CMF for intersection skew angle (CMF1i) are not applicable to three-leg stop-controlled turning intersections. In addition, intersection skew angle was not found to be a significant predictor of crashes at three-leg stop-controlled turning intersections (*20*). Therefore, the CMF for skew angle at three-leg stop-controlled turning intersections is 1.00.

CMF_{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 CMFs for the presence of left-turn lanes are presented in Table 10-13. These CMFs 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 CMFs for installation of left-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF 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. Therefore,~~, so~~ the presence of a left-turn lane on a stop-controlled approach is ~~not considered in applying Table 10-13~~1.00. The CMFs for installation of left-turn lanes are based on research by Harwood et al. (5) and are consistent with the CMFs presented in Chapter 14. A CMF of 1.00 is always be used when no left-turn lanes are present. The CMF for intersection left-turn lanes is not applicable to three-leg stop-controlled turning intersections and four-leg all-way stop-controlled intersections. Therefore, the CMF for intersection left-turn lanes at three-leg stop-controlled turning intersections and four-leg all-way stop-controlled intersections is 1.00.

Table 10-13. Crash Modification Factors (CMF_{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	—	—
	Traffic signal	0.85	0.72~~—~~	—	—
Four-leg Intersection	Minor road stop control[b]	0.72	0.52	—	—
	Traffic signal	0.82	0.67	0.55	0.45

[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.

CMF_{3i}—Intersection Right-Turn Lanes

The base condition for intersection right-turn lanes is the absence of right-turn lanes on the intersection approaches. The CMF for the presence of right-turn lanes is based on research by Harwood et al. (5) and is consistent with the CMFs in Chapter 14. These CMFs 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 CMFs for installation of right-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF 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 Table 10-14.

The CMFs in the table apply to total intersection crashes. A CMF value of 1.00 is always be used when no right-turn lanes are present. This CMF applies only to right-turn lanes that are identified by marking or signing. The CMF is not applicable to long tapers, flares, or paved shoulders that may be used informally by right-turn traffic. The CMF for intersection right-turn lanes is not applicable to three-leg stop-controlled turning intersections and four-leg all-way stop-controlled intersections. Therefore, the CMF for intersection right-turn lanes at three-leg stop-controlled turning intersections and four-leg all-way stop-controlled intersections is 1.00.

Table 10-14. Crash Modification Factors (CMF_{3i}) for Right-Turn Lanes on Approaches to an Intersection on Rural Two-Lane, Two-Way Highways

		Number of Approaches with Right-Turn Lanes[a]			
Intersection Type	**Intersection Traffic Control**	**One Approach**	**Two Approaches**	**Three Approaches**	**Four Approaches**
Three-Leg Intersection	Minor road stop control[b]	0.86	0.74	—	—
	Traffic signal	0.96	0.92	—	—
Four-Leg Intersection	Minor road stop control[b]	0.86	0.74	—	—
	Traffic signal	0.96	0.92	0.88	0.85

[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.

CMF_{4i}—Lighting

The base condition for lighting is the absence of intersection lighting. The CMF for lighted intersections is adapted from the work of Elvik and Vaa (2), as:

$$CMF_{4i} = 1 - 0.38 \times p_{ni} \tag{10-24}$$

Where:

CMF_{4i} = crash modification factor for the effect of lighting on total crashes; and

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

This CMF applies to total intersection crashes. Table 10-15 presents default values for the nighttime crash proportion p_{ni}. HSM users are encouraged to replace the estimates in Table 10-15 with locally derived values.

Table 10-15. Nighttime Crash Proportions for Unlighted Intersections

	Proportion of Crashes that Occur at Night
Intersection Type	P_{ni}
3ST	0.260[a]
~~4ST~~3STT	~~0.244[a]~~0.503[b]
4ST	0.244[a]
4aST	0.284[b]
3SG	0.235[b]
4SG	0.286[a]

Note: [a] Based on HSIS data for California (2002–2006). [b] Based on data from NCHRP Project 17-68.

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. Crash 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, crash reporting threshold, and crash reporting practices. These variations may result in some jurisdictions experiencing a different number of reported traffic crashes 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 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 crashes than the roadways used in the development of the SPFs. The calibration factors for roadways that experience fewer crashes 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 Part C, Appendix A.

Calibration factors provide one method of incorporating local data to improve estimated crash 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 Part C, Appendix A.

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.

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.~~

~~10.11.~~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 10A 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.

~~10.12.~~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), crash modification factors (CMFs), 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 either total crashes or organized by crash-severity or collision-type distribution. In order to account for differences between the base conditions and the specific conditions of the site, CMFs 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 Part C, Appendix A.1.

Section 10.12 presents eight~~six~~ sample problems which detail the application of the predictive method. Appendix 10A contains worksheets which can be used in the calculations for the predictive method steps.

~~10.13.~~10.12. SAMPLE PROBLEMS

In this section, eight~~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 XB illustrates how to calculate the predicted average crash frequency for a three-leg stop-controlled turning intersection. Sample Problem XA illustrates how to calculate the predicted average crash frequency for a three-leg signalized 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).

Table 10-16. List of Sample Problems in Chapter 10

Problem No.	Page No.	Description
1	10–35	Predicted average crash frequency for a tangent roadway segment
2	10–42	Predicted average crash frequency for a curved roadway segment
3	10–49	Predicted average crash frequency for a three-leg stop-controlled intersection
XB		Predicted average crash frequency for a three-leg stop-controlled turning intersection
XA		Predicted average crash frequency for a three-leg signalized intersection
4	10–55	Predicted average crash frequency for a four-leg signalized intersection
5	10–60	Expected average crash frequency for a facility when site-specific observed crash data are available
6	10–62	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 Table 10-4.

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:

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

$$N_{spr\ rf} = 10,000 \times 1.5 \times 365 \times 10^{-6} \times e^{(-0.312)} = 4.008 \text{ crashes/year}$$

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

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

Lane Width (CMF_{1r})

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

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

For a 10-ft lane width and AADT of 10,000, $CMF_{ra} = 1.30$ (see Table 10-8).

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

$CMF_{1r} = (1.3 - 1.0) \times 0.574 + 1.0 = 1.17$

Shoulder Width and Type (CMF_{2r})

CMF_{2r} can be calculated from Equation 10-12, using values from Table 10-9, Table 10-10, and Table 10-4 as follows:

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

For 4-ft shoulders and AADT of 10,000, $CMF_{wra} = 1.15$ (see Table 10-9).

For 4-ft gravel shoulders, $CMF_{tra} = 1.01$ (see Table 10-10).

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

$CMF_{2r} = (1.15 \times 1.01 - 1.0) \times 0.574 + 1.0 = 1.09$

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

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

Horizontal Curves: Superelevation (CMF_{4r})

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

Grade (CMF_{5r})

From Table 10-11, for a two percent grade, $CMF_{5r} = 1.00$

Driveway Density (CMF_{6r})

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

$$\begin{aligned} CMF_{6r} &= \frac{0.322 + DD \times [0.05 - 0.005 \times \ln(AADT)]}{0.322 + 5 \times [0.05 - 0.005 \times \ln(AADT)]} \\ &= \frac{0.322 + 6 \times [0.05 - 0.005 \times \ln(10{,}000)]}{0.322 + 5 \times [0.05 - 0.005 \times \ln(10{,}000)]} \\ &= 1.01 \end{aligned}$$

Centerline Rumble Strips (CMF_{7r})

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

Passing Lanes (CMF_{8r})

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

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

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

Roadside Design (CMF_{10r})

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

$$
\begin{aligned}
CMF_{10r} &= \frac{e^{(-0.6869+0.0668\times RHR)}}{e^{(-0.4865)}} \\
&= \frac{e^{(-0.6869+0.0668\times 4)}}{e^{(-0.4865)}} \\
&= 1.07
\end{aligned}
$$

Lighting (CMF_{11r})

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

Automated Speed Enforcement (CMF_{12r})

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

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

$$CMF_{comb} = 1.17 \times 1.09 \times 1.01 \times 1.07 = 1.38$$

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:

$$
\begin{aligned}
&N_{\text{predicted } rs} = N_{spf\ rs} \times C_r \times \left(CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{12r} \right) \\
&= 4.008 \times 1.10 \times (1.38) = 6.084 \text{ crashes/year}
\end{aligned}
$$

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 SP1A (Corresponds to Worksheet 1A)*—General Information and Input Data for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP1B (Corresponds to Worksheet 1B)*—Crash Modification Factors for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP1C (Corresponds to Worksheet 1C)*—Roadway Segment Crashes for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP1D (Corresponds to Worksheet 1D)*—Crashes by Severity Level and Collision Type for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP1E (Corresponds to Worksheet 1E)*—Summary Results for Rural Two-Lane, Two-Way Roadway Segments

Details of these sample problem worksheets are provided below. Blank versions of corresponding worksheets are provided in Appendix 10A.

Worksheet SP1A—General Information and Input Data for Rural Two-Lane, Two-Way Roadway Segments

Worksheet SP1A is a summary of general information about the roadway segment, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 1.

Worksheet SP1A. 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/mi)	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 SP1B—Crash Modification Factors for Rural Two-Lane, Two-Way Roadway Segments

In Step 10 of the predictive method, crash 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 CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 13 of Worksheet SP1B which indicates the combined CMF value.

Worksheet SP1B. Crash Modification Factors for Rural Two-Lane, Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
CMF for Lane Width	**CMF for Shoulder Width and Type**	**CMF for Horizontal Curves**	**CMF for Superelevation**	**CMF for Grades**	**CMF for Driveway Density**	**CMF for Centerline Rumble Strips**	**CMF for Passing Lanes**	**CMF for Two-Way Left-Turn Lane**	**CMF for Roadside Design**	**CMF for Lighting**	**CMF for Automated Speed Enforcement**	**Combined CMF**
CMF_{1r}	CMF_{2r}	CMF_{3r}	CMF_{4r}	CMF_{5r}	*CMF6r*	CMF_{7r}	CMF_{8r}	CMF_{9r}	CMF_{10r}	CMF_{11r}	CMF_{12r}	CMF_{comb}
from Equation 10-11	from Equation 10-12	from Equation 10-13	from Equations 10-14, 10-15, or 10-16	from Table 10-11	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 SP1C—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 SP1C. 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 Table 10-3. 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 CMF (from Column 13 in Worksheet SP1B), and Column 7 represents the calibration factor. Column 8 calculates the predicted average crash frequency using the values in Column 5, the combined CMF in Column 6, and the calibration factor in Column 7.

Worksheet SP1C. 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 CMFs**	**Calibration Factor,** C_r	**Predicted Average Crash Frequency,** $N_{predicted\ rs}$
	from Equation 10-6	from Equation 10-7	from Table 10-3	(2)total*(4)	(13) from Worksheet SP1B		(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 SP1D—Crashes by Severity Level and Collision for Rural Two-Lane, Two-Way Roadway Segments

Worksheet SP1D presents the default proportions for collision type (from Table 10-4) 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 SP1C) by crash severity and collision type.

Worksheet SP1D. Crashes by Severity Level and Collision Type for Rural Two-Lane, Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	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)**
Collision Type	from Table 10-4	$(8)_{total}$ from Worksheet SP1C	from Table 10-4	$(8)_{FI}$ from Worksheet SP1C	from Table 10-4	$(8)_{PDO}$ from Worksheet SP1C
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 SP1E—Summary Results or Rural Two-Lane, Two-Way Roadway Segments

Worksheet SP1E presents a summary of the results. Using the roadway segment length, the worksheet presents the crash rate in miles per year (Column 5).

Worksheet SP1E. 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 SP1C	(8) from Worksheet SP1C		(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 percent.

The calibration factor is assumed to be 1.10.

Design speed = 60 mph

Maximum superelevation rate, $e_{max} = 6$ percent

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 CMFs to adjust the estimated crash frequency for base conditions to the site specific geometric design and traffic control features.

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

Lane Width (CMF_{1r})

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

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

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

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

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

Shoulder Width and Type (CMF_{2r})

CMF_{2r} can be calculated from Equation 10-12, using values from Table 10-9, Table 10-10, and local data (p_{ra} = 0.78) as follows:

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

For 2-ft shoulders and AADT of 8,000 veh/day, CMF_{wra} = 1.30 (see Table 10-9)

For 2-ft gravel shoulders, CMF_{tra} = 1.01 (see Table 10-10)

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

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

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

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

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

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

$$= 1.43$$

Horizontal Curves: Superelevation (CMF_{4r})

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

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

For a roadway segment with an assumed design speed of 60 mph and an assumed maximum superelevation (e_{max}) of six percent, AASHTO Green Book (1) 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).

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

Grade (CMF_{5r})

From Table 10-11, for a one percent grade, $CMF_{5r} = 1.00$.

Driveway Density (CMF_{6r})

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

Centerline Rumble Strips (CMF_{7r})

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

Passing Lanes (CMF_{8r})

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

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

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

Roadside Design (CMF_{10r})

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

$$
\begin{aligned}
CMF_{10r} &= \frac{e^{(-0.6869+0.0668\times RHR)}}{e^{(-0.4865)}} \\
&= \frac{e^{(-0.6869+0.0668\times 5)}}{e^{(-0.4865)}} \\
&= 1.14
\end{aligned}
$$

Lighting (CMF_{11r})

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

Automated Speed Enforcement (CMF_{12r})

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

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

$$CMF_{comb} = 1.04\times 1.24\times 1.43\times 1.06\times 1.14 = 2.23$$

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:

$$
\begin{aligned}
&N_{\text{predicted } rs} = N_{spf\ rs}\times C_r\times\left(CMF_{1r}\times CMF_{2r}\times\ldots\times CMF_{12r}\right) \\
&= 0.214\times 1.10\times\left(2.23\right) = 0.525 \text{ crashes/year}
\end{aligned}
$$

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 SP2A (Corresponds to Worksheet 1A)*—General Information and Input Data for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP2B (Corresponds to Worksheet 1B)*—Crash Modification Factors for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP2C (Corresponds to Worksheet 1C)*—Roadway Segment Crashes for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP2D (Corresponds to Worksheet 1D)*—Crashes by Severity Level and Collision Type for Rural Two-Lane, Two-Way Roadway Segments
- *Worksheet SP2E (Corresponds to Worksheet 1E)*—Summary Results for Rural Two-Lane, Two-Way Roadway Segments

Details of these sample problem worksheets are provided below. Blank versions of corresponding worksheets are provided in Appendix 10A.

Worksheet SP2A—General Information and Input Data for Rural Two-Lane, Two-Way Roadway Segments

Worksheet SP2A is a summary of general information about the roadway segment, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 2.

Worksheet SP2A. 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/mi)	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 SP2B—Crash Modification Factors for Rural Two-Lane, Two-Way Roadway Segments

In Step 10 of the predictive method, crash 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 CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 13 of Worksheet SP2B which indicates the combined CMF value.

Worksheet SP2B. Crash Modification Factors for Rural Two-Lane, Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
CMF for Lane Width	**CMF for Shoulder Width and Type**	**CMF for Horizontal Curves**	**CMF for Superelevation**	**CMF for Grades**	**CMF for Driveway Density**	**CMF for Centerline Rumble Strips**	**CMF for Passing Lanes**	**CMF for Two-Way Left-Turn Lane**	**CMF for Roadside Design**	**CMF for Lighting**	**CMF for Automated Speed Enforcement**	**Combined CMF**
CMF_{1r}	CMF_{2r}	CMF_{3r}	CMF_{4r}	CMF_{5r}	CMF_{6r}	CMF_{7r}	CMF_{8r}	CMF_{9r}	CMF_{10r}	CMF_{11r}	CMF_{12r}	CMF_{comb}
from Equation 10-11	from Equation 10-12	from Equation 10-13	from Equations 10-14, 10-15, or 10-16	from Table 10-11	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 SP2C—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 SP2C. 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 Table 10-3 (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 CMF (from Column 13 in Worksheet SP2B), and Column 7 represents the calibration factor. Column 8 calculates the predicted average crash frequency using the values in Column 5, the combined CMF in Column 6, and the calibration factor in Column 7.

Worksheet SP2C. 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 CMFs**	**Calibration Factor,** C_r	**Predicted Average Crash Frequency,** $N_{predicted\ rs}$
	from Equation 10-6	from Equation 10-7	from Table 10-3	$(2)_{total}$*(4)	(13) from Worksheet SP2B		(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 SP2D—Crashes by Severity Level and Collision for Rural Two-Lane, Two-Way Roadway Segments

Worksheet SP2D presents the default proportions for collision type (from Table 10-3) 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 SP2C) by crash severity and collision type.

Worksheet SP2D. 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 Table 10-4	$(8)_{total}$ from Worksheet SP2C	from Table 10-4	$(8)_{FI}$ from Worksheet SP2C	from Table 10-4	$(8)_{PDO}$ from Worksheet SP2C
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

Worksheet SP2E—Summary Results for Rural Two-Lane, Two-Way Roadway Segments

Worksheet SP2E presents a summary of the results. Using the roadway segment length, the worksheet presents the crash rate in miles per year (Column 5).

Worksheet SP2E. 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 SP2C	(8) from Worksheet SP2C		(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 Table 10-6.
- 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:

$$N_{spf\ 3ST} = exp\left[-9.86 + 0.79 \times \ln\left(AADT_{maj}\right) + 0.49 \times \ln\left(AADT_{min}\right)\right]$$
$$= exp\left[-9.86 + 0.79 \times \ln\left(8,000\right) + 0.49 \times \ln\left(1,000\right)\right] = 1.867 \text{ crashes/ year}$$

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

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

Intersection Skew Angle (CMF_{1i})

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

$$CMF_{1i} = e^{(0.004 \times skew)}$$

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

$$CMF_{1i} = e^{(0.004 \times 30)} = 1.13$$

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

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

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

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

Lighting (CMF_{4i})

CMF_{4i} can be calculated from Equation 10-24 using Table 10-15.

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

From Table 10-15, for a three-leg stop-controlled intersection, the proportion of total crashes that occur at night (see assumption), p_{ni}, is 0.26.

$$CMF_{4i} = 1 - 0.38 \times 0.26 = 0.90$$

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

$$CMF_{comb} = 1.13 \times 0.90 = 1.02$$

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:

$$N_{\text{predicted } int} = N_{spf\ int} \times C_i \times (CMF_{1i} \times CMF_{2i} \times \ldots \times CMF_{4i})$$
$$= 1.867 \times 1.50 \times (1.02) = 2.857 \text{ crashes/year}$$

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 SP3A (Corresponds to Worksheet 2A)*—General Information and Input Data for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SP3B (Corresponds to Worksheet 2B)*—Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SP3C (Corresponds to Worksheet 2C)*—Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SP3D (Corresponds to Worksheet 2D)*—Crashes by Severity Level and Collision Type for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SP3E (Corresponds to Worksheet 2E)*—Summary Results for Rural Two-Lane, Two-Way Road Intersections

Details of these sample problem worksheets are provided below. Blank versions of corresponding worksheets are provided in Appendix 10A.

Worksheet SP3A—General Information and Input Data for Rural Two-Lane, Two-Way Road Intersections

Worksheet SP3A is a summary of general information about the intersection, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 3.

Worksheet SP3A. 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, 3STT, 3SG, 4ST, 4aST, 4SG)		—	3ST
$AADT_{maj}$ (veh/day), ~~(~~$AADT_{maj1}$ (veh/day) (for 3STT only)		—	8,000
$AADT_{maj2}$ (veh/day)~~,~~ (for ~~(~~3STT only)~~)~~		—	—
$AADT_{min}$ (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 SP3B—Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections

In Step 10 of the predictive method, crash 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 CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 5 of Worksheet SP3B which indicates the combined CMF value.

Worksheet SP3B. Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)
CMF for Intersection Skew Angle	**CMF for Left-Turn Lanes**	**CMF for Right-Turn Lanes**	**CMF for Lighting**	**Combined CMF**
CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{comb}
from Equations 10-22 or 10-23	from Table 10-13	from Table 10-14	from Equation 10-24	(1)*(2)*(3)*(4)
1.13	1.00	1.00	0.90	1.02

Worksheet SP3C—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 SP3C. 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 Table 10-5. 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 CMF (from Column 5~~13~~ in Worksheet SP3B), and Column 7 represents the calibration factor. Column 8 calculates the predicted average crash frequency using the values in Column 5, the combined CMF in Column 6, and the calibration factor in Column 7.

Worksheet SP3C. Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	$N_{spf\ 3ST,\ 3STT,\ 3SG,\ 4ST,\ 4aST,\ or\ 4SG}$	**Overdispersion Parameter, *k***	**Crash Severity Distribution**	$N_{spf\ 3ST,\ 3STT,\ 3SG,\ 4ST,\ 4aST,\ or\ 4SG}$ **by Severity Distribution**	**Combined CMFs**	**Calibration Factor, C_i**	**Predicted Average Crash Frequency, $N_{predicted\ int}$**
	from Equations 10-8, 10-EC, 10-9, 10-EA, 10-EB, or 10-10	from Section 10.6.2	from Table 10-5	$(2)_{total}$*(4)	from (5) of Worksheet SP3B		(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 SP3D—Crashes by Severity Level and Collision for Rural Two-Lane, Two-Way Road Intersections

Worksheet SP3D presents the default proportions for collision type (from Table 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 SP3C) by crash severity and collision type.

Worksheet SP3D. 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 Table 10-6	$(8)_{total}$ from Worksheet SP3C	from Table 10-6	$(8)_{FI}$ from Worksheet SP3C	from Table 10-6	$(8)_{PDO}$ from Worksheet SP3C
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 SP3E—Summary Results for Rural Two-Lane, Two-Way Road Intersections

Worksheet SP3E presents a summary of the results.

Worksheet SP3E. 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 SP3C	(8) from Worksheet SP3C
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 XB

The Site/Facility

A three-leg stop-controlled intersection where the through movement makes a turning maneuver at the intersection located on a rural two-lane roadway.

The Question

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

The Facts

- 3 legs
- Minor-road stop control
- Through movement makes a turning maneuver at the intersection
- AADT of major road approach 1 = 5,000 veh/day
- AADT of major road approach 2 = 5,000 veh/day
- AADT of minor road = 1,250 veh/day
- Intersection lighting is present

Assumptions

- Collision type distributions used are the default values from Table 10-6.
- 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 1.20.

Results

Using the predictive method steps as outlined below, the predicted average crash frequency for the intersection in Sample Problem XB is determined to be 0.6 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 XB, 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 turning intersection can be calculated from Equations 10-EC and 10-ED as follows:

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$$\mathrm{TEV}_3 = 0.5 \times \left(\mathrm{AADT}_{\mathrm{maj},1} + \mathrm{AADT}_{\mathrm{maj},2} + \mathrm{AADT}_{\mathrm{min}}\right)$$

$$= 0.5 \times (5{,}000 + 5{,}000 + 1{,}250) = 5{,}625\ veh/day$$

$$N_{spf\ 3STT} = exp[-6.501 + 0.703 \times \ln(TEV_3)]$$

$$= exp[-6.501 + 0.703 \times \ln(5{,}625)] = 0.634\ crashes/year$$

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

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

CMF_{1i}, CMF_{2i}, and CMF_{3i} equal 1.00 for three-leg turning intersections.

Lighting (CMF_{4i})
CMF_{4i} can be calculated from Equation 10-24 using Table 10-15.

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

Field Code Changed

From Table 10-15, for a three-leg stop-controlled turning intersection, the proportion of total crashes that occur at night (see assumption), p_{ni}, is 0.503.

$$CMF_{4i} = 1 - 0.38 \times 0.503 = 0.81$$

The combined CMF value for Sample Problem XB is calculated below.

$$CMF_{comb} = 1.00 \times 0.81 = 0.81$$

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

It is assumed that a calibration factor, C_i, of 1.20 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:

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

$= 0.634 \times 1.20 \times 0.81 = 0.615\ crashes/year$

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 SPXBA (Corresponds to Worksheet 2A)*—General Information and Input Data for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SPXBB (Corresponds to Worksheet 2B)*—Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SPXBC (Corresponds to Worksheet 2C)*—Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SPXBD (Corresponds to Worksheet 2D)*—Crashes by Severity Level and Collision Type for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SPXBE (Corresponds to Worksheet 2E)*—Summary Results for Rural Two-Lane, Two-Way Road Intersections

Details of these sample problem worksheets are provided below. Blank versions of corresponding worksheets are provided in Appendix 10A.

Worksheet SP3A—General Information and Input Data for Rural Two-Lane, Two-Way Road Intersections

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

Worksheet SPXBA. 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, 3STT, 3SG, 4ST, 4aST, 4SG)		—	3STT
$AADT_{maj}$ (veh/day), $AADT_{maj1}$ (veh/day) (for 3STT only)		—	5,000
$AADT_{maj2}$ (veh/day), (for 3STT only)		—	5,000
$AADT_{min}$ (veh/day)		—	1,250
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	present
Calibration factor, C_i		1.0	1.20

Worksheet SPXBB—Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections

In Step 10 of the predictive method, crash 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 CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 5 of Worksheet SPXBB which indicates the combined CMF value.

Worksheet SPXBB. Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)
CMF for Intersection Skew Angle	**CMF for Left-Turn Lanes**	**CMF for Right-Turn Lanes**	**CMF for Lighting**	**Combined CMF**
CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{comb}
from Equations 10-22 or 10-23	from Table 10-13	from Table 10-14	from Equation 10-24	(1)*(2)*(3)*(4)
1.00	1.00	1.00	0.81	0.81

Worksheet SPXBC—Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections

The SPF for the intersection in Sample Problem XB is calculated using Equation 10-EC and entered into Column 2 of Worksheet SPXBC. The overdispersion parameter associated with the SPF can be entered into Column 3; however, the overdispersion parameter is not needed for Sample Problem XB (as the EB Method is not utilized). Column 4 of the worksheet presents the default proportions for crash severity levels from Table 10-5. 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 CMF (from Column 5 in Worksheet SPXBB), and Column 7 represents the calibration factor. Column 8 calculates the predicted average crash frequency using the values in Column 5, the combined CMF in Column 6, and the calibration factor in Column 7.

Worksheet SPXBC. Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	$N_{spf\ 3ST,\ 3STT,\ 3SG,\ 4ST,\ 4aST,\ or\ 4SG}$	**Overdispersion Parameter, *k***	**Crash Severity Distribution**	$N_{spf\ 3ST,\ 3STT,\ 3SG,\ 4ST,\ 4aST,\ or\ 4SG}$ **by Severity Distribution**	**Combined CMFs**	**Calibration Factor, C_i**	**Predicted Average Crash Frequency, $N_{predicted\ int}$**
	from Equations 10-8, 10-EC, 10-9, 10-EA, 10-EB, or 10-10	from Section 10.6.2	from Table 10-5	$(2)_{total}$*(4)	from (5) of Worksheet SPXBB		(5)*(6)*(7)
Total	0.634	0.24	1.000	0.634	0.81	1.20	0.615
Fatal and injury (FI)	—	—	0.360	0.228	0.81	1.20	0.221

Property damage only (PDO)	—	—	0.640	0.406	0.81	1.20	0.394

Worksheet SPXBD—Crashes by Severity Level and Collision for Rural Two-Lane, Two-Way Road Intersections

Worksheet SPXBD presents the default proportions for collision type (from Table 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 SPXBC) by crash severity and collision type.

Worksheet SPXBD. 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 Table 10-6	(8)$_{total}$ from Worksheet SPXBC	from Table 10-6	(8)$_{FI}$ from Worksheet SPXBC	from Table 10-6	(8)$_{PDO}$ from Worksheet SPXBC
Total	1.000	0.615	1.000	0.222	1.000	0.394
		(2)*(3)$_{total}$		(4)*(5)$_{FI}$		(6)*(7)$_{PDO}$
SINGLE-VEHICLE						
Collision with animal	0.071	0.044	0.000	0.000	0.112	0.044
Collision with bicycle	0.000	0.000	0.000	0.000	0.000	0.000
Collision with pedestrian	0.000	0.000	0.000	0.000	0.000	0.000
Overturned	0.038	0.023	0.069	0.015	0.021	0.008
Ran off road	0.571	0.351	0.611	0.135	0.549	0.216
Other single-vehicle collision	0.039	0.024	0.038	0.008	0.039	0.015
Total single-vehicle crashes	0.719	0.442	0.718	0.159	0.721	0.284
MULTIPLE-VEHICLE						
Angle collision	0.181	0.111	0.198	0.044	0.172	0.068
Head-on collision	0.028	0.017	0.038	0.008	0.021	0.008
Rear-end collision	0.022	0.014	0.015	0.003	0.026	0.010
Sideswipe collision	0.039	0.024	0.023	0.005	0.047	0.019

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Other multiple-vehicle collision	0.011	0.007	0.008	0.002	0.013	0.005
Total multiple-vehicle crashes	0.281	0.173	0.282	0.062	0.279	0.110

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Worksheet SPXBE—Summary Results for Rural Two-Lane, Two-Way Road Intersections

Worksheet SPXBE presents a summary of the results.

Worksheet SPXBE. 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 SPXBC	(8) from Worksheet SPXBC
Total	1.000	0.615
Fatal and injury (FI)	0.360	0.222
Property damage only (PDO)	0.640	0.394

10.12.5. Sample Problem XA

The Site/Facility

A three-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 same given conditions (i.e., facts) are used in this sample problem as in Sample Problem 3. Comparison of results between the two sample problems could be helpful in determining the need to install or remove a signal at a three-leg intersection on a rural two-lane roadway.

The Facts

- 3 legs
- Signalized
- 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 Table 10-6.

- 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 3-leg signalized intersection in Sample Problem XA is determined to be 2.4 crashes per year (rounded to one decimal place). In comparison, the predicted average crash frequency for a 3-leg stop-controlled intersection with the same site characteristics and traffic volume is 2.9 crashes per year (rounded to one decimal place) (see Sample Problem 3).

Steps

Step 1 through 8

To determine the predicted average crash frequency of the intersection in Sample Problem XA, 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 signalized intersection can be calculated from Equation 10-EB as follows:

$N_{spf3SG} = exp\ [-5.88 + 0.54 \times \ln(AADT_{maj}) + 0.23 \times \ln(AADT_{min})]$

$= exp\ [-5.88 + 0.54 \times \ln(8{,}000) + 0.23 \times \ln(1{,}000)] = 1.754$ crashes/year

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

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

Intersection Skew Angle (CMF_{1i})

The intersection skew angle for Sample Problem XA is 30 degrees. However, since this intersection is signalized, $CMF_{1i} = 1.00$.

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

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

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

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

Lighting (CMF_{4i})

CMF_{4i} can be calculated from Equation 10-24 using Table 10-15.

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

From Table 10-15, for a three-leg signalized intersection, the proportion of total crashes that occur at night (see assumption), p_{ni}, is 0.235.

$CMF_{4i} = 1 - 0.38 \times 0.235 = 0.91$

Since CMF_{4i} is the only CMF not equal to 1.00, the combined CMF value for Sample Problem XA is the same as CMF_{4i}.

$CMF_{comb} = 0.91$

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:

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

$= 1.754 \times 1.50 \times (0.91) = 2.396$ 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 SPXAA (Corresponds to Worksheet 2A)*—General Information and Input Data for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SPXAB (Corresponds to Worksheet 2B)*—Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SPXAC (Corresponds to Worksheet 2C)*—Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SPXAD (Corresponds to Worksheet 2D)*—Crashes by Severity Level and Collision Type for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SPXAE (Corresponds to Worksheet 2E)*—Summary Results for Rural Two-Lane, Two-Way Road Intersections

Details of these sample problem worksheets are provided below. Blank versions of corresponding worksheets are provided in Appendix 10A.

Worksheet SPXAA—General Information and Input Data for Rural Two-Lane, Two-Way Road Intersections

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

Worksheet SPXAA. 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, 3STT, 3SG, 4ST, 4aST, 4SG)		—	3SG
$AADT_{maj}$ (veh/day), ~~(~~$AADT_{maj1}$ (veh/day) (for 3STT only)		—	8,000
$AADT_{maj2}$ (veh/day)~~,~~ (for 3STT only)		—	—
$AADT_{min}$ (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 SPXAB—Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections

In Step 10 of the predictive method, crash 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 CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 5 of Worksheet SPXAB which indicates the combined CMF value.

Worksheet SPXAB. Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)
CMF for Intersection Skew Angle	CMF for Left-Turn Lanes	CMF for Right-Turn Lanes	CMF for Lighting	Combined CMF
CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{comb}
from Equations 10-22 or 10-23	from Table 10-13	from Table 10-14	from Equation 10-24	(1)*(2)*(3)*(4)
1.00	1.00	1.00	0.91	0.91

Worksheet SPXAC—Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections

The SPF for the intersection in Sample Problem XA is calculated using Equation 10-EB and entered into Column 2 of Worksheet SPXAC. The overdispersion parameter associated with the SPF can be entered into Column 3; however, the overdispersion parameter is not needed for Sample Problem XA (as the EB Method is not utilized). Column 4 of the worksheet presents the default proportions for crash severity levels from Table 10-5. 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 CMF (from Column 5~~13~~ in Worksheet SPXAB), and Column 7 represents the calibration factor. Column 8 calculates the predicted average crash frequency using the values in Column 5, the combined CMF in Column 6, and the calibration factor in Column 7.

Worksheet SPXAC. Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	$N_{spf\ 3ST,\ 3STT,\ 3SG,\ 4ST,\ 4aST\ or\ 4SG}$	Overdispersion Parameter, k	Crash Severity Distribution	$N_{spf\ 3ST,\ 3STT,\ 3SG,\ 4ST,\ 4aST\ or\ 4SG}$ by Severity Distribution	Combined CMFs	Calibration Factor, C_i	Predicted Average Crash Frequency, $N_{predicted\ int}$
	from Equations 10-8,10-EC, 10-9, ~~10-10,~~ 10-EA, ~~or~~ 10-EB, or 10-10	from Section 10.6.2	from Table 10-5	$(2)_{total}$*(4)	from (5) of Worksheet SPXAB		(5)*(6)*(7)
Total	1.754	0.31	1.000	1.754	0.91	1.50	2.396
Fatal and injury (FI)	—	—	0.373	0.654	0.91	1.50	0.894
Property damage only (PDO)	—	—	0.627	1.100	0.91	1.50	1.502

Worksheet SPXAD—Crashes by Severity Level and Collision for Rural Two-Lane, Two-Way Road Intersections

Worksheet SPXAD presents the default proportions for collision type (from Table 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 SPXAC) by crash severity and collision type.

Worksheet SPXAD. 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 Table 10-6	$(8)_{total}$ from Worksheet SPXAC	from Table 10-6	$(8)_{FI}$ from Worksheet SPXAC	from Table 10-6	$(8)_{PDO}$ from Worksheet SPXAC
Total	1.000	2.396	1.000	0.894	1.000	1.502
		$(2)*(3)_{total}$		$(4)*(5)_{FI}$		$(6)*(7)_{PDO}$
SINGLE-VEHICLE						
Collision with animal	0.018	0.043	0.000	0.000	0.034	0.051
Collision with bicycle	0.003	0.007	0.007	0.006	0.002	0.003
Collision with pedestrian	0.000	0.000	0.000	0.000	0.000	0.000
Overturned	0.018	0.043	0.046	0.041	0.006	0.009
Ran off road	0.001	0.002	0.000	0.000	0.002	0.003
Other single-vehicle collision	0.154	0.369	0.124	0.111	0.189	0.284
Total single-vehicle crashes	0.194	0.465	0.177	0.158	0.233	0.350
MULTIPLE-VEHICLE						
Angle collision	0.193	0.462	0.262	0.234	0.158	0.237
Head-on collision	0.027	0.065	0.057	0.051	0.017	0.026
Rear-end collision	0.460	1.102	0.426	0.381	0.463	0.696
Sideswipe collision	0.048	0.115	0.025	0.022	0.046	0.069
Other multiple-vehicle collision	0.077	0.184	0.053	0.047	0.082	0.123
Total multiple-vehicle crashes	0.805	1.929	0.823	0.736	0.766	1.151

Worksheet SPXAE—Summary Results for Rural Two-Lane, Two-Way Road Intersections

Worksheet SPXAE presents a summary of the results.

Worksheet SPXAE. 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 SPXAC	(8) from Worksheet SPXAC
Total	1.000	2.4
Fatal and injury (FI)	0.373	0.9
Property damage only (PDO)	0.627	1.5

~~10.12.4.~~10.12.6. 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 Table 10-6.
- 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:

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

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

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

Intersection Skew Angle (CMF_{1i})

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

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

From Table 10-13 for a signalized intersection with left-turn lanes on two approaches, $CMF_{2i} = 0.67$.

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

From Table 10-14 for a signalized intersection with a right-turn lane on one approach, $CMF_{3i} = 0.96$.

Lighting (CMF_{4i})

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

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

$$CMF_{comb} = 0.67 \times 0.96 = 0.64$$

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:

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

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 SP4A (Corresponds to Worksheet 2A)*—General Information and Input Data for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SP4B (Corresponds to Worksheet 2B)*—Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SP4C (Corresponds to Worksheet 2C)*—Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections

- *Worksheet SP4D (Corresponds to Worksheet 2D)*—Crashes by Severity Level and Collision for Rural Two-Lane, Two-Way Road Intersections
- *Worksheet SP4E (Corresponds to Worksheet 2E)*—Summary Results for Rural Two-Lane, Two-Way Road Intersections

Details of these sample problem worksheets are provided below. Blank versions of corresponding worksheets are provided in Appendix 10A.

Worksheet SP4A—General Information and Input Data for Rural Two-Lane, Two-Way Road Intersections

Worksheet SP4A is a summary of general information about the intersection, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 4.

Worksheet SP4A. 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, 3STT, 3SG, 4ST, 4aST, 4SG)	—	4SG
AADT$_{maj}$ (veh/day), (AADT$_{maj1}$ (veh/day) (for 3STT only)	—	10,000
AADT$_{maj2}$ (veh/day), (for 3STT only)	—	—
AADT$_{min}$ (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 SP4B—Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections

In Step 10 of the predictive method, crash 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 CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 5 of Worksheet SP4B which indicates the combined CMF value.

Worksheet SP4B. Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections

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(1)	(2)	(3)	(4)	(5)
CMF for Intersection Skew Angle	**CMF for Left-Turn Lanes**	**CMF for Right-Turn Lanes**	**CMF for Lighting**	**Combined CMF**
CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{comb}
from Equations 10-22 or10-23	from Table 10-13	from Table 10-14	from Equation 10-24	(1)*(2)*(3)*(4)
1.00	0.67	0.96	1.00	0.64

Worksheet SP4C—Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections

The SPF the intersection in Sample Problem 4 is calculated using Equation 10-10~~8~~ and entered into Column 2 of Worksheet SP4C. 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 Table 10-5. 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 CMF (from Column 5~~13~~ in Worksheet SP4B), and Column 7 represents the calibration factor. Column 8 calculates the predicted average crash frequency using the values in Column 5, the combined CMF in Column 6, and the calibration factor in Column 7.

Worksheet SP4C. Intersection Crashes for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crash Severity Level	$N_{spf\ 3ST,\ 3STT,\ 3SG,\ 4ST,\ 4aST\ or\ 4SG}$ ~~$N_{spf\ 3ST,\ 4ST,\ or\ 4SG}$~~	**Overdispersion Parameter,** k	**Crash Severity Distribution**	$N_{spf\ 3ST,\ 3STT,\ 3SG,\ 4ST,\ 4aST\ or\ 4SG}$ ~~$N_{spf\ 3ST,\ 4ST,\ or\ 4SG}$~~ **by Severity Distribution**	**Combined CMFs**	**Calibration Factor,** C_i	**Predicted Average Crash Frequency,** $N_{predicted\ int}$
	from Equations 10-8, 10-EC, 10-9, 10-EA, 10-EB, or 10-10	from Section 10.6.2	from Table 10-5	$(2)_{total}$*(4)	from (5) of Worksheet SP4B		(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 SP4D—Crashes by Severity Level and Collision for Rural Two-Lane, Two-Way Road Intersections

Worksheet SP4D presents the default proportions for collision type (from Table 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 SP4C) by crash severity and collision type.

Worksheet SP4D. 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 Table 10-6	$(8)_{total}$ from Worksheet SP4C	from Table 10-6	$(8)_{FI}$ from Worksheet SP4C	from Table 10-6	$(8)_{PDO}$ from Worksheet SP4C
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 SP4E—Summary Results for Rural Two-Lane, Two-Way Road Intersections

Worksheet SP4E presents a summary of the results.

Worksheet SP4E. 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 SP4C	(8) from Worksheet SP4C
Total	1.000	5.654
Fatal and injury (FI)	0.340	1.923
Property damage only (PDO)	0.660	3.732

~~10.12.5.~~10.12.7. 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 Part C, Appendix A.2.4.

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 SP5A (Corresponds to 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 SP5B (Corresponds to Worksheet 3B)*—Site-Specific EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

Details of these sample problem worksheets are provided below. Blank versions of corresponding worksheets are provided in Appendix 10A.

Worksheets SP5A—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 SP5A. 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 A 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 SP5A. 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)
	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, k	Weighted Adjustment, w	Expected average crash frequency, $N_{expected}$
Site Type	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$			Equation A-5	Equation A-4
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 as follows:

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

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 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 SP5B—Site-Specific EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

Worksheet SP5B 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 SP5B. 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 SP5A	$(8)_{comb}$ from Worksheet SP5A
	9.466	12.3
Fatal and injury (FI)	$(3)_{comb}$ from Worksheet SP5A	$(3)_{total}*(2)_{FI}/(2)_{total}$
	3.309	4.3
Property damage only (PDO)	$(4)_{comb}$ from Worksheet SP5A	$(3)_{total}*(2)_{PDO}/(2)_{total}$
	6.158	8.0

~~10.12.6.~~10.12.8. 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 Part C, Appendix A.2.5.

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 SP6A (Corresponds to 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 SP6B (Corresponds to Worksheet 4B)*—Project-Level EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

Details of these sample problem worksheets are provided below. Blank versions of corresponding worksheets are provided in Appendix 10A.

Worksheets SP6A—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 SP6A. 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 A 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. Part C, Appendix A.2.5 defines all the variables used in this worksheet. Detailed calculations of Columns 9 through 13 are provided below.

Worksheet SP6A. 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)
	Predicted Average Crash Frequency (crashes/year)					$N_{\text{predicted } w0}$	$N_{\text{predicted } w1}$	w_0	N_0	w_1	N_1	$N_{\text{expected/comb}}$
Site Type	$N_{\text{predicted (total)}}$	$N_{\text{predicted (FI)}}$	$N_{\text{predicted (PDO)}}$	**Observed Crashes,** N_{observed} **(crashes/year)**	**Overdispersion Parameter,** k	**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: $N_{\text{predicted } w0}$ = Predicted number of total crashes assuming that crash frequencies are statistically independent

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

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

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

Column 9—w_0

The weight placed on predicted crash frequency under the assumption that crashes frequencies for different roadway elements are statistically independent, $\mathbf{w_0}$, is calculated using Equation A-10 as follows:

$$w_0 = \frac{1}{1 + \frac{N_{\text{predicted } w0}}{N_{\text{predicted (total)}}}} \quad \text{(A-10)}$$

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

$$= 0.463$$

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 as follows:

$$N_0 = w_0 \times N_{\text{predicted(total)}} + (1 - w_0) \times N_{\text{observed(total)}}$$
$$= 0.463 \times 9.466 + (1 - 0.463) \times 15 = 12.438 \quad \text{(A-11)}$$

Column 11—w_1

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

$$w_1 = \frac{1}{1 + \frac{N_{\text{predicted } w1}}{N_{\text{predicted (total)}}}} \quad \text{(A-12)}$$
$$= \frac{1}{1 + \frac{3.342}{9.466}}$$
$$= 0.739$$

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 as follows:

$$N_1 = w_1 \times N_{\text{predicted(total)}} + (1 - w_1) \times N_{\text{observed(total)}} \quad \text{(A-13)}$$
$$= 0.739 \times 9.466 + (1 - 0.739) \times 15 = 10.910$$

Column 13—$N_{\text{expected/comb}}$

The expected average crash frequency based of combined sites, $N_{\text{expected/}comb}$, is calculated using Equation A-14 as follows:

$$N_{\text{expected/}comb} = \frac{N_0 + N_1}{2} \quad \text{(A-14)}$$
$$= \frac{12.438 + 10.910}{2}$$
$$= 11.674$$

Worksheet SP6B—Project-Level EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

Worksheet SP6B 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 SP6B. 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 SP6A	$(13)_{comb}$ from Worksheet SP6A
	9.466	11.7
Fatal and injury (FI)	$(3)_{comb}$ from Worksheet SP6A	$(3)_{total}*(2)_{FI}/(2)_{total}$
	3.309	4.1
Property damage only (PDO)	$(4)_{comb}$ from Worksheet SP6A	$(3)_{total}*(2)_{PDO}/(2)_{total}$
	6.158	7.6

~~10.14.~~10.13. REFERENCES

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APPENDIX 10A. 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. Crash Modification Factors for Rural Two-Lane, Two-Way Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
CMF for Lane Width	**CMF for Shoulder Width and Type**	**CMF for Horizontal Curves**	**CMF for Superelevation**	**CMF for Grades**	**CMF for Driveway Density**	**CMF for Centerline Rumble Strips**	**CMF for Passing Lanes**	**CMF for Two-Way Left-Turn Lane**	**CMF for Roadside Design**	**CMF for Lighting**	**CMF for Automated Speed Enforcement**	**Combined CMF**
CMF_{1r}	CMF_{2r}	CMF_{3r}	CMF_{4r}	CMF_{5r}	CMF_{6r}	CMF_{7r}	CMF_{8r}	CMF_{9r}	CMF_{10r}	CMF_{11r}	CMF_{12r}	CMF_{comb}
from Equation 10-11	from Equation 10-12	from Equation 10-13	from Equations 10-14, 10-15, or 10-16	from Table 10-11	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)

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 CMFs**	**Calibration Factor, C_r**	**Predicted Average Crash Frequency, $N_{predicted\ rs}$**
	from Equation 10-6	from Equation 10-7	from Table 10-3	$(2)_{total}$*(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)
	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)**
Collision Type	**from Table 10-4**	**(8)total from Worksheet 1C**	**from Table 10-4**	**(8)FI from Worksheet 1C**	**from Table 10-4**	**(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 Distribution	Predicted Average Crash Frequency (crashes/year)	Roadway Segment Length (mi)	Crash Rate (crashes/mi/year)
Crash Severity Level	(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, 3STT, 3SG, 4ST, 4aST, 4SG)	—	
$AADT_{maj}$ (veh/day), ~~(~~$AADT_{maj1}$ (veh/day) (for 3STT only)	—	
$AADT_{maj2}$ (veh/day)~~,~~ (for 3STT only)		
$AADT_{min}$ (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. Crash Modification Factors for Rural Two-Lane, Two-Way Road Intersections

(1)	(2)	(3)	(4)	(5)
CMF for Intersection Skew Angle	CMF for Left-Turn Lanes	CMF for Right-Turn Lanes	CMF for Lighting	Combined CMF
CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{comb}
from Equations 10-22 or 10-23	from Table 10-13	from Table 10-14	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	$N_{spf\ 3ST,\ 3STT,\ 3SG,\ 4ST,\ 4aST,\ or\ 4SG}$	**Overdispersion Parameter, k**	**Crash Severity Distribution**	$N_{spf\ 3ST,\ 3STT,\ 3SG,\ 4ST,\ 4aST,\ or\ 4SG}$ **by Severity Distribution**	**Combined CMFs**	**Calibration Factor, C_i**	**Predicted Average Crash Frequency, $N_{predicted\ int}$**
	from Equations 10-8, 10-EC, 10-9, 10-EA, 10-EB, or 10-10	from Section 10.6.2	from Table 10-5	$(2)_{total}$*(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 Table 10-6	$(8)_{total}$ from Worksheet 2C	from Table 10-6	$(8)_{FI}$ from Worksheet 2C	from Table 10-6	$(8)_{PDO}$ 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)
	Predicted Average Crash Frequency (crashes/year)					**Weighted Adjustment, w**	**Expected Average Crash Frequency, $N_{expected}$**
Site Type	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$	**Observed Crashes, $N_{observed}$ (crashes/year)**	**Overdispersion Parameter, k**	**Equation A-5**	**Equation A-4**
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 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)
	Predicted Average Crash Frequency (crashes/year)					$N_{predicted\ w0}$	$N_{predicted\ w1}$	w_0	N_0	w_1	N_1	$N_{expected/comb}$
Site Type	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$	**Observed Crashes, $N_{observed}$ (crashes/year)**	**Overdispersion Parameter, k**	**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	$N_{predicted}$	$N_{expected/comb}$
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	$(3)_{total}*(2)_{PDO}/(2)_{total}$

CHAPTER 11. PREDICTIVE METHOD FOR RURAL MULTILANE HIGHWAYS

11.1. INTRODUCTION

This chapter presents for the predictive method for rural multilane highways. 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 multilane highways provides a structured methodology to estimate the expected average crash frequency, crash severity, and collision types for a rural multilane highway 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 in a period of time that occurred in the past (i.e., what did or would have occurred) or in the future (i.e., what is expected to occur). The development of the predictive models in Chapter 11 is documented in Lord et al. (5). The CMFs used in the predictive models have been reviewed and updated by Harkey et al. (3) and in related work by Srinivasan et al. (6). The SPF coefficients, default collision type distributions, and default nighttime crash proportions have been adjusted to a consistent basis by Srinivasan et al. (7). SPFs, default collision type distributions, and default nighttime crash proportions for three-leg signalized intersections were added to Chapter 11 in the second edition of the *Highway Safety Manual* based on NCHRP Project 17-68 (9).

This chapter presents the following information about the predictive method for rural multilane highways:

- A concise overview of the predictive method.
- The definitions of the facility types included in Chapter 11 and site types for which predictive models have been developed for Chapter 11.
- The steps of the predictive method in graphical and descriptive forms.
- Details for dividing a rural multilane facility into individual sites, consisting of intersections and roadway segments.
- Safety performance functions (SPFs) for rural multilane highways.
- Crash modification factors (CMFs) applicable to the SPFs in Chapter 11.
- Guidance for application of the Chapter 11 predictive method and limitations of the predictive method specific to Chapter 11.
- Sample problems illustrating the application of the Chapter 11 predictive method for rural multilane highways.

11.2. 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 signalized and unsignalized 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 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 predictive models used in Chapter 11 to determine the predicted average crash frequency, $N_{\text{predicted}}$, are of the general form shown in Equation 11-1.

$$N_{\text{predicted}} = N_{spf\ x} \times (CMF_{1x} \times CMF_{2x} \times \ldots \times CMF_{yx}) \times C_x \qquad (11\text{-}1)$$

Where:

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

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

CMF_{yx} = crash modification factors specific to site type x and specific geometric design and traffic control features y; and

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

11.3. RURAL MULTILANE HIGHWAYS—DEFINITIONS AND PREDICTIVE MODELS IN CHAPTER 11

This section provides the definitions of the facility and site types and the predictive models for each of the site types included in Chapter 11. These predictive models are applied following the steps of the predictive method presented in Section 11.4.

11.3.1. Definition of Chapter 11 Facility and Site Types

Chapter 11 applies to rural multilane highway facilities. The term “multilane” refers to facilities with four through lanes. Rural multilane highway facilities may have occasional grade-separated interchanges, but these are not to be the primary form of access and egress. The predictive method does not apply to any section of a multilane highway within the limits of an interchange which has free-flow ramp terminals on the multilane highway of interest. Facilities with six or more lanes are not covered in Chapter 11.

The terms “highway” and “road” are used interchangeably in this chapter and apply to all rural multilane 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 less 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.

Table 11-1 identifies the specific site types on rural multilane highways for which predictive models have been developed for estimating expected average crash frequency, severity, and collision type. The four-leg signalized intersection models do not have base conditions and, therefore, can be used only for generalized predictions of crash frequencies. No predictive models are available for roadway segments with more than four lanes or for other intersection types such as all-way stop-controlled intersections, yield-controlled intersections, or uncontrolled intersections.

Table 11-1. Rural Multilane Highway Site Type with SPFs in Chapter 11

Site Type	Site Types with SPFs in Chapter 11
Roadway Segments	Rural four-lane undivided segments (4U) Rural four-lane divided segments (4D)
Intersections	Unsignalized three-leg (Stop control on minor-road approaches) (3ST) Unsignalized four-leg (Stop control on minor-road approaches) (4ST) Signalized three-leg (3SG) Signalized four-leg (4SG)[a]

[a] The four-leg signalized intersection models do not have base conditions and, therefore, can be used only for generalized predictions of crash frequency.

These specific site types are defined as follows:

- *Undivided four-lane roadway segment (4U)*—a roadway consisting of four lanes with a continuous cross-section which provides two directions of travel in which the lanes are not physically separated by either distance or a barrier. While multilane roadways whose opposing lanes are separated by a flush median (i.e., a painted median) are considered undivided facilities, not divided facilities, the predictive models in Chapter 11 do not address rural multilane highways with flush separators.
- Divided four-lane roadway segment (4D)—Divided highways are non-freeway facilities (i.e., facilities without full control of access) that have the lanes in the two directions of travel separated by a raised, depressed, or flush median which is not designed to be traversed by a vehicle; this may include raised or depressed medians with or without a physical median barrier, or flush medians with physical median barriers.
- *Three-leg intersection with stop control (3ST)*—an intersection of a rural multilane highway (i.e., four lane divided or undivided roadway) 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 multilane highway (i.e., four lane divided or undivided roadway) and two minor roads. A stop sign is provided on both minor-road approaches to the intersection.
- *Three-leg signalized intersection (3SG)*—an intersection of a rural multilane highway (i.e., four-lane divided or undivided roadway) and a minor road. Signalized control is provided at the intersection by traffic lights.
- *Four-leg signalized intersection (4SG)*—an intersection of a rural multilane highway (i.e., four lane divided or undivided roadway) and two other rural roads which may be two lane or four lane rural highways. Signalized control is provided at the intersection by traffic lights.

11.3.2. Predictive Models for Rural Multilane Roadway Segments

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

The predictive models for roadway segments estimate the predicted average crash frequency of non-intersection-related crashes. In other words, the roadway segment predictive models estimate crashes that would occur regardless of the presence of an intersection.

The predictive models for undivided roadway segments, divided roadway segments and intersections are presented in Equations 11-2, 11-3, and 11-4 below.

For undivided roadway segments the predictive model is:

$$N_{\text{predicted } rs} = N_{spf\ ru} \times C_r \times (CMF_{1ru} \times CMF_{2ru} \times \ \ldots \ \times CMF_5 ru) \tag{11-2}$$

For divided roadway segments the predictive model is:

$$N_{\text{predicted } rs} = N_{spf\ rd} \times C_r \times (CMF_{1rd} \times CMF_{2rd} \times \ \ldots \ \times CMF_{5rd}) \tag{11-3}$$

Where:

$N_{\text{predicted } rs}$ = predictive model estimate of expected average crash frequency for an individual roadway segment for the selected year;

$N_{spf\ ru}$ = expected average crash frequency for an undivided roadway segment with base conditions;

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

$CMF_{1ru}\ldots CMF_{5ru}$ = crash modification factors for undivided roadway segments;

$N_{spf\ rd}$ = expected average crash frequency for a divided roadway segment with base conditions; and

$CMF_{1rd}\ldots CMF_{5rd}$ = crash modification factors for divided roadway segments.

11.3.3. Predictive Models for Rural Multilane Highway Intersections

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

For all intersection types in Chapter 11 the predictive model is:

$$N_{\text{predicted } int} = N_{spf\ int} \times C_i \times (CMF_{1i} \times CMF_{2i} \times \ldots \times CMF_{4i}) \tag{11-4}$$

Where:

$N_{\text{predicted } int}$ = 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;

$CMF_{1i}\ldots CMF_{4i}$ = crash modification factors for intersections— $CMF_{1i}\ldots CMF_{4i}$ ~~however, these CMFs~~ are ~~only~~ applicable to three- and four-leg stop-controlled intersections. $CMF_{2i}\ldots CMF_{4i}$ are applicable to three-leg signalized intersections. No CMFs are available for four-leg signalized intersections; and

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

The SPFs for rural multilane highways are presented in Section 11.6. The associated CMFs for each of the SPFs are presented in Section 11.7, and summarized in Table 11-10. Only the specific CMFs associated with each SPF are applicable to that SPF (as these CMFs have base conditions which are identical to the base conditions of the SPF). The calibration factors, C_r and C_i, are determined in 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.

11.4. PREDICTIVE METHOD FOR RURAL MULTILANE HIGHWAYS

The predictive method for rural multilane highways is shown in Figure 11-1. Applying the predictive method yields an estimate of the expected average crash frequency (and/or crash severity and collision types) for a rural multilane highway facility. The components of the predictive models in Chapter 11 are determined and applied in Steps 9, 10, and 11 of the predictive method. Further information needed to apply each step is provided in the following sections and in Part C, Appendix A.

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 rural multilane highways.

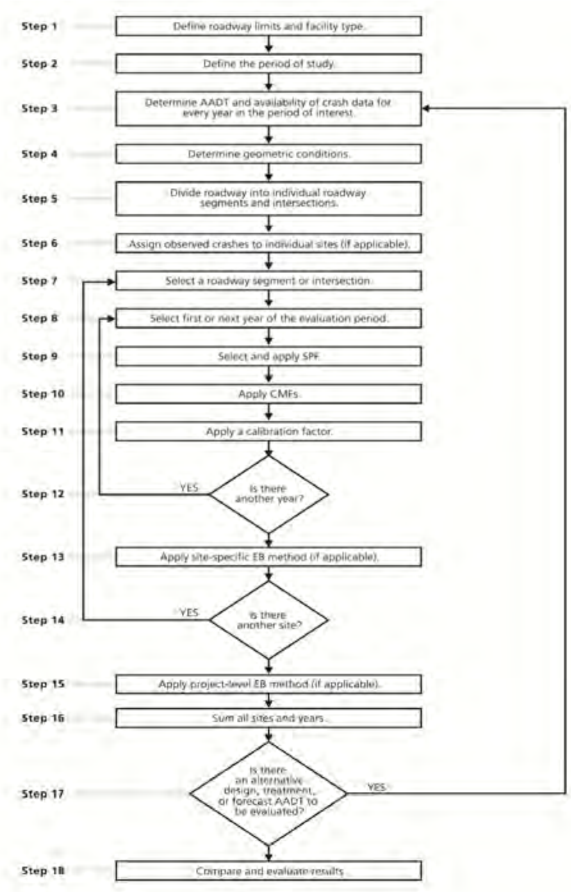


Figure 11-1. The HSM Predictive Method

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 an individual site. A site is either an intersection or a homogeneous roadway segment. Sites may consist of a number of types, such as signalized and unsignalized intersections. The definitions of a rural multilane highway, an intersection and roadway segments, and the specific site types included in Chapter 11 are provided in Section 11.3.

The predictive method can be undertaken for an existing roadway, a design alternative for an existing, or a 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 very long corridor for the purposes of network screening (determining which sites require upgrading to reduce crashes) which is discussed in Chapter 4, Network Screening.

Step 2—Define the period of interest.

The predictive method can be undertaken for either a past or future period measured in years. Years of interest will be determined by the availability of observed or forecast ~~average annual daily traffic~~annual average daily traffic (AADT) volumes, 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 CMFs 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.

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.

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

In Chapter 11, $AADT_{maj}$ 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 are used for $AADT_{maj}$. For a three-leg intersection, the AADT of the minor-road leg is used for $AADT_{min}$. For a four-leg intersection, the larger of the AADTs for the two minor-road legs should be used for $AADT_{min}$. ~~If a highway agency lacks data on the entering traffic volumes, but has two-way AADT data for the major and minor-road legs of the intersection, these may be used as a substitute for the entering volume data.~~ Where needed, $AADT_{total}$ can be estimated as the sum of $AADT_{maj}$ and $AADT_{min}$.

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 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 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 crash 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 Part C, Appendix A.2.1.

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 cannot 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 to avoid unnecessary data collection, it is necessary to understand the base conditions of the SPFs in Step 9 and the CMFs in Step 10. The base conditions are defined in Sections 11.6.1 and 11.6.2 for roadway segments and in Section 11.6.3 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 a CMF is applicable:

- Length of roadway segment (miles)
- AADT (vehicles per day)
- Presence of median and median width (feet) (for divided roadway segments)
- Sideslope (for undivided roadway segments)

- Shoulder widths (feet)
- Lane width (feet)
- Presence of lighting
- Presence of automated speed enforcement

For each intersection in 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 signalized)
- Intersection skew angle (stop-controlled and three-leg signalized intersections)
- Presence of left-turn and right-turn lanes (stop-controlled and three-leg signalized intersections)
- Presence or absence of lighting (stop-controlled and three-leg signalized intersections)

Step 5—Divide the roadway network or facility under consideration into individual homogenous roadway segments and intersections, which are referred to as sites.
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 11 predictive models are provided in Section 11.5. 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.

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 crashes to individual roadway segments or intersections are presented in Part C, Appendix A.2.3.

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 has been 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 is desired (crashes per year), 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 14.
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 CMFs (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.

Steps 9 through 13, described below, 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 11 follow the general form shown in Equation 11-1. Each predictive model consists of a SPF, which is adjusted to site specific conditions using CMFs (in Step 10) and adjusted to local jurisdiction conditions (in Step 11) using a calibration factor (C). The SPFs, CMFs and calibration factor obtained in Steps 9, 10, and 11 are applied to calculate the predictive model estimate of predicted average crash frequency for the selected year of the selected site. The SPFs available for rural multilane highways are presented in Section 11.6.

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 11.6. A detailed explanation and overview of the SPFs in Part C is provided in Section C.6.3.

The SPFs (and base conditions) developed for Chapter 11 are summarized in Table 11-2. For the selected site, determine the appropriate SPF for the site type (intersection or roadway segment) and geometric and traffic control features (undivided roadway, divided roadway, stop-controlled intersection, signalized intersection). The SPF for the selected site is calculated using the AADT determined in Step 3 (or $AADT_{maj}$ and $AADT_{min}$ for intersections) for the selected year.

Each SPF determined in Step 9 is provided with default distributions of crash severity and collision type (presented in Section 11.6). 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.

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric conditions and traffic control features.

In order to account for differences between the base conditions (Section 11.6) and the site specific conditions, CMFs are used to adjust the SPF estimate. An overview of CMFs and guidance for their use is provided in Section C.6.4, including the limitations of current knowledge related to the effects of simultaneous application of multiple CMFs. In using multiple CMFs, engineering judgment is required to assess the interrelationships and/or independence of individual elements or treatments being considered for implementation within the same project.

All CMFs used in Chapter 11 have the same base conditions as the SPFs used in Chapter 11 (i.e., when the specific site has the same condition as the SPF base condition, the CMF value for that condition is 1.00). Only the CMFs presented in Section 11.7 may be used as part of the Chapter 11 predictive method. Table 11-10 indicates which CMFs are applicable to the SPFs in Section 11.6.

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 in the data sets. Calibration of the SPFs to local conditions will account for differences in the data set. 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 Section C.6.5. 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 11-2, 11-3, and 11-4 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 11 predictive model estimate of predicted average crash frequency, $N_{\text{predicted}}$, 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, overdispersion parameter, k, for the SPF is used. This is in addition to the material in Part C, Appendix A.2.4. 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 $N_{\text{predicted}}$ and N_{observed}. Overdispersion parameters are provided for each SPF in Section 11.6.

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. Part C, Appendix A.2.6 provides a method to convert the estimate of expected average crash frequency for a past time period 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 cannot 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.

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 11-5:

$$N_{\text{total}} = \sum_{\substack{\text{all} \\ \text{roadway} \\ \text{segments}}} N_{rs} + \sum_{\substack{\text{all} \\ \text{intersections}}} N_{int} \tag{11-5}$$

Where:

N_{total} = total expected number of crashes within the limits of a rural multilane highway 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; and

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

Equation 11-5 represents the total expected number of crashes estimated to occur during the study period. Equation 11-6 is used to estimate the total expected average crash frequency within the network or facility limits during the study period.

$$N_{\text{total averange}} = \frac{N_{\text{total}}}{n} \tag{11-6}$$

$$N_{\text{total}} = \sum_{\substack{\text{all} \\ \text{roadway} \\ \text{segments}}} N_{rs} + \sum_{\substack{\text{all} \\ \text{intersections}}} N_{int} \tag{11-6}$$

Where:

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

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 11.6. 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.

11.5. ROADWAY SEGMENTS AND INTERSECTIONS

Section 11.4 provides an explanation of the predictive method. Sections 11.5 through 11.8 provide the specific detail necessary to apply the predictive method steps on rural multilane roads. Detail regarding the procedure for determining a calibration factor to apply in Step 11 is provided in Part C, Appendix A.1. Detail regarding the EB Method, which is applied in Steps 6, 13, and 15, is provided in 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 for 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 Figure 11-2. When a roadway segment begins or ends at an intersection, the length of the roadway segment is measured from the center of the intersection.

Chapter 11 provides predictive models for stop-controlled (three- and four-leg) and signalized (three- and four-leg) intersections. The intersection models estimate the predicted average frequency of crashes that occur within the curbline limits of an intersection (Region A of Figure 11-2) and intersection-related crashes that occur on the intersection legs (Region B in Figure 11-2).

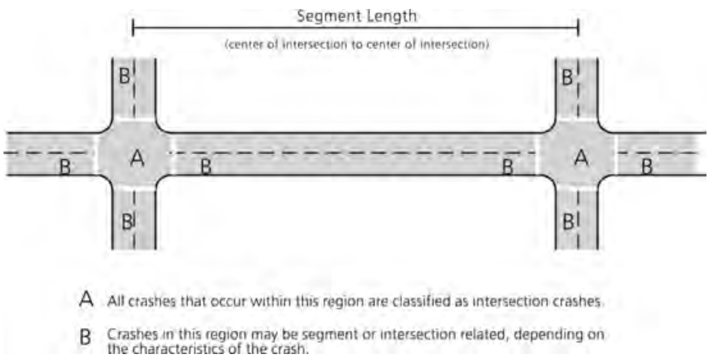


Figure 11-2. Definition of Segments and Intersections

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, key roadway design characteristics, and traffic control features. Figure 11-2 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 an intersection or where there is a change in at least one of the following characteristics of the roadway:

- ~~Average annual daily traffic~~Annual average daily traffic (vehicles per day)
- Presence of median and median width (feet)

The following rounded median widths are recommended before determining "homogeneous" segments:

Measured Median Width	Rounded Median Width
1 ft to 14 ft	10 ft
15 ft to 24 ft	20 ft
25 ft to 34 ft	30 ft
35 ft to 44 ft	40 ft
45 ft to 54 ft	50 ft
55 ft to 64 ft	60 ft
65 ft to 74 ft	70 ft
75 ft to 84 ft	80 ft
85 ft to 94 ft	90 ft
95 ft or more	100 ft

- Sideslope (for undivided roadway segments)
- Shoulder type
- Shoulder width (feet)

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

- Lane width (feet)

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

- Presence of lighting
- Presence of automated speed enforcement

In addition, each individual intersection is treated as a separate site for which the intersection-related crashes are estimated using the predictive method.

There is no minimum roadway segment length, L, for application of the predictive models for roadway segments. However, as a practical matter, 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 Part C, Appendix A.2.3.

11.6. 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 predicted crash frequencies for base conditions are calculated from the predictive method in Equations 11-2, 11-3, and 11-4. A detailed discussion of SPFs and their use in the HSM is presented in Sections 3.5.2 and 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 Part C, Appendix A. The SPFs in Chapter 11 are summarized in Table 11-2.

Table 11-2. Safety Performance Functions included in Chapter 11

Chapter 11 SPFs for Rural Multilane Highways	SPF Equations and Exhibits
Undivided rural four-lane roadway segments	Equations 11-7 and 11-8, Table 11-3, Figure 11-3
Divided roadway segments	Equations 11-9 and 11-10, Tables 11-4 and 11-5
Three- and four-leg stop-controlled intersections	Equation 11-11, Table 11-7
Three- and ~~F~~four-leg signalized intersections	Equations 11-11 and 11-12, Table~~s 11-7 and~~ 11-8

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 Part C, Appendix A.

11.6.1. Safety Performance Functions for Undivided Roadway Segments

The predictive model for estimating predicted average crash frequency on a particular undivided rural multilane roadway segment was presented in Equation 11-2. The effect of traffic volume (AADT) on crash frequency is incorporated through the SPF, while the effects of geometric design and traffic control features are incorporated through the CMFs.

The base conditions of the SPF for undivided roadway segments on rural multilane highways are:

- Lane width (LW) 12 feet
- Shoulder width 6 feet
- Shoulder type Paved
- Sideslopes 1V:7H or flatter
- Lighting None
- Automated speed enforcement None

The SPF for undivided roadway segments on a rural multilane highway is shown in Equation 11-7 and presented graphically in Figure 11-3:

$$N_{spf\ ru} = e^{(a + b \times \ln(AADT) + \ln(L))} \tag{11-7}$$

Where:

$N_{spf\ ru}$ =base total expected average crash frequency for a roadway segment;

$AADT$ =annual average daily traffic (vehicles per day) on roadway segment;

L =length of roadway segment (miles); and

a, b =regression coefficients.

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 11.4. The SPFs for undivided roadway segments on rural multilane highways are applicable to the AADT range from zero to 33,200 vehicles per day. Application to sites with AADTs substantially outside this range may not provide accurate results.

The value of the overdispersion parameter associated with $N_{spf\ ru}$ is determined as a function of segment length. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. The value is determined as:

$$k = \frac{1}{e^{(c+\ln(L))}} \tag{11-8}$$

Where:

k = overdispersion parameter associated with the roadway segment;

L = length of roadway segment (miles); and

c = a regression coefficient used to determine the overdispersion parameter.

Table 11-3 presents the values of the coefficients used for applying Equations 11-7 and 11-8 to determine the SPF for expected average crash frequency by total crashes, fatal-and-injury crashes, and fatal, injury and possible injury crashes.

Table 11-3. SPF Coefficients for Total and Fatal-and-Injury Crashes on Undivided Roadway Segments (for use in Equations 11-7 and 11-8)

Crash Severity Level	a	b	c
4-lane total	–9.653	1.176	1.675
4-lane fatal and injury	–9.410	1.094	1.796
4-lane fatal and injury[a]	–8.577	0.938	2.003

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included

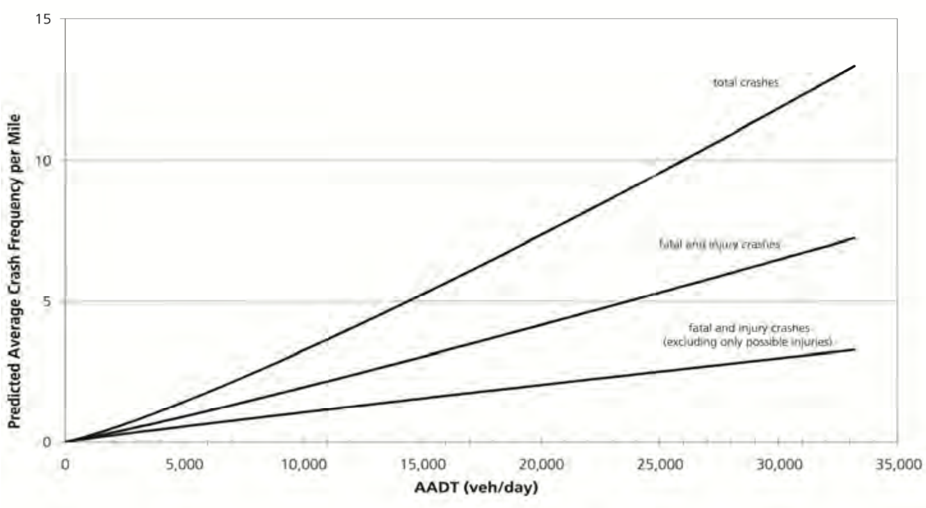


Figure 11-3. Graphical Form of the SPF for Undivided Roadway Segments (from Equation 11-7 and Table 11-3)

The default proportions in Table 11-4 are used to break down the crash frequencies from Equation 11-7 into specific collision types. To do so, the user multiplies the crash frequency for a specific severity level from Equation 11-7 by the appropriate collision type proportion for that severity level from Table 11-4 to estimate the number of crashes for that collision type. Table 11-4 is intended to separate the predicted frequencies for total crashes (all severity levels combined), fatal-and-injury crashes, and fatal-and-injury crashes (with possible injuries excluded) into components by collision type. Table 11-4 cannot be used to separate predicted total crash frequencies into components by severity level. Ratios for PDO crashes are provided for application where the user has access to predictive models for that severity level. The default collision type proportions shown in Table 11-4 may be updated with local data.

There are a variety of factors that may affect the distribution of crashes among crash types and severity levels. To account for potential differences in these factors between jurisdictions, it is recommended that the values in Table 11-4 be updated with local data. The values for total, fatal-and-injury, and fatal-and-injury (with possible injuries excluded) crashes in this exhibit are used in the worksheets described in Appendix 11A.

Table 11-4. Default Distribution of Crashes by Collision Type and Crash Severity Level for Undivided Roadway Segments

	Proportion of Crashes by Collision Type and Crash Severity Level			
	Severity Level			
Collision Type	**Total**	**Fatal and Injury**	**Fatal and Injury[a]**	**PDO**
Head-on	0.009	0.029	0.043	0.001
Sideswipe	0.098	0.048	0.044	0.120
Rear-end	0.246	0.305	0.217	0.220
Angle	0.356	0.352	0.348	0.358
Single	0.238	0.238	0.304	0.237
Other	0.053	0.028	0.044	0.064

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Appendix 11B presents alternative SPFs that can be applied to predict crash frequencies for selected collision types for undivided roadway segments on rural multilane highways. Use of these alternative models may be considered when estimates are needed for a specific collision type rather than for all crash types combined. It should be noted that the alternative SPFs in Appendix 11B do not address all potential collision types of interest and there is no assurance that the estimates for individual collision types would sum to the estimate for all collision types combined provided by the models in Table 11-3.

11.6.2. Safety Performance Functions for Divided Roadway Segments

The predictive model for estimating predicted average crash frequency on a particular divided rural multilane roadway segment was presented in Equation 11-3. The effect of traffic volume (AADT) on crash frequency is incorporated through the SPF, while the effects of geometric design and traffic control features are incorporated through the CMFs. The SPF for divided rural multilane highway segments is presented in this section. Divided rural multilane highway roadway segments are defined in Section 11.3.

Some divided highways have two roadways, built at different times, with independent alignments and distinctly different roadway characteristics, separated by a wide median. In this situation, it may be appropriate to apply the divided highway methodology twice, separately for the characteristics of each roadway but using the combined traffic volume, and then average the predicted crash frequencies.

The base conditions for the SPF for divided roadway segments on rural multilane highways are:

- Lane width (LW) 12 feet

- Right shoulder width 8 feet
- Median width 30 feet
- Lighting None
- Automated speed enforcement None

The SPF for expected average crash frequency for divided roadway segments on rural multilane highways is shown in Equation 11-9 and presented graphically in Figure 11-4:

$$N_{spf\ rd} = e^{(a + b \times \ln(AADT) + \ln(L))} \tag{11-9}$$

Where:

$N_{spf\ rd}$	=	base total number of roadway segment crashes per year;
$AADT$	=	annual average daily traffic (vehicles/day) on roadway segment;
L	=	length of roadway segment (miles); and
a, b	=	regression coefficients.

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 11.4. The SPFs for divided roadway segments on rural multilane highways are applicable to the AADT range from zero to 89,300 vehicles per day. Application to sites with AADTs substantially outside this range may not provide reliable results.

The value of the overdispersion parameter is determined as a function of segment length as:

$$k = \frac{1}{e^{(c + \ln(L))}} \tag{11-10}$$

Where:

k	=	overdispersion parameter associated with the roadway segment;
L	=	length of roadway segment (mi); and
c	=	a regression coefficient used to determine the overdispersion parameter.

Table 11-5 presents the values for the coefficients used in applying Equations 11-9 and 11-10.

Table 11-5. SPF Coefficients for Total and Fatal-and-Injury Crashes on Divided Roadway Segments (for use in Equations 11-9 and 11-10)

Severity Level	a	b	c
4-lane total	–9.025	1.049	1.549
4-lane fatal and injury	–8.837	0.958	1.687
4-lane fatal and injury[a]	–8.505	0.874	1.740

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

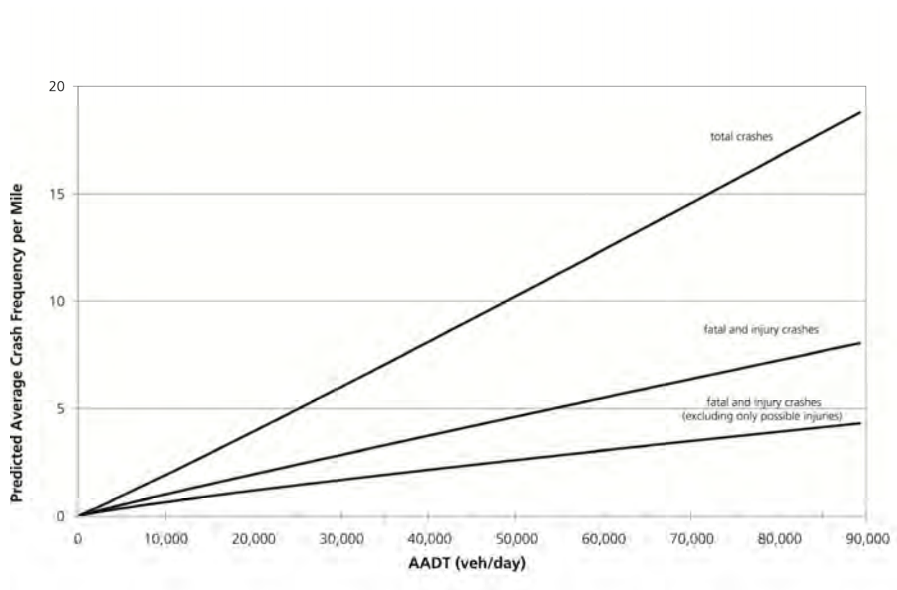


Figure 11-4. Graphical Form of SPF for Rural Multilane Divided Roadway Segments (from Equation 11-9 and Table 11-5)

The default proportions in Table 11-6 are used to break down the crash frequencies from Equation 11-9 into specific collision types. To do so, the user multiplies the crash frequency for a specific severity level from Equation 11-9 by the appropriate collision type proportion for that severity level from Table 11-6 to estimate the number of crashes for that collision type. Table 11-6 is intended to separate the predicted frequencies for total crashes (all severity levels combined), fatal-and-injury crashes, and fatal-and-injury crashes (with possible injuries excluded) into components by collision type. Table 11-6 cannot be used to separate predicted total crash frequencies into components by severity level. Ratios for property-damage-only (PDO) crashes are provided for application where the user has access to predictive models for that severity level. The default collision type proportions shown in Table 11-6 may be updated with local data.

Table 11-6. Default Distribution of Crashes by Collision Type and Crash Severity Level for Divided Roadway Segments

	Proportion of Crashes by Collision Type and Crash Severity Level			
	Severity Level			
Collision Type	Total	Fatal and Injury	Fatal and Injury[a]	PDO
Head-on	0.006	0.013	0.018	0.002
Sideswipe	0.043	0.027	0.022	0.053
Rear-end	0.116	0.163	0.114	0.088
Angle	0.043	0.048	0.045	0.041
Single	0.768	0.727	0.778	0.792
Other	0.024	0.022	0.023	0.024

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

11.6.3. Safety Performance Functions for Intersections

The predictive model for estimating predicted average crash frequency at particular rural multilane intersection was presented in Equation 11-4. The effect of traffic volume (AADT) on crash frequency is incorporated through the SPF, while the effects of geometric design and traffic control features are incorporated through the CMFs. The SPFs for rural multilane highway intersection are presented in this section. Three- and four-leg stop-controlled intersections and three- and four-leg signalized rural multilane highway intersections are defined in Section 11.3.

SPFs have been developed for four~~three~~ types of intersections on rural multilane highways. These models can be used for intersections located on both divided and undivided rural four-lane highways. The four~~three~~ types of intersections are:

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

The SPFs for four-leg signalized intersections (4SG) on rural multilane highways have no specific base conditions and, therefore, can only be applied for generalized predictions. No CMFs are provided for 4SG intersections and predictions of average crash frequency cannot be made for intersections with specific geometric design and traffic control features.

~~Models for three-leg signalized intersections on rural multilane roads are not available.~~

The SPFs for three- and four-leg stop-controlled intersections (3ST and 4ST) and three-leg signalized intersections (3SG) on rural multilane highways are applicable to the following base conditions:

- Intersection skew angle 0° (only applicable to 3ST and 4ST)
- Intersection left-turn lanes 0, except on stop-controlled approaches
- Intersection right-turn lanes 0, except on stop-controlled approaches
- Lighting None

The SPFs for crash frequency have two alternative functional forms, shown in Equations 11-11 and 11-12, and presented graphically in Figures 11-5, 11-6, 11-EA, and 11-7 (for total crashes only):

$$N_{spf\ int} = exp[a + b \times 1\mathrm{n}(AADT_{maj}) + c \times 1\mathrm{n}(AADT_{min})] \quad (11\text{-}11)$$

or

$$N_{spf\ int} = exp[a + d \times 1\mathrm{n}(AADT_{total})] \quad (11\text{-}12)$$

Where:

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

$AADT_{maj}$ = AADT (vehicles per day) for major-road approaches;

$AADT_{min}$ = AADT (vehicles per day) for minor-road approaches;

$AADT_{total}$ = AADT (vehicles per day) for minor and major-roads combined approaches; and

a, b, c, d = regression coefficients.

The functional form shown in Equation 11-11 is used for most site types and crash severity levels; the functional form shown in Equation 11-12 is used for only one specific combination of site type and facility type—four-leg signalized intersections for fatal-and-injury crashes (excluding possible injuries)—as shown in Table 11-8.

Guidance on the estimation of traffic volumes for the major- and minor-road legs for use in the SPFs is presented in Step 3 of the predictive method described in Section 11.4. The intersection SPFs for rural multilane highways are applicable to the following AADT ranges:

3ST: $AADT_{maj}$ 0 to 78,300 vehicles per day and
$AADT_{min}$ 0 to 23,000 vehicles per day

4ST: $AADT_{maj}$ 0 to 78,300 vehicles per day and
$AADT_{min}$ 0 to 7,400 vehicles per day

3SG: $AADT_{maj}$ 0 to 56,000 vehicles per day and
$AADT_{min}$ 0 to 27,000 vehicles per day

4SG: $AADT_{maj}$ 0 to 43,500 vehicles per day and
$AADT_{min}$ 0 to 18,500 vehicles per day

Application to sites with AADTs substantially outside these ranges may not provide reliable results.

Table 11-7 presents the values of the coefficients a, b, and c used in applying Equation 11-11 for stop-controlled intersections along with the overdispersion parameter and the base conditions.

Table 11-8 presents the values of the coefficients a, b, c, and d used in applying Equations 11-11 and 11-12 for three- and four-leg signalized intersections along with the overdispersion parameter. Coefficients a, b, and c are provided for total crashes and are applied to the SPF shown in Equation 11-11. Coefficients a and d are provided for injury crashes and are applied to the SPF shown in Equation 11-12. ~~SPFs for three-leg signalized intersections on rural multilane roads are not currently available.~~

If feasible, separate calibration of the models in Tables 11-7 and 11-8 for application to intersections on divided and undivided roadway segments is preferable. Calibration procedures are presented in Part C, Appendix A.

Table 11-7. SPF Coefficients for Three- and Four-Leg Intersections with Minor-Road Stop Control for Total and Fatal-and-Injury Crashes (for use in Equation 11-11)

Intersection Type/Severity Level	a	B	c	Overdispersion Parameter (Fixed *k*)[a]
4ST Total	–10.008	0.848	0.448	0.494
4ST Fatal and injury	–11.554	0.888	0.525	0.742
4ST Fatal and injury[b]	–10.734	0.828	0.412	0.655
3ST Total	–12.526	1.204	0.236	0.460
3ST Fatal and injury	–12.664	1.107	0.272	0.569
3ST Fatal and injury[b]	–11.989	1.013	0.228	0.566

[a] This value should be used directly as the overdispersion parameter; no further computation is required.
[b] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Table 11-8. SPF Coefficients for Three- and Four-Leg Signalized Intersections for Total and Fatal-and-Injury Crashes (for use in Equations 11-11 and 11-12)

Intersection Type/Severity Level	A	B	c	d	Overdispersion Parameter (Fixed *k*)[a]
3SG Total	-6.28	0.52	0.31		0.40
3SG Fatal and injury	-11.03	0.79	0.39		1.15
4SG Total	–7.182	0.722	0.337		0.277
4SG Fatal and injury	–6.393	0.638	0.232		0.218
4SG Fatal and injury[b]	–12.011			1.279	0.566

[a] This value should be used directly as the overdispersion parameter; no further computation is required.

[b] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

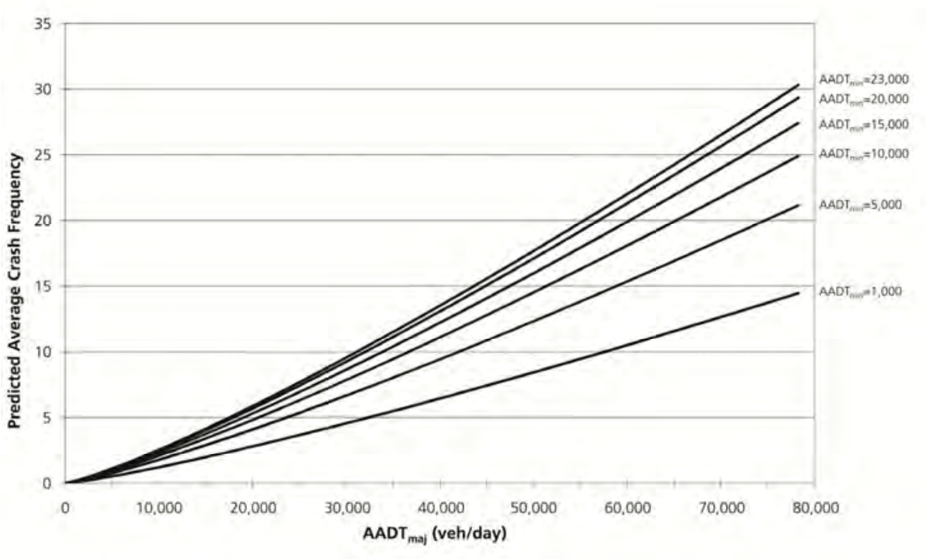


Figure 11-5. Graphical Form of SPF for Three-Leg Stop-Controlled Intersections—for Total Crashes Only (from Equation 11-11 and Table 11-7)

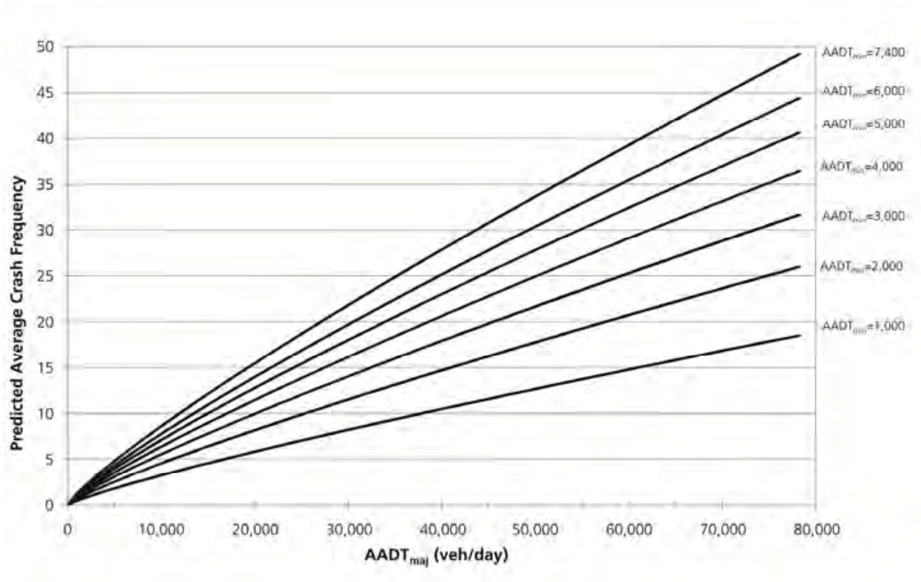


Figure 11-6. Graphical Form of SPF for Four-Leg Stop-Controlled Intersections—for Total Crashes Only (from Equation 11-11 and Table 11-7)

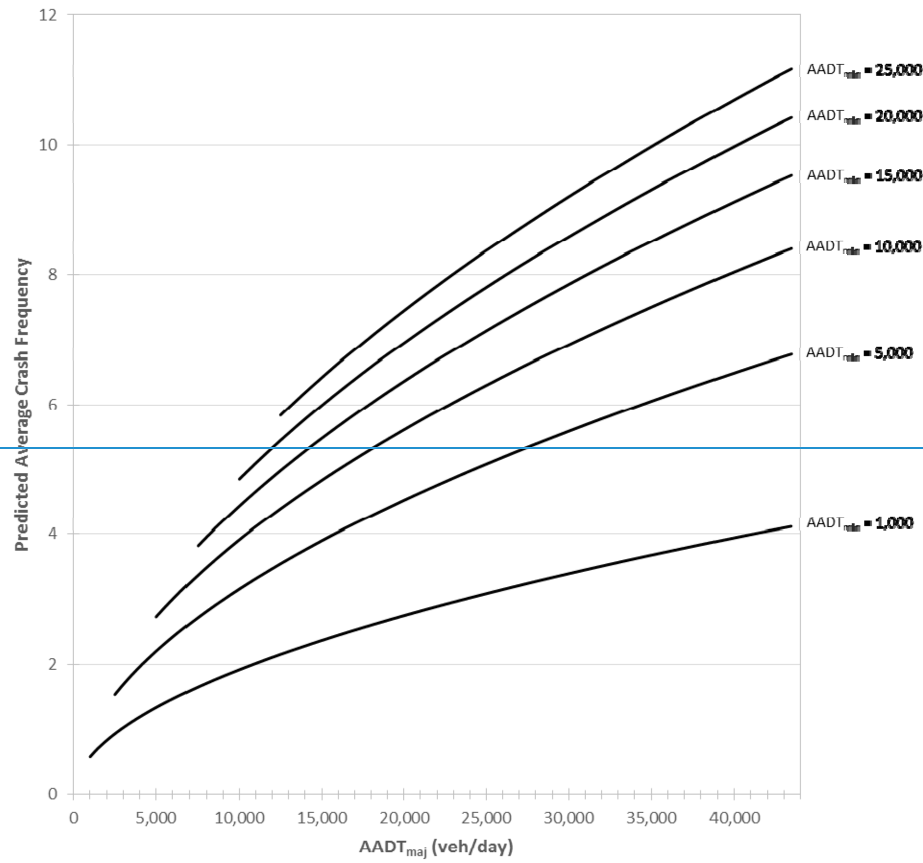


Figure 11-EA. Graphical Form of SPF for Three-leg Signalized Intersections—for Total Crashes Only (from Equation 11-11 and Table 11-8)

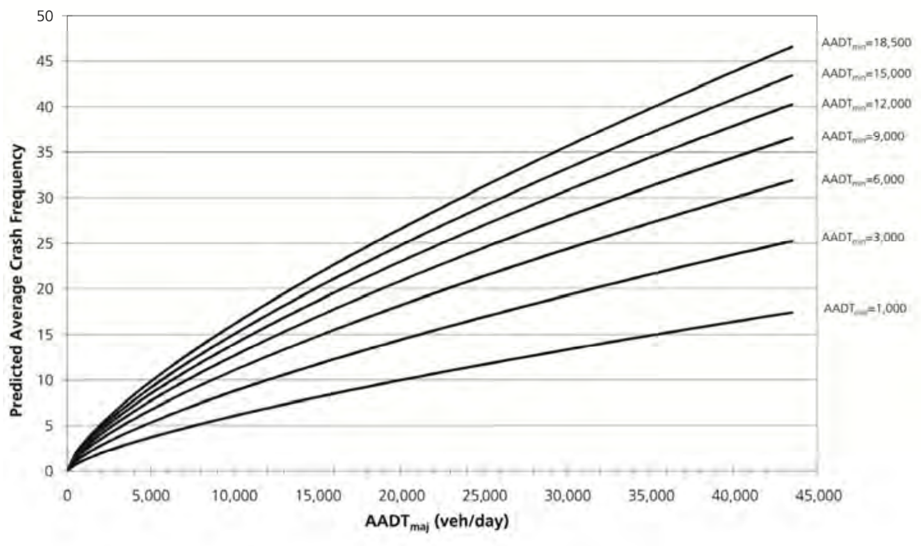


Figure 11-7. Graphical Form of SPF for Four-leg Signalized Intersections—for Total Crashes Only (from Equation 11-11 and Table 11-8~~7~~)

The default proportions in Table 11-9 are used to break down the crash frequencies from Equation 11-11 into specific collision types. To do so the user multiplies the predicted average frequency for a specific crash severity level from Equation 11-11 by the appropriate collision type proportion for that crash severity level from Table 11-9 to estimate the predicted average crash frequency for that collision type. Table 11-9 separates the predicted frequencies for total crashes (all severity levels combined), fatal-and-injury crashes, and fatal-and-injury crashes (with possible injuries excluded) into components by collision type. Table 11-9 cannot be used to separate predicted total crash frequencies into components by crash severity level. Ratios for PDO crashes are provided for application where the user has access to predictive models for that crash severity level. The default collision type proportions shown in Table 11-9 may be updated with local data.

There are a variety of factors that may affect the distribution of crashes among crash types and crash severity levels. To account for potential differences in these factors between jurisdictions, it is recommended that the values in Table 11-9 be updated with local data. The values for total, fatal-and-injury, and fatal-and-injury (excluding crashes involving only possible injuries) in this exhibit are used in the worksheets described in Appendix 11A.

Table 11-9. Default Distribution of Intersection Crashes by Collision Type and Crash Severity

Collision Type	Proportion of Crashes by Severity Level							
	Three-Leg Intersections with Minor-Road Stop Control				Four-Leg Intersections with Minor-Road Stop Control			
	Total	Fatal and Injury	Fatal and Injury[a]	PDO	Total	Fatal and Injury	Fatal and Injury[a]	PDO
Head-on	0.029	0.043	0.052	0.020	0.016	0.018	0.023	0.015
Sideswipe	0.133	0.058	0.057	0.179	0.107	0.042	0.040	0.156
Rear-end	0.289	0.247	0.142	0.315	0.228	0.213	0.108	0.240
Angle	0.263	0.369	0.381	0.198	0.395	0.534	0.571	0.292
Single	0.234	0.219	0.284	0.244	0.202	0.148	0.199	0.243
Other	0.052	0.064	0.084	0.044	0.051	0.046	0.059	0.055
Collision Type	Three-Leg Signalized Intersections				Four-Leg Signalized Intersections			
	Total	Fatal and Injury	Fatal and Injury[a]	PDO	Total	Fatal and Injury	Fatal and Injury[a]	PDO
Head-on	0.024	0.041	---	0.018	0.054	0.083	0.093	0.034
Sideswipe	0.080	0.034	---	0.108	0.106	0.047	0.039	0.147
Rear-end	0.432	0.367	---	0.441	0.492	0.472	0.314	0.505
Angle	0.280	0.408	---	0.221	0.256	0.315	0.407	0.215
Single	0.113	0.097	---	0.151	0.062	0.041	0.078	0.077
Other	0.072	0.053	---	0.062	0.030	0.041	0.069	0.023

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Appendix 11B presents alternative SPFs that can be applied to predict crash frequencies for selected collision types for intersections with minor-road stop control on rural multilane highways. Use of these alternative models may be considered when safety predictions are needed for a specific collision type rather than for all crash types combined. Care must be exercised in using the alternative SPFs in Appendix 11B because they do not address all potential collision types of interest and because there is no assurance that the safety predictions for individual collision types would sum to the predictions for all collision types combined provided by the models in Table 11-7.

11.7. CRASH MODIFICATION FACTORS

In Step 10 of the predictive method shown in Section 11.4, crash modification factors are applied to the selected safety performance function, which was selected in Step 9. SPFs provided in Chapter 11 are presented in Section 11.6. A general overview of crash modification factors (CMFs) is presented in Section 3.5.3. The Part C—Introduction and Applications Guidance provides further discussion on the relationship of CMFs to the predictive method. This section provides details of the specific CMFs applicable to the safety performance functions presented in Section 11.6.

Crash modification factors (CMFs) are used to adjust the SPF estimate of expected average crash frequency for the effect of individual geometric design and traffic control features, as shown in the general predictive model for Chapter 11 shown in Equation 11-1. The CMF for the SPF base condition of each geometric design or traffic control feature has a value of 1.00. Any feature associated with higher average crash frequency than the SPF base condition has a CMF with a value greater than 1.00; any feature associated with lower average crash frequency than the SPF base condition has a CMF with a value less than 1.00.

The CMFs in Chapter 11 were determined from a comprehensive literature review by an expert panel (5). They represent the collective judgment of the expert panel concerning the effects of each geometric design and traffic control feature of interest. Others were derived by modeling data assembled for developing the predictive models rural multilane roads. The CMFs used in Chapter 11 are consistent with the CMFs in Part D—Crash Modification Factors, although they have, in some cases, been expressed in a different form to be applicable to the base conditions. The CMFs presented in Chapter 11, and the specific SPFs to which they apply, are summarized in Table 11-10.

Table 11-10. Summary of CMFs in Chapter 11 and the Corresponding SPFs

Applicable SPF	CMF	CMF Description	CMF Equations and Exhibits
Undivided Roadway Segment SPF	CMF_{1ru}	Lane Width on Undivided Segments	Equation 11-13, Table 11-11, Figure 11-8
	CMF_{2ru}	Shoulder Width and Shoulder Type	Equation 11-14, Figure 11-9, Tables 11-12 and 11-13
	CMF_{3ru}	Sideslopes	Table 11-14
	CMF_{4ru}	Lighting	Equation 11-15, Table 11-15
	CMF_{5ru}	Automated Speed Enforcement	See text
Divided Roadway Segment SPF	CMF_{1rd}	Lane Width on Divided Segments	Equation 11-16, Table 11-16, Figure 11-10
	CMF_{2rd}	Right Shoulder Width on Divided Roadway Segment	Table 11-17
	CMF_{3rd}	Median Width	Table 11-18
	CMF_{4rd}	Lighting	Equation 11-17, Table 11-19
	CMF_{5rd}	Automated Speed Enforcement	See text
Three- and Four-Leg Stop-Controlled Intersection and Three-Leg Signalized Intersection[a] SPFs	CMF_{1i}	Intersection Angle	Tables 11-20, 11-21
	CMF_{2i}	Left-Turn Lane on Major Road	Tables 11-20, 11-21, and 11-XA
	CMF_{3i}	Right-Turn Lane on Major Road	Tables 11-20, 11-21, and 11-XA
	CMF_{4i}	Lighting	Tables 11-20, 11-21, and 11-XA

[a] CMF for intersection angle (CMF_{1i}) is not applicable to this intersection type. CMFs for intersection left-turn (CMF_{2i}) and right-turn (CMF_{3i}) lanes and lighting (CMF_{4i}) are applicable to three-leg signalized intersections.

11.7.1. Crash Modification Factors for Undivided Roadway Segments

The CMFs for geometric design and traffic control features of undivided roadway segments are presented below. These CMFs are applicable to the SPF presented in Section 11.6.1 for undivided roadway segments on rural multilane highways. Each of the CMFs applies to all of the crash severity levels shown in Table 11-3.

CMF_{1ru}—Lane Width

The CMF for lane width on undivided segments is based on the work of Harkey et al. (3) and is determined as follows:

$$CMF_{1ru} = (CMF_{RA} - 1.0) \times p_{RA} + 1.0 \tag{11-13}$$

Where:

CMF_{1ru} = crash modification factor for total crashes;

CMF_{RA} = crash modification factor for related crashes (run-off-the-road, head-on, and sideswipe), from Table 11-11; and

p_{RA} = proportion of total crashes constituted by related crashes (default is 0.27).

CMF_{RA} is determined from Table 11-11 based on the applicable lane width and traffic volume range. The relationships shown in Table 11-11 are illustrated in Figure 11-8. This effect represents 75 percent of the effect of lane width on rural two-lane roads shown in Chapter 10, Predictive Method for Rural Two-Lane, Two-Way Roads. The default value of p_{RA} for use in Equation 11-13 is 0.27, which indicates that run-off-the-road, head-on, and sideswipe crashes typically represent 27 percent of total crashes. This default value may be updated based on local data. The SPF base condition for the lane width is 12 ft. Where the lane widths on a roadway vary, the CMF is determined separately for the lane width in each direction of travel and the resulting CMFs are then averaged.

For lane widths with 0.5-ft increments that are not depicted specifically in Table 11-11 or in Figure 11-8, a CMF value can be interpolated using either of these exhibits since there is a linear transition between the various AADT effects.

Table 11-11. CMF_{RA} for Collision Types Related to Lane Width

	~~Average~~ Annual Avarage Daily Traffic (AADT) (vehicles per day)		
Lane Width	**< 400**	**400 to 2000**	**> 2000**
9 ft or less	1.04	$1.04+2.13\times10^{-4}(AADT-400)$	1.38
10 ft	1.02	$1.02+1.31\times10^{-4}(AADT-400)$	1.23
11 ft	1.01	$1.01+1.88\times10^{-5}(AADT-400)$	1.04
12 ft or more	1.00	1.00	1.00

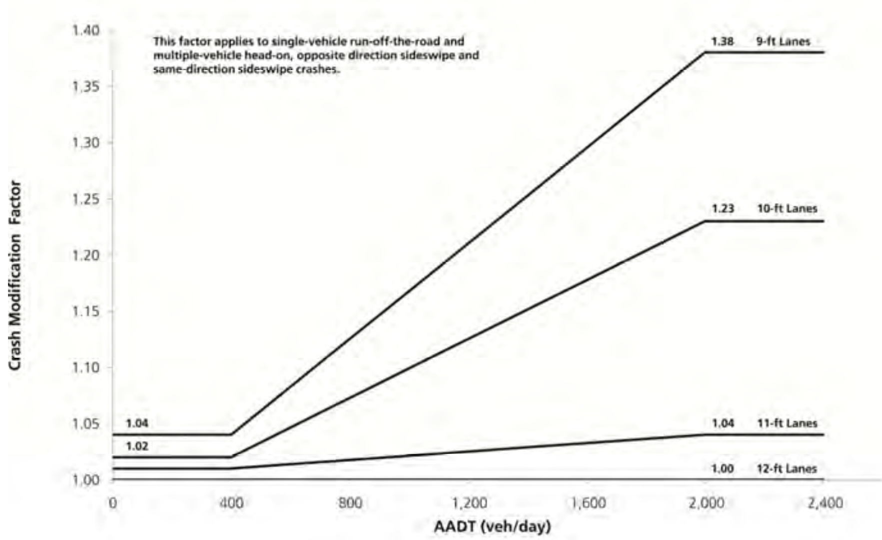


Figure 11-8. CMF_{RA} for Lane Width on Undivided Segments

$CMF2_{ru}$—Shoulder Width

The CMF for shoulder width on undivided segments is based on the work of Harkey et al. (3) and is determined as follows:

$$CMF_{2ru} = (CMF_{WRA} \times CMF_{TRA} - 1.0) \times p_{RA} + 1.0 \quad (11\text{-}14)$$

Where:

CMF_{2ru} = crash modification factor for total crashes;

CMF_{WRA} = crash modification factor for related crashes based on shoulder width from Table 11-12;

CMF_{TRA} = crash modification factor for related crashes based on shoulder type from Table 11-13; and

p_{RA} = proportion of total crashes constituted by related crashes (default is 0.27).

CMF_{WRA} is determined from Table 11-12 based on the applicable shoulder width and traffic volume range. The relationships shown in Table 11-12 are illustrated in Figure 11-9. The default value of p_{RA} for use in Equation 11-14 is 0.27, which indicates that run-off-the-road, head-on, and sideswipe crashes typically represent 27 percent of total crashes. This default value may be updated based on local data. The SPF base condition for shoulder width is 6 ft.

Table 11-12. CMF for Collision Types Related to Shoulder Width (CMF_{WRA})

	Annual Average Daily Traffic (AADT) (vehicles per day)		
Shoulder Width	**< 400**	**400 to 2000**	**> 2000**
0 ft	1.10	$1.10+2.5\times10^{-4}(\text{AADT}-400)$	1.50
2 ft	1.07	$1.07+1.43\times10^{-4}(\text{AADT}-400)$	1.30
4 ft	1.02	$1.02+8.125\times10^{-5}(\text{AADT}-400)$	1.15
6 ft	1.00	1.00	1.00
8 ft or more	0.98	$0.98-6.875\times10^{-5}(\text{AADT}-400)$	0.87

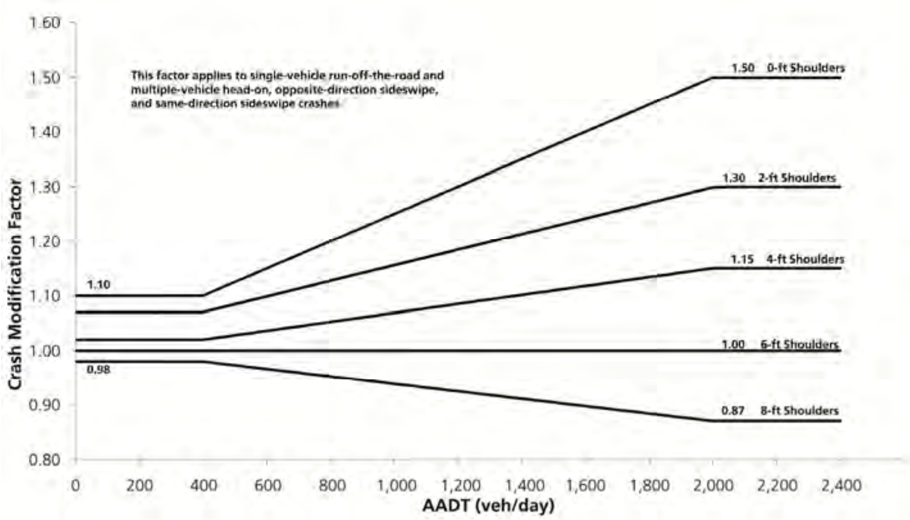


Figure 11-9. CMF_{WRA} for Shoulder Width on Undivided Segments

CMF_{TRA} is determined from Table 11-13 based on the applicable shoulder type and shoulder width.

Table 11-13. CMF for Collision Types Related to Shoulder Type and Shoulder Width (CMF_{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

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

CMF_{3ru}—Sideslopes

A CMF for the sideslope for undivided roadway segments of rural multilane highways has been developed by Harkey et al. (3) from the work of Zegeer et al. (8). The CMF is presented in Table 11-14. The base conditions are for a sideslope of 1:7 or flatter.

Table 11-14. CMF for Sideslope on Undivided Roadway Segments (CMF_{3ru})

1:2 or Steeper	1:3	1:4	1:5	1:6	1:7 or Flatter
1.18	1.15	1.12	1.09	1.05	1.00

CMF_{4ru}—Lighting

The SPF base condition for lighting of roadway segments is the absence of lighting. The CMF for lighted roadway segments is determined, based on the work of Elvik and Vaa (1), as:

$$CMF_{4ru} = 1 - [(1 - 0.72 \times p_{inr} - 0.83 \times p_{pnr}) \times p_{nr}] \quad (11\text{-}15)$$

Where:

CMF_{4ru} = crash modification factor for the effect of lighting on total crashes;

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

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

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

This CMF applies to total roadway segment crashes. Table 11-15 presents default values for the nighttime crash proportions p_{inr}, p_{pnr}, and p_{nr}. HSM users are encouraged to replace the estimates in Table 11-15 with locally derived values.

Table 11-15. Nighttime Crash Proportions for Unlighted Roadway Segments

Roadway Type	Proportion of Total Night-Time Crashes by Severity Level		Proportion of Crashes that Occur at Night
	Fatal and Injury p_{inr}	**PDO p_{pnr}**	**p_{nr}**
4U	0.361	0.639	0.255

CMF_{5ru}—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 SPF base condition for automated speed enforcement is that it is absent. Chapter 17, Road Networks presents a CMF of 0.83 for the reduction of all types of injury crashes from implementation of automated speed enforcement. This CMF applies to roadway segments with fixed camera sites where the camera is always present or where drivers have no way of knowing whether the camera is present or not. Fatal-and-injury crashes constitute 31 percent of total crashes on rural two-lane highway segments. No information is available on the effect of automated speed enforcement on noninjury crashes. With the conservative assumption that automated speed enforcement has no effect on noninjury crashes, the value of CMF_{5ru} for automated speed enforcement would be 0.95 based on the injury crash proportion.

11.7.2. Crash Modification Factors for Divided Roadway Segments

The CMFs for geometric design and traffic control features of divided roadway segments for rural multilane highways are presented below. Each of the CMFs applies to all of the crash severity levels shown in Table 11-5.

CMF_{1rd}—Lane Width on Divided Roadway Segments

The CMF for lane width on divided segments is based on the work of Harkey et al. (3) and is determined as follows:

$$CMF_{1rd} = (CMF_{RA} - 1.0) \times p_{RA} + 1.0 \quad (11\text{-}16)$$

Where:

CMF_{1rd} = crash modification factor for total crashes;

CMF_{RA} = crash modification factor for related crashes (run-off-the-road, head-on, and sideswipe), from Table 11-16; and

p_{RA} = proportion of total crashes constituted by related crashes (default is 0.50).

CMF_{RA} is determined from Table 11-16 based on the applicable lane width and traffic volume range. The relationships shown in Table 11-16 are illustrated in Figure 11-10. This effect represents 50 percent of the effect of lane width on rural two-lane roads shown in Chapter 10. The default value of p_{RA} for use in Equation 11-16 is 0.50, which indicates that run-off-the-road, head-on, and sideswipe crashes typically represent 50 percent of total crashes. This default value may be updated based on local data. The SPF base condition for lane width is 12 ft. Where the lane widths on a roadway vary, the CMF is determined separately for the lane width in each direction of travel and the resulting CMFs are then averaged.

Table 11-16. CMF for Collision Types Related to Lane Width (CMF_{RA})

	Annual Average Daily Traffic (AADT) (vehicles/day)		
Lane Width	**< 400**	**400 to 2000**	**> 2000**
9 ft	1.03	$1.03+1.38\times10^{-4}(AADT-400)$	1.25
10 ft	1.01	$1.01+8.75\times10^{-5}(AADT-400)$	1.15
11 ft	1.01	$1.01+1.25\times10^{-5}(AADT-400)$	1.03
12 ft	1.00	1.00	1.00

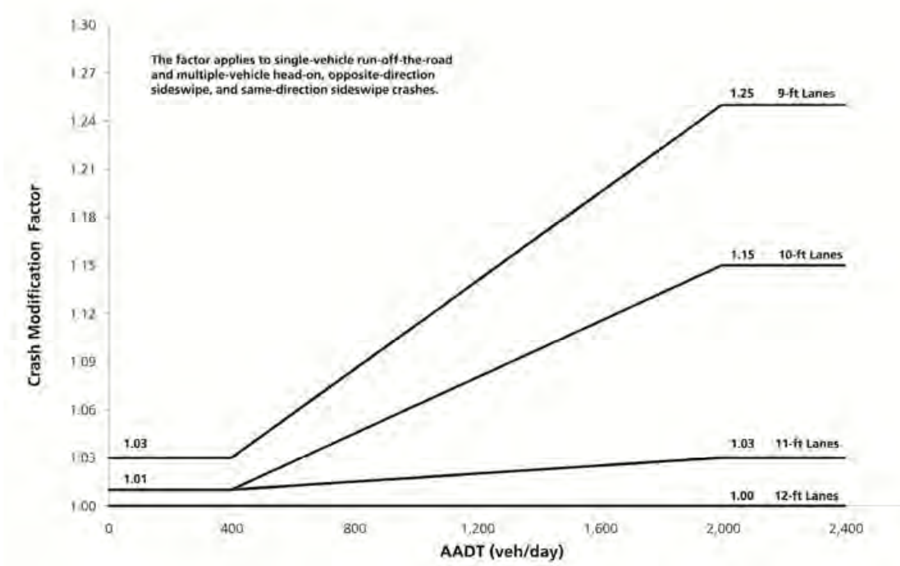


Figure 11-10. CMF_{RA} for Lane Width on Divided Roadway Segments

CMF_{2rd}—Right Shoulder Width on Divided Roadway Segments

The CMF for right shoulder width on divided roadway segments was developed by Lord et al. (5) and is presented in Table 11-17. The SPF base condition for the right shoulder width variable is 8 ft. If the shoulder widths for the two directions of travel differ, the CMF is based on the average of the shoulder widths. The safety effects of shoulder widths wider than 8 ft are unknown, but it is recommended that a CMF of 1.00 be used in this case.

The effects of unpaved right shoulders on divided roadway segments and of left (median) shoulders of any width or material are unknown. No CMFs are available for these cases.

Table 11-17. CMF for Right Shoulder Width on Divided Roadway Segments (CMF_{2rd})

Average Shoulder Width (ft)				
0	**2**	**4**	**6**	**8 or more**
1.18	1.13	1.09	1.04	1.00

Note: This CMF applies to paved shoulders only.

CMF_{3rd}—Median Width

A CMF for median widths on divided roadway segments of rural multilane highways is presented in Table 11-18 based on the work of Harkey et al. (3). The median width of a divided highway is measured between the inside edges of the through travel lanes in the opposing direction of travel; thus, inside shoulder and turning lanes are included in the median width. The base condition for this CMF is a median width of 30 ft. The CMF applies to total crashes, but represents the effect of median width in reducing cross-median collisions; the CMF assumes that nonintersection collision types other than cross-median collisions are not affected by median width. The CMF in Table 11-18 has been adapted from the CMF in Table 13-13 based on the estimate by Harkey et al. (3) that cross-median collisions represent 12.2 percent of crashes on multilane divided highways.

This CMF applies only to traversable medians without traffic barriers. The effect of traffic barriers on safety would be expected to be a function of the barrier type and offset, rather than the median width; however, the effects of these factors on safety have not been quantified. Until better information is available, a CMF value of 1.00 is used for medians with traffic barriers.

Table 11-18. CMFs for Median Width on Divided Roadway Segments without a Median Barrier (CMF_{3rd})

Median Width (ft)	CMF
10	1.04
20	1.02
30	1.00
40	0.99
50	0.97
60	0.96
70	0.96
80	0.95
90	0.94
100	0.94

Note: This CMF applies only to medians without traffic barriers.

CMF_{4rd}—Lighting

The SPF base condition for lighting is the absence of roadway segment lighting. The CMF for lighted roadway segments is determined, based on the work of Elvik and Vaa (1), as:

$$CMF_{4rd} = 1 - [(1 - 0.72 \times p_{inr} - 0.83 \times p_{pnr}) \times p_{nr}] \tag{11-17}$$

Where:

CMF_{4rd} = crash modification factor for the effect of lighting on total crashes;

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

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

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

This CMF applies to total roadway segment crashes. Table 11-19 presents default values for the nighttime crash proportions p_{inr}, p_{pnr}, and p_{nr}. HSM users are encouraged to replace the estimates in Table 11-19 with locally derived values.

Table 11-19. Nighttime Crash Proportions for Unlighted Roadway Segments

	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occur at Night
Roadway Type	**Fatality and Injury p_{inr}**	**PDO p_{pnr}**	**p_{nr}**
4D	0.323	0.677	0.426

CMF_{5rd}—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 SPF base condition for automated speed enforcement is that it is absent. Chapter 17 presents a CMF of 0.83 for the reduction of all types of fatal-and-injury crashes from implementation of automated speed enforcement. This CMF applies to roadway segments with fixed camera sites where the camera is always present or where drivers have no way of knowing whether the camera is present or not. Fatal-and-injury crashes constitute 37 percent of total crashes on rural multilane divided highway segments. No information is available on the effect of automated speed enforcement on noninjury crashes. With the conservative assumption that automated speed enforcement has no effect on noninjury crashes, the value of CMF_{5rd} for automated speed enforcement would be 0.94 based on the injury crash proportion.

11.7.3. Crash Modification Factors for Intersections

The effects of individual geometric design and traffic control features of intersections are represented in the safety prediction procedure by CMFs. The equations and exhibits relating to CMFs for stop-controlled intersections are summarized in Tables 11-20 and 11-21 and presented below. The equations and exhibits relating to CMFs for three-leg signalized intersections are summarized in Table 11-XA and presented below. Except where separate CMFs by crash severity level are shown, each of the CMFs applies to all of the crash severity levels shown in Tables 11-7 and 11-8. As noted earlier, CMFs are not available for four-leg signalized intersections.

Table 11-20. CMFs for Three-Leg Intersections with Minor-Road Stop Control (3ST)

CMFs	Total	Fatal and Injury
Intersection Angle	Equation 11-18	Equation 11-19
Left-Turn Lane on Major Road	Table 11-22	Table 11-22
Right-Turn Lane on Major Road	Table 11-23	Table 11-23
Lighting	Equation 11-22	Equation 11-22

Table 11-21. CMFs for Four-Leg Intersection with Minor-Road Stop Control (4ST)

CMFs	Total	Fatal and Injury
Intersection Angle	Equation 11-20	Equation 11-21
Left-Turn Lane on Major Road	Table 11-22	Table 11-22
Right-Turn Lane on Major Road	Table 11-23	Table 11-23
Lighting	Equation 11-22	Equation 11-22

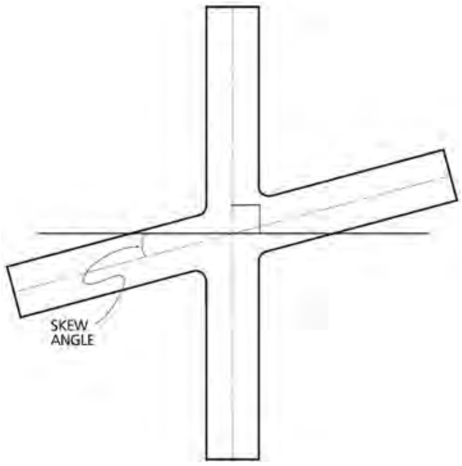
Table 11-XA. CMFs for Three-Leg Signalized Intersection (3SG)

CMFs	Total	Fatal and Injury
Left-Turn Lane	Table 11-22	
Right-Turn Lane	Table 11-23	Table 11-23
Lighting	Equation 11-22	Equation 11-22

CMF_{1i}—Intersection Skew Angle

The SPF base condition for intersection skew angle is 0 degrees of skew (i.e., an intersection angle of 90 degrees). Reducing the skew angle of three- or four-leg stop-controlled intersections on rural multilane highways reduces total intersection crashes, as shown below. The skew angle is the deviation from an intersection angle of 90 degrees. Skew carries a positive or negative sign that indicates whether the minor road intersects the major road at an acute or obtuse angle, respectively.

Illustration of Intersection Skew Angle



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

The CMF for total crashes for intersection skew angle at three-leg intersections with stop-control on the minor approach is:

$$CMF_{1i} = \frac{0.016 \times skew}{(0.98 + 0.016 \times skew)} + 1 \qquad (11\text{-}18)$$

$$CMF_{1i} = \frac{0.016 \times skew}{(0.98 + 0.16 \times skew)} + 1.0 \qquad (11\text{-}18)$$

and the CMF for fatal-and-injury crashes is:

$$CMF_{1i} = \frac{0.017 \times skew}{(0.52 + 0.017 \times skew)} + 1 \qquad (11\text{-}19)$$

$$CMF_{1i} = \frac{0.017 \times skew}{(0.52 + 0.17 \times skew)} + 1.0 \qquad (11\text{-}19)$$

Where:

CMF_{1i} = crash modification factor for the effect of intersection skew on total crashes; and

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

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

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

$$CMF_{1i} = \frac{0.053 \times skew}{(1.43 + 0.053 \times skew)} + 1.0 \quad (11\text{-}20)$$

$$CMF_{1i} = \frac{0.053 \times skew}{(1.43 + 0.53 \times skew)} + 1.0 \quad (11\text{-}20)$$

The CMF for fatal-and-injury crashes is:

$$CMF_{1i} = \frac{0.048 \times skew}{(0.72 + 0.048 \times skew)} + 1.0 \quad (11\text{-}21)$$

$$CMF_{1i} = \frac{0.048 \times skew}{(0.72 + 0.48 \times skew)} + 1.0 \quad (11\text{-}21)$$

Three-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 CMF for skew angle at three-leg signalized intersections is 1.00 for all cases.

CMF_{2i}—Intersection Left-Turn Lanes

The SPF base condition for intersection left-turn lanes is the absence of left-turn lanes on all of the intersection approaches. The CMFs for presence of left-turn lanes are presented in Table 11-22 for total crashes and injury crashes. These CMFs apply to installation of left-turn lanes on any approach to a signalized intersection, but only on uncontrolled major-road approaches to stop-controlled intersections. The CMFs for installation of left-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF for installation of a left-turn lane on one approach raised to a power equal to the number of approaches with left-turn lanes (i.e., the CMFs are multiplicative, and Equation 3-7 can be used). There is no indication of any 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 Table 11-22. The CMFs for installation of left-turn lanes are based on research by Harwood et al. (4) and are consistent with the CMFs presented in Chapter 14, Intersections. A CMF of 1.00 is used when no left-turn lanes are present.

Table 11-22. Crash Modification Factors (*CMF_{2i}*) for Installation of Left-Turn Lanes on Intersection Approaches

		Number of Non-Stop-Controlled Approaches with Left-Turn Lanes[a]	
Intersection Type	**Crash Severity Level**	**One Approach**	**Two Approaches**
Three-leg minor-road stop control[b]	Total	0.56	—
	Fatal and Injury	0.45	—
Four-leg minor-road stop control[b]	Total	0.72	0.52
	Fatal and Injury	0.65	0.42
Three-leg signalized intersection	Total	0.85	0.72

[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.

CMF_{3i}—Intersection Right-Turn Lanes

The SPF base condition for intersection right-turn lanes is the absence of right-turn lanes on the intersection approaches. The CMFs for the presence of right-turn lanes are based on research by Harwood et al. (4) and are consistent with the CMFs in Chapter 14. These CMFs 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 CMFs for installation of right-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF for installation of a right-turn lane on one approach raised to a power equal to the number of approaches with right-turn lanes (i.e., the CMFs are multiplicative, and Equation 3-7 can be used). 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 Table 11-23. The CMFs for presence of right-turn lanes are presented in Table 11-23 for total crashes and injury crashes. A CMF value of 1.00 is used when no right-turn lanes are present. This CMF applies only to right-turn lanes that are identified by marking or signing. The CMF is not applicable to long tapers, flares, or paved shoulders that may be used informally by right-turn traffic.

Table 11-23. Crash Modification Factors (*CMF_{3i}*) for Installation of Right-Turn Lanes on Intersections Approaches

		Number of Non-Stop-Controlled Approaches with Right-Turn Lanes[a]	
Intersection Type	**Crash Severity Level**	**One Approach**	**Two Approaches**
Three-leg minor-road stop control[b]	Total	0.86	—
	Fatal and Injury	0.77	—
Four-leg minor-road stop control[b]	Total	0.86	0.74
	Fatal and Injury	0.77	0.59
Three-leg signalized intersection	Total	0.96	0.92
	Fatal and Injury	0.91	0.83

[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.

CMF_{4i}—Lighting

The SPF base condition for lighting is the absence of intersection lighting. The CMF for lighted intersections is adapted from the work of Elvik and Vaa (1), as:

$$CMF_{4i} = 1.0 - 0.38 \times p_{ni} \tag{11-22}$$

Where:

CMF_{4i} = crash modification factor for the effect of lighting on total crashes; and

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

This CMF applies to total intersections crashes. Table 11-24 presents default values for the nighttime crash proportion, p_{ni}. HSM users are encouraged to replace the estimates in Table 11-24 with locally derived values.

Table 11-24. Default Nighttime Crash Proportions for Unlighted Intersections

Intersection Type	Proportion of Crashes that Occur at Night, p_{ni}
3ST	0.276
4ST	0.273
3SG	0.205

11.8. CALIBRATION TO LOCAL CONDITIONS

In Step 10 of the predictive method, presented in Section 11.4, the predictive model is calibrated to local state or geographic conditions. Crash 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, crash-reporting threshold, and crash-reporting practices. These variations may result in some jurisdictions experiencing a different number of traffic crashes on rural multilane highways than others. Calibration factors are included in the methodology to allow highway agencies to adjust the SPFs to match actual local conditions.

The calibration factors for roadway segments and intersections (defined below as C_r and C_i, respectively) will have values greater than 1.0 for roadways that, on average, experience more crashes than the roadways used in the development of the SPFs. The calibration factors for roadways that experience fewer crashes 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 Part C, Appendix A.

Calibration factors provide one method of incorporating local data to improve estimated crash frequencies for individual agencies or locations. Several other default values used in the methodology, 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 Part C, Appendix A.

11.9. LIMITATIONS OF PREDICTIVE METHODS IN CHAPTER 11

This section discusses limitations of the specific predictive models and the application of the predictive method in Chapter 11.

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

~~The SPFs developed for Chapter 11 do not include signalized three-leg intersection models. Such intersections may be found on rural multilane highways.~~

CMFs have not been developed for the SPF for four-leg signalized intersections on rural multilane highways.

11.10. APPLICATION OF CHAPTER 11, PREDICTIVE METHOD

The predictive method presented in Chapter 11 applies to rural multilane highways. The predictive method is applied to a rural multilane highway facility by following the 18 steps presented in Section 11.4. Worksheets are presented in Appendix 11A for applying calculations in the predictive method steps specific to Chapter 11. All computations of crash frequencies within these worksheets are conducted with values expressed to three decimal places. This level of precision is needed only for consistency in computations. In the last stage of computations, rounding the final estimates of expected average crash frequency be to one decimal place is appropriate.

11.11. SUMMARY

The predictive method can be used to estimate the expected average crash frequency for an entire rural multilane highway facility, a single individual site, or series of contiguous sites. A rural multilane highway facility is defined in Section 11.3, and consists of a four-lane highway facility which does not have access control and is outside of cities or towns with a population greater than 5,000 persons.

The predictive method for rural multilane highways is applied by following the 18 steps of the predictive method presented in Section 11.4. Predictive models, developed for rural multilane highway 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 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 11 consists of a safety performance function (SPF), crash modification factors (CMFs), 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. This estimate can be for either total crashes or organized by crash-severity or collision-type distribution. In order to account for differences between the base conditions and the specific conditions of the site, CMFs 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 Part C, Appendix A.1.

Where observed data are available, the EB Method is applied to improve the reliability of the estimate. The EB Method can be applied at the site-specific level or at the project-specific level. It may also be applied to a future time period if site conditions will not change in the future period. The EB Method is described in Part C, Appendix A.2.

Section 11.12 presents seven~~six~~ sample problems which detail the application of the predictive method. Appendix 11A contains worksheets which can be used in the calculations for the predictive method steps.

11.12. SAMPLE PROBLEMS

In this section, seven~~six~~ sample problems are presented using the predictive method for rural multilane highways. Sample Problem 1 illustrates how to calculate the predicted average crash frequency for a divided rural four-lane highway segment. Sample Problem 2 illustrates how to calculate the predicted average crash frequency for an undivided rural four-lane highway segment. Sample Problem 3 illustrates how to calculate the predicted average crash frequency for a three-leg stop-controlled intersection. Sample Problem XA illustrates how to calculate the predicted average crash frequency for a three-leg signalized intersection. Sample Problem 4 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 5 illustrates how to combine the results from Sample Problems 1 through 3 in a case where site-specific observed crash data are not available (i.e., using project level EB Method). Sample Problem 6 applies the Project Estimation Method 1, presented in Section C.7, to determine the effectiveness of a proposed upgrade from a rural two-lane roadway to a rural four-lane highway.

Table 11-25. List of Sample Problems in Chapter 11

Problem No.	Page No.	Description
1	11–37	Predicted average crash frequency for a divided roadway segment
2	11–43	Predicted average crash frequency for an undivided roadway segment
3	11–49	Predicted average crash frequency for a three-leg stop-controlled intersection
XA		Predicted average crash frequency for a three-leg signalized intersection
4	11–54	Expected average crash frequency for a facility when site-specific observed crash frequencies are available
5	11–56	Expected average crash frequency for a facility when site-specific observed crash frequencies are not available
6	11–60	Expected average crash frequency and the crash reduction for a proposed rural four-lane highway facility that will replace an existing rural two-lane roadway

11.12.1. Sample Problem 1

The Site/Facility
A rural four-lane divided highway segment.

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

The Facts

- 1.5-mi length
- 10,000 veh/day
- 12-ft lane width
- 6-ft paved right shoulder
- 20-ft traversable median
- No roadway lighting
- No automated enforcement

Assumptions
Collision type distributions are the defaults values presented in Table 11-6.

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 3.3 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 divided roadway segment is calculated from Equation 11-9 and Table 11-5 as follows:

$$N_{spf\ rd} = e^{(a+b\times\ln(AADT)+\ln(L))}$$
$$= e^{(-9.025+1.049\times\ln(10,000)+\ln(1.5))} = 2.835 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric conditions and traffic control features.

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

Lane Width (CMF_{1rd})

Since the roadway segment in Sample Problem 1 has 12-ft lanes, $CMF_{1rd} = 1.00$ (i.e., the base condition for CMF_{1rd} is 12-ft lane width).

Shoulder Width and Type (CMF_{2rd})

From Table 11-17, for 6-ft paved shoulders, $CMF_{2rd} = 1.04$.

Median Width (CMF_{3rd})

From Table 11-18, for a traversable median width of 20 ft, $CMF_{3rd} = 1.02$.

Lighting (CMF_{4rd})

Since there is no lighting in Sample Problem 1, $CMF_{4rd} = 1.00$ (i.e., the base condition for CMF_{4rd} is absence of roadway lighting).

Automated Speed Enforcement (CMF_{5rd})

Since there is no automated speed enforcement in Sample Problem 1, $CMF_{5rd} = 1.00$ (i.e., the base condition for CMF_{5rd} is the absence of automated speed enforcement).

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

$$CMF_{comb} = 1.04\times1.02$$
$$= 1.06$$

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

It is assumed in Sample Problem 1 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 11-3 based on the results obtained in Steps 9 through 11 as follows:

$$N_{\text{predicted}\ rs} = N_{spf\ rd}\times C_r\times(CMF_{1rd}\times CMF_{2rd}\times\ldots\times CMF_{5rd})$$
$$= 2.835\times1.10\times(1.06)$$
$$= 3.305 \text{ crashes/year}$$

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 the predicted average crash frequency. The five worksheets include:

- *Worksheet SP1A (Corresponds to Worksheet 1A)*—General Information and Input Data for Rural Multilane Roadway Segments
- Worksheet SP1B (Corresponds to Worksheet 1B (a))—Crash Modification Factors for Rural Multilane Divided Roadway Segments
- Worksheet SP1C (Corresponds to Worksheet 1C (a))—Roadway Segment Crashes for Rural Multilane Divided Roadway Segments
- Worksheet SP1D (Corresponds to Worksheet 1D (a))—Crashes by Severity Level and Collision Type for Rural Multilane Divided Roadway Segments
- Worksheet SP1E (Corresponds to Worksheet 1E)—Summary Results for Rural Multilane Roadway Segments

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 11A.

Worksheet SP1A—General Information and Input Data for Rural Multilane Roadway Segments

Worksheet SP1A is a summary of general information about the roadway segment, analysis, input data (i.e., "The Facts") and assumptions for Sample Problem 1.

Worksheet SP1A. General Information and Input Data for Rural Multilane Roadway Segments

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

Input Data	**Base Conditions**	**Site Conditions**
Roadway type (divided/undivided)	—	divided
Length of segment, L (mi)	—	1.5
AADT (veh/day)	—	10,000
Lane width (ft)	12	12
Shoulder width (ft)—right shoulder width for divided	8	6
Shoulder type—right shoulder type for divided	paved	paved
Median width (ft)—for divided only	30	20
Sideslopes—for undivided only	1:7 or flatter	N/A
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 SP1B—Crash Modification Factors for Rural Multilane Divided Roadway Segments

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 11.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs multiplied together in Column 6 of Worksheet SP1B which indicates the combined CMF value.

Worksheet SP1B. Crash Modification Factors for Rural Multilane Divided Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
CMF for Lane Width	**CMF for Right Shoulder Width**	**CMF for Median Width**	**CMF for Lighting**	**CMF for Auto Speed Enforcement**	**Combined CMF**
CMF_{1rd}	CMF_{2rd}	CMF_{3rd}	CMF_{4rd}	CMF_{5rd}	CMF_{comb}
from Equation 11-16	from Table 11-17	from Table 11-18	from Equation 11-17	from Section 11.7.2	(1)*(2)*(3)*(4)*(5)
1.00	1.04	1.02	1.00	1.00	1.06

Worksheet SP1C—Roadway Segment Crashes for Rural Multilane Divided Roadway Segments

The SPF for the roadway segment in Sample Problem 1 is calculated using the coefficients found in Table 11-5 (Column 2), which are entered into Equation 11-9 (Column 3). The overdispersion parameter associated with the SPF can be calculated using Equation 11-10 and entered into Column 4; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized). Column 5 represents the combined CMF (from Column 6 in Worksheet SP1B), and Column 6 represents the calibration factor. Column 7 calculates predicted average crash frequency using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SP1C. Roadway Segment Crashes for Rural Multilane Divided Roadway Segments

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	**SPF Coefficients**			$N_{spf\ rd}$	**Overdispersion Parameter, k**	**Combined CMFs**	**Calibration Factor, C_r**	**Predicted Average Crash Frequency, $N_{predicted\ rs}$**
	from Table 11-5			**from Equation 11-9**	**from Equation 11-10**	**(6) from Worksheet SP1B**		**(3)*(5)*(6)**
	a	**b**	**c**					
Total	–9.025	1.049	1.549	2.835	0.142	1.06	1.10	3.306
Fatal and injury (FI)	–8.837	0.958	1.687	1.480	0.123	1.06	1.10	1.726
Fatal and injury[a] (FI[a])	–8.505	0.874	1.740	0.952	0.117	1.06	1.10	1.110
Property damage only (PDO)								$(7)_{total}–(7)_{FI}$
								1.580

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet SP1D—Crashes by Severity Level and Collision Type for Rural Multilane Divided Roadway Segments

Worksheet SP1D presents the default proportions for collision type (from Table 11-6) by crash severity level as follows:

- Total crashes (Column 2)
- Fatal-and-injury crashes (Column 4)
- Fatal-and-injury crashes, not including "possible injury" crashes (i.e., on a KABCO injury scale, only KAB crashes) (Column 6)
- Property-damage-only crashes (Column 8)

Using the default proportions, the predicted average crash frequency by collision type is presented in Columns 3 (Total), 5 (Fatal and Injury, FI), 7 (Fatal and Injury, not including "possible injury"), and 9 (Property Damage Only, PDO).

These proportions may be used to separate the predicted average crash frequency (from Column 7, Worksheet SP1C) by crash severity and collision type.

Worksheet SP1D. Crashes by Severity Level and Collision Type for Rural Multilane Divided Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
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 $_{(FI^a)}$**	$N_{predicted\ rs\ (FI^a)}$ **(crashes/year)**	**Proportion of Collision Type $_{(PDO)}$**	$N_{predicted\ rs\ (PDO)}$
	from Table 11-6	**(7)$_{total}$ from Worksheet SP1C**	**from Table 11-6**	**(7)$_{FI}$ from Worksheet SP1C**	**from Table 11-6**	**(7)$_{FI^a}$ from Worksheet SP1C**	**from Table 11-6**	**(7)$_{PDO}$ from Worksheet SP1C**
Total	1.000	3.306	1.000	1.726	1.000	1.110	1.000	1.580
		(2)*(3)$_{total}$		(4)*(5)$_{FI}$		(6)*(7)$_{FI^a}$		(8)*(9)$_{PDO}$
Head-on collision	0.006	0.020	0.013	0.022	0.018	0.020	0.002	0.003
Sideswipe collision	0.043	0.142	0.027	0.047	0.022	0.024	0.053	0.084
Rear-end collision	0.116	0.383	0.163	0.281	0.114	0.127	0.088	0.139
Angle collision	0.043	0.142	0.048	0.083	0.045	0.050	0.041	0.065
Single-vehicle collision	0.768	2.539	0.727	1.255	0.778	0.864	0.792	1.251
Other collision	0.024	0.079	0.022	0.038	0.023	0.026	0.024	0.038

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet SP1E—Summary Results for Rural Multilane Roadway Segments

Worksheet SP1E presents a summary of the results. Using the roadway segment length, the worksheet presents the crash rate in miles per year (Column 4).

Worksheet SP1E. Summary Results for Rural Multilane Roadway Segments

(1)	(2)	(3)	(4)
	Predicted Average Crash Frequency (crashes/year)		Crash Rate (crashes/mi/year)
Crash Severity Level	(7) from Worksheet SP1C	Roadway Segment Length (mi)	(2)/(3)
Total	3.306	1.5	2.2
Fatal and injury (FI)	1.726	1.5	1.2
Fatal and injury[a] (FI[a])	1.110	1.5	0.7
Property damage only (PDO)	1.580	1.5	1.1

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

11.12.2. Sample Problem 2

The Site/Facility
A rural four-lane undivided highway segment.

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

The Facts

- 0.1-mi length
- 8,000 veh/day
- 11-ft lane width
- 2-ft gravel shoulder
- Sideslope of 1:6
- Roadside lighting present
- Automated enforcement present

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 33 percent.

The proportion of crashes that occur at night are not known, so the default proportions for nighttime crashes will be used.

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 2 is determined to be 0.3 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 an undivided roadway segment is calculated from Equation 11-7 and Table 11-3 as follows:

$$N_{spf\ ru} = e^{(a + b \times \ln(\text{AADT}) + \ln(L))}$$
$$= e^{(-9.653 + 1.176 \times \ln(8{,}000) + \ln(0.1))} = 0.250 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric conditions and traffic control features.

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

Lane Width (CMF_{1ru})

CMF_{1ru} can be calculated from Equation 11-13 as follows:

$$CMF_{1ru} = (CMF_{RA} - 1.0) \times p_{RA} + 1.0$$

For 11-ft lane width and AADT of 8,000, $CMF_{RA} = 1.04$ (see Table 11-11).

The proportion of related crashes, p_{RA}, is 0.33 (from local experience, see assumptions).

$$CMF_{1ru} = (1.04 - 1.0) \times 0.33 + 1.0 = 1.01$$

Shoulder Width and Type (CMF_{2ru})

CMF_{2ru} can be calculated from Equation 11-14 as follows:

$$CMF_{2ru} = (CMF_{WRA} \times CMF_{TRA} - 1.0) \times p_{RA} + 1.0$$

For 2-ft shoulders and AADT of 8,000, $CMF_{WRA} = 1.30$ (see Table 11-12).

For 2-ft gravel shoulders, $CMF_{TRA} = 1.01$ (see Table 11-13).

The proportion of related crashes, p_{RA}, is 0.33 (from local experience, see assumptions).

$$CMF_{2ru} = (1.30 \times 1.01 - 1.0) \times 0.33 + 1.0 = 1.10$$

Sideslopes (CMF_{3ru})

From Table 11-14, for a sideslope of 1:6, $CMF_{3ru} = 1.05$.

Lighting (CMF_{4ru})

CMF_{4ru} can be calculated from Equation 11-15 as follows:

$CMF_{4ru} = 1 - [(1 - 0.72 \times p_{inr} - 0.83 \times p_{pnr}) \times p_{nr}]$

Local values for nighttime crashes proportions are not known. The default nighttime crash proportions used are $p_{inr} = 0.361$, $p_{pnr} = 0.639$, and $p_{nr} = 0.255$ (see Table 11-15).

$$CMF_{4ru} = 1 - \left[(1 - 0.72 \times 0.361 - 0.83 \times 0.639) \times 0.255\right] = 0.95$$

Automated Speed Enforcement (CMF_{5ru})

For an undivided roadway segment with automated speed enforcement, $CMF_{5ru} = 0.95$ (see Section 11.7.1).

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

$$CMF_{comb} = 1.04 \times 1.02 \times 1.05 \times 0.95 \times 0.95 = 1.05$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed in Sample Problem 2 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 11-2 based on the results obtained in Steps 9 through 11 as follows:

$$\begin{aligned} N_{\text{predicted } rs} &= N_{spf\ ru} \times C_r \times (CMF_{1ru} \times CMF_{2ru} \times \ldots \times CMF_{5ru}) \\ &= 0.250 \times 1.10 \times (1.05) \\ &= 0.289 \text{ crashes/year} \end{aligned}$$

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 the predicted average crash frequency. The five worksheets include:

- *Worksheet SP2A (Corresponds to Worksheet 1A)*—General Information and Input Data for Rural Multilane Roadway Segments
- Worksheet SP2B (Corresponds to Worksheet 1B (b))—Crash Modification Factors for Rural Multilane Undivided Roadway Segments
- Worksheet SP2C (Corresponds to Worksheet 1C (b))—Roadway Segment Crashes for Rural Multilane Undivided Roadway Segments
- Worksheet SP2D (Corresponds to Worksheet 1D (b))—Crashes by Severity Level and Collision Type for Rural Multilane Undivided Roadway Segments
- Worksheet SP2E (Corresponds to Worksheet 1E)—Summary Results for Rural Multilane Roadway Segments

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Chapter 11, Appendix 11A.

Worksheet SP2A—General Information and Input Data for Rural Multilane Roadway Segments

Worksheet SP2A is a summary of general information about the roadway segment, analysis, input data (i.e., "The Facts") and assumptions for Sample Problem 2.

Worksheet SP2A. General Information and Input Data for Rural Multilane Roadway Segments

General Information		Location Information	
Analyst		Highway	
Agency or Company		Roadway Section	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		**Base Conditions**	**Site Conditions**
Roadway type (divided/undivided)		—	undivided
Length of segment, L (mi)		—	0.1
AADT (veh/day)		—	8,000
Lane width (ft)		12	11
Shoulder width (ft)—right shoulder width for divided		6	2
Shoulder type—right shoulder type for divided		paved	gravel
Median width (ft)—for divided only		30	N/A
Sideslopes—for undivided only		1:7 or flatter	1:6
Lighting (present/not present)		not present	present
Auto speed enforcement (present/not present)		not present	present
Calibration factor, C_r		1.0	1.1

Worksheet SP2B—Crash Modification Factors for Rural Multilane Undivided Roadway Segments

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 11.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs multiplied together in Column 6 of Worksheet SP2B which indicates the combined CMF value.

Worksheet SP2B. Crash Modification Factors for Rural Multilane Undivided Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
CMF for Lane Width	**CMF for Shoulder Width**	**CMF for Sideslopes**	**CMF for Lighting**	**CMF for Automated Speed Enforcement**	**Combined CMF**
CMF_{1ru}	CMF_{2ru}	CMF_{3ru}	CMF_{4ru}	CMF_{5ru}	CMF_{comb}
from Equation 11-13	from Equation 11-14	from Table 11-14	from Equation 11-15	from Section 11.7.1	(1)*(2)*(3)*(4)*(5)
1.01	1.10	1.05	0.95	0.95	1.05

Worksheet SP2C—Roadway Segment Crashes for Rural Multilane Undivided Roadway Segments

The SPF for the roadway segment in Sample Problem 2 is calculated using the coefficients found in Table 11-3 (Column 2), which are entered into Equation 11-7 (Column 3). The overdispersion parameter associated with the SPF can be calculated using Equation 11-8 and entered into Column 4; however, the overdispersion parameter is not needed for Sample Problem 2 (as the EB Method is not utilized). Column 5 represents the combined CMF (from Column 6 in Worksheet SP2B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SP2C. Roadway Segment Crashes for Rural Multilane Undivided Roadway Segments

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients			$N_{spf\ ru}$	Overdispersion Parameter, *k*	Combined CMFs	Calibration Factor, C_r	Predicted Average Crash Frequency, $N_{predicted\ rs}$
	from Table 11-3			from Equation 11-7	from Equation 11-8	(6) from Worksheet SP2B		(3)*(5)*(6)
	a	b	c					
Total	−9.653	1.176	1.675	0.250	1.873	1.05	1.10	0.289
Fatal and injury (FI)	−9.410	1.094	1.796	0.153	1.660	1.05	1.10	0.177
Fatal and injury[a] (FI[a])	−8.577	0.938	2.003	0.086	1.349	1.05	1.10	0.099
Property damage only (PDO)	—	—	—	—	—	—	—	$(7)_{total}-(7)_{FI}$ = 0.112

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet SP2D—Crashes by Severity Level and Collision Type for Rural Multilane Undivided Roadway Segments

Worksheet SP2D presents the default proportions for collision type (from Table 11-4) by crash severity level as follows:

- Total crashes (Column 2)
- Fatal-and-injury crashes (Column 4)
- Fatal-and-injury crashes, not including “possible-injury” crashes (i.e., on a KABCO injury scale, only KAB crashes) (Column 6)
- Property-damage-only crashes (Column 8)

Using the default proportions, the predicted average crash frequency by collision type is presented in Columns 3 (Total), 5 (Fatal and Injury, FI), 7 (Fatal and Injury, not including “possible injury”), and 9 (Property Damage Only, PDO).

These proportions may be used to separate the predicted average crash frequency (from Column 7, Worksheet SP2C) by crash severity and collision type.

Worksheet SP2D. Crashes by Severity Level and Collision Type for Rural Multilane Undivided Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	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 $_{(FI^a)}$	$N_{predicted\ rs\ (FI^a)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	$N_{predicted\ rs\ (PDO)}$ (crashes/year)
Collision Type	from Table 11-4	$(7)_{total}$ from Worksheet SP2C	from Table 11-4	$(7)_{FI}$ from Worksheet SP2C	from Table 11-4	$(7)_{FI}{}^{a}$ from Worksheet SP2C	from Table 11-4	$(7)_{PDO}$ from Worksheet SP2C
Total	1.000	0.289	1.000	0.177	1.000	0.099	1.000	0.112
		$(2)*(3)_{total}$		$(4)*(5)_{FI}$		$(6)*(7)_{FI}{}^{a}$		$(8)*(9)_{PDO}$
Head-on collision	0.009	0.003	0.029	0.005	0.043	0.004	0.001	0.000
Sideswipe collision	0.098	0.028	0.048	0.008	0.044	0.004	0.120	0.013
Rear-end collision	0.246	0.071	0.305	0.054	0.217	0.021	0.220	0.025
Angle collision	0.356	0.103	0.352	0.062	0.348	0.034	0.358	0.040
Single-vehicle collision	0.238	0.069	0.238	0.042	0.304	0.030	0.237	0.027
Other collision	0.053	0.015	0.028	0.005	0.044	0.004	0.064	0.007

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet SP2E—Summary Results for Rural Multilane Roadway Segments

Worksheet SP2E presents a summary of the results. Using the roadway segment length, the worksheet presents the crash rate in miles per year (Column 4).

Worksheet SP2E. Summary Results for Rural Multilane Roadway Segments

(1)	(2)	(3)	(4)
Crash Severity Level	Predicted Average Crash Frequency (crashes/year)	Roadway Segment Length (mi)	Crash Rate (crashes/mi/year)
	(7) from Worksheet SP2C		(2)/(3)
Total	0.289	0.1	2.9
Fatal and injury (FI)	0.177	0.1	1.8
Fatal and injury[a] (FI[a])	0.099	0.1	1.0
Property damage only (PDO)	0.112	0.1	1.1

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

11.12.3. Sample Problem 3

The Site/Facility
A three-leg stop-controlled intersection located on a rural four-lane highway.

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
- 0 right-turn lanes on major road
- 1 left-turn lane on major road
- 30-degree skew angle
- AADT of major road = 8,000 veh/day
- AADT of minor road = 1,000 veh/day
- Calibration factor = 1.50
- Intersection lighting is present

Assumptions

- Collision type distributions are the default values from Table 11-9.
- 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 0.8 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 three-leg intersection with minor-road stop control is calculated from Equation 11-11 and Table 11-7 as follows:

$$N_{spf\ int} = exp\left[a + b \times 1n(AADT_{maj}) + c \times 1n(AADT_{min})\right]$$
$$= exp[-12.526 + 1.204 \times \ln(8{,}000) + 0.236 \times \ln(1{,}000)] = 0.928 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric conditions and traffic control features
Each CMF used in the calculation of the predicted average crash frequency of the intersection is calculated below:

Intersection Skew Angle (CMF_{1i})

CMF_{1i} can be calculated from Equation 11-18 as follows:

$$CMF_{1i} = \frac{0.016 \times skew}{(0.98 + 0.016 \times skew} + 1$$

$$CMF_{1i} = \frac{0.016 \times skew}{(0.98 + 0.16 \times skew)} + 1$$

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

$$CMF_{1i} = \frac{0.016 \times 30}{(0.98 + 0.016 \times 30)} + 1 = 1.08$$

$$CMF_{1i} = \frac{0.016 \times 30}{(0.98 + 0.16 \times 30)} + 1 = 1.08$$

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

From Table 11-22, for a left-turn lane on one non-stop-controlled approach at a three-leg stop-controlled intersection, $CMF_{2i} = 0.56$.

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

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

Lighting (CMF_{4i})

CMF_{4i} can be calculated from Equation 11-22 as follows:

$$CMF_{4i} = 1.0 - 0.38 \times p_{ni}$$

From Table 11-24, for intersection lighting at a three-leg stop-controlled intersection, $p_{ni} = 0.276$.

$$CMF_{4i} = 1.0 - 0.38 \times 0.276 = 0.90$$

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

$$CMF_{comb} = 1.33 - 0.56 \times 0.90 = 0.67$$

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 11-4 based on the results obtained in Steps 9 through 11 as follows:

$$N_{\text{predicted } int} = N_{spf\ int} \times C_i \times (CMF_{1i} \times CMF_{2i} \times \ldots \times CMF_{4i})$$
$$= 0.928 \times 1.50 \times (0.67) = 0.933 \text{ crashes/year}$$

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, a series of five worksheets are provided for determining the predicted average crash frequency. The five worksheets include:

- *Worksheet SP3A (Corresponds to Worksheet 2A)*—General Information and Input Data for Rural Multilane Highway Intersections
- *Worksheet SP3B (Corresponds to Worksheet 2B)*—Crash Modification Factors for Rural Multilane Highway Intersections
- *Worksheet SP3C (Corresponds to Worksheet 2C)*—Intersection Crashes for Rural Multilane Highway Intersections
- Worksheet SP3D (Corresponds to Worksheet 2D)—Crashes by Severity Level and Collision Type for Rural Multilane Highway Intersections
- Worksheet SP3E (Corresponds to Worksheet 2E)—Summary Results for Rural Multilane Highway Intersections

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 11A.

Worksheet SP3A—General Information and Input Data for Rural Multilane Highway Intersections

Worksheet SP3A is a summary of general information about the intersection, analysis, input data (i.e., "The Facts") and assumptions for Sample Problem 3.

Worksheet SP3A. General Information and Input Data for Rural Multilane Highway Intersections

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

Input Data	Base Conditions	Site Conditions
Intersection type (3ST, 3SG, 4ST, 4SG)	—	3ST
$AADT_{maj}$ (veh/day)	—	8,000
$AADT_{min}$ (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	1
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	1.5

Worksheet SP3B—Crash Modification Factors for Rural Multilane Highway Intersections

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 11.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 6 of Worksheet SP3B which indicates the combined CMF value.

Worksheet SP3B. Crash Modification Factors for Rural Multilane Highway Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	CMF for Intersection Skew Angle	**CMF for Left-Turn Lanes**	**CMF for Right-Turn Lanes**	**CMF for Lighting**	**Combined CMF**
	CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{comb}
Crash Severity Level	**from Equations 11-18 or 11-20 and 11-19 or 11-21**	**from Table 11-22**	**from Table 11-23**	**from Equation 11-22**	**(1)*(2)*(3)*(4)**
Total	1.33	0.56	1.00	0.90	0.67
Fatal and injury (FI)	1.50	0.45	1.00	0.90	0.61

Worksheet SP3C—Intersection Crashes for Rural Multilane Highway Intersections

The SPF for the intersection in Sample Problem 3 is calculated using the coefficients shown in Table 11-7 (Column 2), which are entered into Equation 11-11 (Column 3). The overdispersion parameter associated with the SPF is also found in Table 11-7 and entered into Column 4; however, the overdispersion parameter is not needed for Sample Problem 3 (as the EB Method is not utilized). Column 5 represents the combined CMF (from Column 6 in Worksheet SP3B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency using the values in Column 3, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SP3C. Intersection Crashes for Rural Multilane Highway Intersections

(1)	(2)			(3)	(4)	(5)	(6)	(7)
	SPF Coefficients			$N_{spf\ int}$	**Overdispersion Parameter, k**	**Combined CMFs**		**Predicted Average Crash Frequency, $N_{predicted\ int}$**
	from Tables 11-7 or 11-8							
Crash Severity Level	**a**	**b**	**c**	**from Equation 11-11 or 11-12**	**from Tables 11-7 or 11-8**	**from (6) of Worksheet SP3B**	**Calibration Factor, C_i**	**(3)*(5)*(6)**
Total	–12.526	1.204	0.236	0.928	0.460	0.67	1.50	0.933
Fatal and injury (FI)	–12.664	1.107	0.272	0.433	0.569	0.61	1.50	0.396
Fatal and injury[a] (FI[a])	–11.989	1.013	0.228	0.270	0.566	0.61	1.50	0.247
Property damage only (PDO)	—	—	—	—	—	—	—	$(7)_{total}–(7)_{FI}$ = 0.537

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet SP3D—Crashes by Severity Level and Collision Type for Rural Multilane Highway Intersections

Worksheet SP3D presents the default proportions for collision type (from Table 11-9) by crash severity level as follows:

- Total crashes (Column 2)
- Fatal-and-injury crashes (Column 4)
- Fatal-and-injury crashes, not including “possible-injury” crashes (i.e., on a KABCO injury scale, only KAB crashes) (Column 6)
- Property-damage-only crashes (Column 8)

Using the default proportions, the predicted average crash frequency by collision type in Columns 3 (Total), 5 (Fatal and Injury, FI), 7 (Fatal and Injury, not including “possible injury”), and 9 (Property Damage Only, PDO).

These proportions may be used to separate the predicted average crash frequency (from Column 7, Worksheet SP3C) by crash severity and collision type.

Worksheet SP3D. Crashes by Severity Level and Collision Type for Rural Multilane Highway Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Collision Type	**Proportion of Collision Type (total)**	$N_{\text{predicted } int \text{ (total)}}$ **(crashes/year)**	**Proportion of Collision Type (FI)**	$N_{\text{predicted } int\ (FI)}$ **(crashes/year)**	**Proportion of Collision Type (FI^a)**	$N_{\text{predicted } int\ (FI^a)}$ **(crashes/year)**	**Proportion of Collision Type (PDO)**	$N_{\text{predicted } int\ (PDO)}$ **(crashes/year)**
	from Table 11-9	**$(7)_{\text{total}}$ from Worksheet SP3C**	**from Table 11-9**	**$(7)_{FI}$ from Worksheet SP3C**	**from Table 11-9**	**$(7)_{FI^a}$ from Worksheet SP3C**	**from Table 11-9**	**$(7)_{PDO}$ from Worksheet SP3C**
Total	1.000	0.933	1.000	0.396	1.000	0.247	1.000	0.537
		$(2)*(3)_{\text{total}}$		$(4)*(5)_{FI}$		$(6)*(7)_{FI}{}^{a}$		$(8)*(9)_{PDO}$
Head-on collision	0.029	0.027	0.043	0.017	0.052	0.013	0.020	0.011
Sideswipe collision	0.133	0.124	0.058	0.023	0.057	0.014	0.179	0.096
Rear-end collision	0.289	0.270	0.247	0.098	0.142	0.035	0.315	0.169
Angle collision	0.263	0.245	0.369	0.146	0.381	0.094	0.198	0.106
Single-vehicle collision	0.234	0.218	0.219	0.087	0.284	0.070	0.244	0.131
Other collision	0.052	0.049	0.064	0.025	0.084	0.021	0.044	0.024

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet SP3E—Summary Results for Rural Multilane Highway Intersections

Worksheet SP3E presents a summary of the results.

Worksheet SP3E. Summary Results for Rural Multilane Highway Intersections

(1)	(2)
	Predicted Average Crash Frequency (crashes/year)
Crash Severity Level	**(7) from Worksheet SP3C**
Total	0.933
Fatal and injury (FI)	0.396
Fatal and injury[a] (FI[a])	0.247
Property damage only (PDO)	0.537

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

11.12.4. Sample Problem XA

The Site/Facility

A three-leg signalized intersection located on a rural four-lane highway.

The Question

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

The Facts

- 3 legs
- Signal control
- 1 right-turn lane on major road
- 1 left-turn lane on major road
- 0-degree skew angle
- AADT of major road = 28,000 veh/day
- AADT of minor road = 8,000 veh/day
- Calibration factor = 1.20
- Intersection lighting is present

Assumptions

- Collision type distributions are the default values from Table 11-9.
- The calibration factor is assumed to be 1.20.

Results

Using the predictive method steps as outlined below, the predicted average crash frequency for the intersection in Sample Problem XA is determined to be 5.6 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 XA, 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 SPFs for a three-leg intersection with signal control are calculated from Equation 11-11 and Table 11-8 as follows:

$$N_{spf\ int\ total} = exp\ [\ a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min})\ ]$$

$$= exp\ [\ -6.280 + 0.520 \times \ln(28{,}000) + 0.310 \times \ln(8{,}000)\ ] = 6.239 \text{ crashes/year}$$

$$N_{spf\ int\ FI} = exp\ [\ a + b \times \ln(AADT_{maj}) + c \times \ln(AADT_{min})\ ]$$

$$= exp\ [\ -11.030 + 0.790 \times \ln(28{,}000) + 0.390 \times \ln(8{,}000)\ ] = 1.759 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric conditions and traffic control features

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

Intersection Skew Angle (CMF_{1i})

CMF_{1i} equals 1.00 for signalized intersections.

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

From Table 11-22, for a left-turn lane on one approach at a three-leg signalized intersection, $CMF_{2i} = 0.85$ for total crashes and fatal-and-injury crashes.

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

From Table 11-23, for a right-turn lane on one approach at a three-leg signalized intersection, $CMF_{3i} = 0.96$ for total crashes and $CMF_{3i} = 0.91$ fatal-and-injury crashes.

Lighting (CMF_{4i})

CMF_{4i} can be calculated from Equation 11-22 as follows:

$CMF_{4i} = 1.0 - 0.38 \times p_{ni}$

From Table 11-24, for intersection lighting at a three-leg signalized intersection, $p_{ni} = 0.205$.

$CMF_{4i} = 1.0 - 0.38 \times 0.205 = 0.92$

The combined CMF value for Sample Problem XA is calculated below.

$CMF_{comb\ total} = 0.85 \times 0.96 \times 0.92 = 0.75$

$CMF_{comb\ FI} = 0.85 \times 0.91 \times 0.92 = 0.71$

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

It is assumed that a calibration factor, C_i, of 1.20 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 11-4 based on the results obtained in Steps 9 through 11 as follows:

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

$= 6.239 \times 1.20 \times (0.75) = 5.633$ crashes/yr

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

$= 1.759 \times 1.20 \times (0.71) = 1.505$ crashes/yr

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, a series of five worksheets are provided for determining the predicted average crash frequency. The five worksheets include:

- *Worksheet SPXAA (Corresponds to Worksheet 2A)*—General Information and Input Data for Rural Multilane Highway Intersections
- *Worksheet SPXAB (Corresponds to Worksheet 2B)*—Crash Modification Factors for Rural Multilane Highway Intersections
- *Worksheet SPXAC (Corresponds to Worksheet 2C)*—Intersection Crashes for Rural Multilane Highway Intersections
- Worksheet SPXAD (Corresponds to Worksheet 2D)—Crashes by Severity Level and Collision Type for Rural Multilane Highway Intersections
- Worksheet SPXAE (Corresponds to Worksheet 2E)—Summary Results for Rural Multilane Highway Intersections

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 11A.

Worksheet SPXAA—General Information and Input Data for Rural Multilane Highway Intersections

Worksheet SPXAA is a summary of general information about the intersection, analysis, input data (i.e., “The Facts”) and assumptions for Sample Problem XA.

Worksheet SPXAA. General Information and Input Data for Rural Multilane Highway Intersections

General Information		**Location Information**	
Analyst		Highway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		**Base Conditions**	**Site Conditions**
Intersection type (3ST, 3SG, 4ST, 4SG)		—	3SG
$AADT_{maj}$ (veh/day)		—	28,000
$AADT_{min}$ (veh/day)		—	8,000
Intersection skew angle (degrees)		0	0
Number of signalized or uncontrolled approaches with a left-turn lane (0, 1, 2, 3, 4)		0	1
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	present
Calibration factor, C_i		1.0	1.2

Worksheet SPXAB—Crash Modification Factors for Rural Multilane Highway Intersections

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 11.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 6 of Worksheet SPXAB which indicates the combined CMF value.

Worksheet SPXAB. Crash Modification Factors for Rural Multilane Highway Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	CMF for Intersection Skew Angle	**CMF for Left-Turn Lanes**	**CMF for Right-Turn Lanes**	**CMF for Lighting**	**Combined CMF**
	CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{comb}
Crash Severity Level	**from Equations 11-18 or 11-20 and 11-19 or 11-21**	**from Table 11-22**	**from Table 11-23**	**from Equation 11-22**	**(1)*(2)*(3)*(4)**
Total	1.00	0.85	0.96	0.92	0.75
Fatal and injury (FI)	1.00	0.85	0.91	0.92	0.71

Worksheet SPXAC—Intersection Crashes for Rural Multilane Highway Intersections

The SPFs for the intersection in Sample Problem XA are calculated using the coefficients shown in Table 11-8 (Column 2), which are entered into Equation 11-11 (Column 3). The overdispersion parameters associated with the SPFs are also found in Table 11-8 and entered into Column 4; however, the overdispersion parameters are not needed for Sample Problem XA (as the EB Method is not utilized). Column 5 represents the combined CMF (from Column 6 in Worksheet SPXAB), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency using the values in Column 3, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SPXAC. Intersection Crashes for Rural Multilane Highway Intersections

(1)	(2)			(3)	(4)	(5)	(6)	(7)
	SPF Coefficients			$N_{spf\ int}$	Overdispersion Parameter, k	Combined CMFs		Predicted Average Crash Frequency, $N_{predicted\ int}$
	from Tables 11-7 or 11-8							
Crash Severity Level	a	B	c	from Equation 11-11 or 11-12	from Tables 11-7 or 11-8	from (6) of Worksheet SPXAB	Calibration Factor, C_i	(3)*(5)*(6)
Total	-6.280	0.520	0.310	6.239	0.40	0.75	1.20	5.633
Fatal and injury (FI)	-11.030	0.790	0.390	1.759	1.15	0.71	1.20	1.505
Fatal and injury[a] (FI[a])	—	—	—	—	—	—	—	—
Property damage only (PDO)	—	—	—	—	—	—	—	$(7)_{total}-(7)_{FI}$ = 4.128

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet SPXAD—Crashes by Severity Level and Collision Type for Rural Multilane Highway Intersections

Worksheet SPXAD presents the default proportions for collision type (from Table 11-9) by crash severity level as follows:

- Total crashes (Column 2)
- Fatal-and-injury crashes (Column 4)
- Fatal-and-injury crashes, not including "possible-injury" crashes (i.e., on a KABCO injury scale, only KAB crashes) (Column 6)
- Property-damage-only crashes (Column 8)

Using the default proportions, the predicted average crash frequency by collision type is shown in Columns 3 (Total), 5 (Fatal and Injury, FI), 7 (Fatal and Injury, not including "possible injury"), and 9 (Property Damage Only, PDO).

These proportions may be used to separate the predicted average crash frequency (from Column 7, Worksheet SPXAC) by crash severity and collision type.

Worksheet SPXAD. Crashes by Severity Level and Collision Type for Rural Multilane Highway Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
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 $_{(FI^a)}$	$N_{predicted\ int\ (FI^a)}$ (crashes/year)	Proportion of Collision Type (PDO)	$N_{predicted\ int\ (PDO)}$ (crashes/year)
	from Table 11-9	$(7)_{total}$ from Worksheet SPXAC	from Table 11-9	$(7)_{FI}$ from Worksheet SPXAC	from Table 11-9	$(7)_{FI^a}$ from Worksheet SPXAC	from Table 11-9	$(7)_{PDO}$ from Worksheet SPXAC
Total	1.000	5.633	1.000	1.505	1.000	--	1.000	4.128
		$(2)*(3)_{total}$		$(4)*(5)_{FI}$		$(6)*(7)_{FI}{}^{a}$		$(8)*(9)_{PDO}$
Head-on collision	0.024	0.133	0.041	0.061	--	--	0.018	0.074
Sideswipe collision	0.080	0.451	0.034	0.052	--	--	0.108	0.445
Rear-end collision	0.432	2.432	0.367	0.552	--	--	0.441	1.821
Angle collision	0.280	1.577	0.408	0.613	--	--	0.221	0.910
Single-vehicle collision	0.113	0.636	0.097	0.146	--	--	0.151	0.624
Other collision	0.072	0.406	0.053	0.080	--	--	0.062	0.254

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet SPXAE—Summary Results for Rural Multilane Highway Intersections

Worksheet SPXAE presents a summary of the results.

Worksheet SPXAE. Summary Results for Rural Multilane Highway Intersections

(1)	(2)
	Predicted Average Crash Frequency (crashes/year)
Crash Severity Level	(7) from Worksheet SPXAC
Total	5.6
Fatal and injury (FI)	1.5
Fatal and injury[a] (FI[a])	--
Property damage only (PDO)	4.1

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

~~11.12.4.~~11.12.5. Sample Problem 4

The Project

A project of interest consists of three sites: a rural four-lane divided highway segment, a rural four-lane undivided highway 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 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 (4D segment, 4U segment)
- 1 intersection (3ST intersection)
- 9 observed crashes (4D segment: 4 crashes; 4U 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 Part C, Appendix A.2.4.

Results

The expected average crash frequency for the project is 5.7 crashes per year (rounded to one decimal place).

WORKSHEETS

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

- *Worksheet SP4A (Corresponds to 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 SP4B (Corresponds to Worksheet 3B)—Site-Specific EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 11A.

Worksheets SP4A—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 SP4A. Column 5 presents the observed crash frequencies by site type, and Column 6 the overdispersion parameter. 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 A 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.

Worksheet SP4A. 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)
	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, k	Weighted Adjustment, w	Expected Average Crash Frequency, $N_{expected}$
Site Type	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$			Equation A-5	Equation A-4
Roadway Segments							
Segment 1	3.306	1.726	1.580	4	0.142	0.681	3.527
Segment 2	0.289	0.177	0.112	2	1.873	0.649	0.890
Intersections							
Intersection 1	0.933	0.396	0.537	3	0.460	0.700	1.554
Combined (Sum of Column)	4.528	2.299	2.229	9	—	—	5.971

Column 7—Weighted Adjustment

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

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

Segment 1

$$w = \frac{1}{1 + 0.142 \times (3.306)} = 0.681$$

Segment 2

$$w = \frac{1}{1 + 1.873 \times (0.289)} = 0.649$$

Intersection 1

$$w = \frac{1}{1 + 0.460 \times (0.933)} = 0.700$$

Column 8—Expected Average Crash Frequency

The estimate of expected average crash frequency, N_{expected}, is calculated using Equation A-4 as follows:

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

Segment 1: $N_{\text{expected}} = 0.681 \times 3.306 + (1 - 0.681) \times 4 = 3.527$

Segment 2: $N_{\text{expected}} = 0.649 \times 0.289 + (1 - 0.649) \times 2 = 0.890$

Intersection 1: $N_{\text{expected}} = 0.700 \times 0.933 + (1 - 0.700) \times 3 = 1.554$

Worksheet SP4B—Site-Specific EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

Worksheet SP4B 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 SP4B. Site-Specific EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

(1)	(2)	(3)
Crash Severity Level	$N_{\text{predicted}}$	N_{expected}
Total	$(2)_{comb}$ from Worksheet SP4A	$(8)_{comb}$ from Worksheet SP4A
	4.528	6.0
Fatal and injury (FI)	$(3)_{comb}$ from Worksheet SP4A	$(3)_{\text{total}}$*$(2)_{FI}$/$(2)_{\text{total}}$
	2.299	3.0
Property damage only (PDO)	$(4)_{comb}$ from Worksheet SP4A	$(3)_{\text{total}}$*$(2)_{PDO}$/$(2)_{\text{total}}$
	2.229	3.0

~~11.12.5.~~11.12.6. Sample Problem 5

The Project
A project of interest consists of three sites: a rural four-lane divided highway segment, a rural four-lane undivided highway 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 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 (4D segment, 4U segment)
- 1 intersection (3ST intersection)
- 9 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 Part C, Appendix A.2.5.

Results

The expected average crash frequency for the project is 5.8 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 multilane highway combined, two worksheets are provided for determining the expected average crash frequency. The two worksheets include:

- *Worksheet SP5A (Corresponds to 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 SP5B (Corresponds to Worksheet 4B)*—Project-Level Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 11A.

Worksheets SP5A—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 SP5A. Column 5 presents the observed crash frequencies by site type, and Column 6 the overdispersion parameter. 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 A 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. Part C, Appendix A.2.5 defines all the variables used in this worksheet.

Worksheet SP5A. 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)
	Predicted Average Crash Frequency (crashes/year)					N_{w0}	N_{w1}	w_0	N_0	w_1	N_1	$N_{expected/comb}$
Site Type	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$	Observed Crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, *k*	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	3.306	1.726	1.580	4	0.142	1.552	0.685	—	—	—	—	—
Segment 2	0.289	0.177	0.112	2	1.873	0.156	0.736	—	—	—	—	—
Intersections												
Intersection 1	0.933	0.396	0.537	3	0.460	0.400	0.655	—	—	—	—	—
Combined (sum of column)	4.528	2.299	2.229	9	—	2.109	2.076	0.682	5.95	0.686	5.932	5.941

Note: $N_{predicted\ w0}$ = Predicted number of total crashes assuming that crash frequencies are statistically independent

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

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

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

Column 9—w_0

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

$$w_0 = \frac{1}{1 + \frac{N_{\text{predicted } w0}}{N_{\text{predicted (total)}}}}$$
$$= \frac{1}{1 + \frac{2.109}{4.528}}$$
$$= 0.682$$

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 as follows:

$$N_0 = w_0 \times N_{\text{predicted (total)}} + (1 - w_0) \times N_{\text{observed (total)}}$$
$$= 0.682 \times 4.528 + (1 - 0.682) \times 9 = 5.950$$

Column 11—w_1

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

$$w_1 = \frac{1}{1 + \frac{N_{\text{predicted } w1}}{N_{\text{predicted (total)}}}}$$
$$= \frac{1}{1 + \frac{2.076}{4.528}}$$
$$= 0.686$$

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 as follows:

$$N_1 = w_1 \times N_{\text{predicted (total)}} + (1 - w_1) \times N_{\text{observed (total)}}$$
$$= 0.686 \times 4.528 + (1 - 0.686) \times 9 = 5.932$$

Column 13—$N_{\text{expected/comb}}$

The expected average crash frequency based of combined sites, $N_{\text{expected}/comb}$, is calculated using Equation A-14 as follows:

$$N_{\text{expected}/comb} = \frac{N_0 + N_1}{2}$$
$$= \frac{5.950 + 5.932}{2}$$
$$= 5.941$$

Worksheet SP5B—Project-Level EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

Worksheet SP5B 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 SP5B. Project-Level EB Method Summary Results for Rural Two-Lane, Two-Way Roads and Multilane Highways

(1)	(2)	(3)
Crash Severity Level	$N_{predicted}$	$N_{expected}$
Total	$(2)_{comb}$ from Worksheet SP5A	$(13)_{comb}$ from Worksheet SP5A
	4.528	5.9
Fatal and injury (FI)	$(3)_{comb}$ from Worksheet SP5A	$(3)_{total}$*$(2)_{FI}$/$(2)_{total}$
	2.299	3.0
Property damage only (PDO)	$(4)_{comb}$ from Worksheet SP5A	$(3)_{total}$*$(2)_{PDO}$/$(2)_{total}$
	2.229	2.9

~~11.12.6.~~11.12.7. Sample Problem 6

The Project

An existing rural two-lane roadway is proposed for widening to a four-lane highway facility. One portion of the project is planned as a four-lane divided highway, while another portion is planned as a four-lane undivided highway. There is one three-leg stop-controlled intersection located within the project limits.

The Question

What is the expected average crash frequency of the proposed rural four-lane highway facility for a particular year, and what crash reduction is expected in comparison to the existing rural two-lane highway facility?

The Facts

- Existing rural two-lane roadway facility with two roadway segments and one intersection equivalent to the facilities in Chapter 10's Sample Problems 1, 2, and 3.
- Proposed rural four-lane highway facility with two roadway segments and one intersection equivalent to the facilities in Sample Problems 1, 2, and 3 presented in this chapter.

Outline of Solution

Sample Problem 6 applies the Project Estimation Method 1 presented in Section C.7 (i.e., the expected average crash frequency for existing conditions is compared to the predicted average crash frequency of proposed conditions). The expected average crash frequency for the existing rural two-lane roadway can be represented by the results from applying the site-specific EB Method in Chapter 10's Sample Problem 5. The predicted average crash frequency for the proposed four-lane facility can be determined from the results of Sample Problems 1, 2, and 3 in this chapter. In this case, Sample Problems 1 through 3 are considered to represent a proposed facility rather than an existing facility; therefore, there is no observed crash frequency data, and the EB Method is not applicable.

Results

The predicted average crash frequency for the proposed four-lane facility project is 4.5 crashes per year, and the predicted crash reduction from the project is 7.8 crashes per year. Table 11-26 presents a summary of the results.

Table 11-26. Summary of Results for Sample Problem 6

Site	Expected Average Crash Frequency for the Existing Condition (crashes/year)[a]	Predicted Average Crash Frequency for the Proposed Condition (crashes/year)[b]	Predicted Crash Reduction from Project Implementation (crashes/year)
Segment 1	8.02	3.3	4.7
Segment 2	1.34	0.3	1.1
Intersection 1	2.94	0.9	2.0
Total	12.3	4.5	7.8

[a] From Sample Problems 5 in Chapter 10
[b] From Sample Problems 1 through 3 in Chapter 11

11.13. REFERENCES

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APPENDIX 11A. WORKSHEETS FOR APPLYING THE PREDICTIVE METHOD FOR RURAL MULTILANE ROADS

Worksheet 1A. General Information and Input Data for Rural Multilane Roadway Segments

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

Input Data	**Base Conditions**	**Site Conditions**
Roadway type (divided/undivided)	—	
Length of segment, L (mi)	—	
AADT (veh/day)	—	
Lane width (ft)	12	
Shoulder width (ft)—right shoulder width for divided	8	
Shoulder type—right shoulder type for divided	paved	
Median width (ft)—for divided only	30	
Sideslopes—for undivided only	1:7 or flatter	
Lighting (present/not present)	not present	
Auto speed enforcement (present/not present)	not present	
Calibration factor, C_r	1.0	

Worksheet 1B (a). Crash Modification Factors for Rural Multilane Divided Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
CMF for Lane Width	**CMF for Right Shoulder Width**	**CMF for Median Width**	**CMF for Lighting**	**CMF for Auto Speed Enforcement**	**Combined CMF**
CMF_{1rd}	CMF_{2rd}	CMF_{3rd}	CMF_{4rd}	CMF_{5rd}	CMF_{comb}
from Equation 11-16	from Table 11-17	from Table 11-18	from Equation 11-17	from Section 11.7.2	(1)*(2)*(3)*(4)*(5)

Worksheet 1B (b). Crash Modification Factors for Rural Multilane Undivided Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
CMF for Lane Width	**CMF for Shoulder Width**	**CMF for Sideslopes**	**CMF for Lighting**	**CMF for Auto Speed Enforcement**	**Combined CMF**
CMF_{1ru}	CMF_{2ru}	CMF_{3ru}	CMF_{4ru}	CMF_{5ru}	CMF_{comb}
from Equation 11-13	from Equation 11-14	from Table 11-14	from Equation 11-15	from Section 11.7.1	(1)*(2)*(3)*(4)*(5)

Worksheet 1C (a). Roadway Segment Crashes for Rural Multilane Divided Roadway Segments

(1)	(2)			(3)	(4)	(5)	(6)	(7)
	SPF Coefficients			$N_{spf\ rd}$	**Overdispersion Parameter, *k***	**Combined CMFs**		**Predicted Average Crash Frequency, $N_{predicted\ rs}$**
	from Table 11-5							
Crash Severity Level	**a**	**b**	**c**	**from Equation 11-9**	**from Equation 11-10**	**(6) from Worksheet 1B (a)**	**Calibration Factor, C_r**	**(3)*(5)*(6)**
Total	–9.025	1.049	1.549					
Fatal and injury (FI)	–8.837	0.958	1.687					
Fatal and injury[a] (FI[a])	–8.505	0.874	1.740					
Property damage only (PDO)	—	—	—	—	—	—	—	$(7)_{total}–(7)_{FI}$

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet 1C (b). Roadway Segment Crashes for Rural Multilane Undivided Roadway Segments

(1)	(2)			(3)	(4)	(5)	(6)	(7)
	SPF Coefficients			$N_{spf\ ru}$	Overdispersion Parameter, *k*	Combined CMFs		Predicted Average Crash Frequency, $N_{predicted\ rs}$
	from Table 11-3							
Crash Severity Level	a	b	c	from Equation 11-7	from Equation 11-8	(6) from Worksheet 1B (b)	Calibration Factor, C_r	(3)*(5)*(6)
Total	–9.653	1.176	1.675					
Fatal and injury (FI)	–9.410	1.094	1.796					
Fatal and injury[a] (FI[a])	–8.577	0.938	2.003					
Property damage only (PDO)	—	—	—	—	—	—	—	$(7)_{total}–(7)_{FI}$

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet 1D (a). Crashes by Severity Level and Collision Type for Rural Multilane Divided Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	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 $_{(FIa)}$	$N_{predicted\ rs\ (FI^a)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	$N_{predicted\ rs\ (PDO)}$
Collision Type	from Table 11-6	$(7)_{total}$ from Worksheet 1C (a)	from Table 11-6	$(7)_{FI}$ from Worksheet 1C (a)	from Table 11-6	$(7)_{FIa}$ from Worksheet 1C (a)	from Table 11-6	$(7)_{PDO}$ from Worksheet 1C (a)
Total	1.000		1.000		1.000		1.000	
		$(2)*(3)_{total}$		$(4)*(5)_{FI}$		$(6)*(7)_{FI^a}$		$(8)*(9)_{PDO}$
Head-on collision	0.006		0.013		0.018		0.002	
Sideswipe collision	0.043		0.027		0.022		0.053	
Rear-end collision	0.116		0.163		0.114		0.088	
Angle collision	0.043		0.048		0.045		0.041	
Single-vehicle collision	0.768		0.727		0.778		0.792	
Other collision	0.024		0.022		0.023		0.024	

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet 1D (b). Crashes by Severity Level and Collision Type for Rural Multilane Undivided Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	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 $_{(FI^a)}$	$N_{predicted\ rs\ (FI^a)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	$N_{predicted\ rs\ (PDO)}$ (crashes/year)
Collision Type	from Table 11-4	$(7)_{total}$ from Worksheet 1C (b)	from Table 11-4	$(7)_{FI}$ from Worksheet 1C (b)	from Table 11-4	$(7)_{FI^a}$ from Worksheet 1C (b)	from Table 11-4	$(7)_{PDO}$ from Worksheet 1C (b)
Total	1.000		1.000		1.000		1.000	
		$(2)*(3)_{total}$		$(4)*(5)_{FI}$		$(6)*(7)_{FI^a}$		$(8)*(9)_{PDO}$
Head-on collision	0.009		0.029		0.043		0.001	
Sideswipe collision	0.098		0.048		0.044		0.120	
Rear-end collision	0.246		0.305		0.217		0.220	
Angle collision	0.356		0.352		0.348		0.358	
Single-vehicle collision	0.238		0.238		0.304		0.237	
Other collision	0.053		0.028		0.044		0.064	

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet 1E. Summary Results for Rural Multilane Roadway Segments

(1)	(2)	(3)	(4)
	Predicted Average Crash Frequency (crashes/year)		Crash Rate (crashes/mi/year)
Crash Severity Level	(7) from Worksheet 1C (a) or (b)	Roadway Segment Length (mi)	(2)/(3)
Total			
Fatal and injury (FI)			
Fatal and injury[a] (FI[a])			
Property damage only (PDO)			

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet 2A. General Information and Input Data for Rural Multilane Highway Intersections

General Information		Local Information	
Analyst		Highway	
Agency or Company		Intersection	
Date Performed		Jurisdiction	
		Analysis Year	

Input Data	Base Conditions	Site Conditions
Intersection type (3ST, 3SG, 4ST, 4SG)	—	
$AADT_{maj}$ (veh/day)	—	
$AADT_{min}$ (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. Crash Modification Factors for Rural Multilane Highway Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	CMF for Intersection Skew Angle	CMF for Left-Turn Lanes	CMF for Right-Turn Lanes	CMF for Lighting	
	CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	Combined CMF
Crash Severity Level	from Equations 11-18 or 11-20 and 11-19 or 11-21	from Table 11-22	from Table 11-23	from Equation 11-22	(1)*(2)*(3)*(4)
Total					
Fatal and injury (FI)					

Worksheet 2C. Intersection Crashes for Rural Multilane Highway Intersections

(1)	(2)			(3)	(4)	(5)	(6)	(7)
	SPF Coefficients			$N_{spf\ int}$	**Overdispersion Parameter, k**	**Combined CMFs**	**Calibration Factor**	**Predicted Average Crash Frequency, $N_{predicted\ int}$**
Crash Severity Level	**from Table 11-7 or 11-8**			**from Equation 11-11 or 11-12**	**from Table 11-7 or 11-8**	**from (6) of Worksheet 2B**	C_i	**(3)*(5)*(6)**
	a	**b**	**c**					
Total								
Fatal and injury (FI)								
Fatal and injury[a] (FI[a])								
Property damage only (PDO)	—	—	—	—	—	—	—	$(7)_{total}—(7)_{FI}$

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet 2D. Crashes by Severity Level and Collision Type for Rural Multilane Highway Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	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 $_{(FIa)}$**	$N_{predicted\ int\ (FI^a)}$ **(crashes/year)**	**Proportion of Collision Type $_{(PDO)}$**	$N_{predicted\ int\ (PDO)}$ **(crashes/year)**
Collision Type	**from Table 11-9**	**(7)total from Worksheet 2C**	**from Table 11-9**	**$(7)_{FI}$ from Worksheet 2C**	**from Table 11-9**	**$(7)_{FI^a}$ from Worksheet 2C**	**from Table 11-9**	**$(7)_{PDO}$ from Worksheet 2C**
Total	1.000		1.000		1.000		1.000	
		$(2)*(3)_{total}$		$(4)*(5)_{FI}$		$(6)*(7)_{FI}{}^{a}$		$(8)*(9)_{PDO}$
Head-on collision								
Sideswipe collision								
Rear-end collision								
Angle collision								
Single-vehicle collision								
Other collision								

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet 2E. Summary Results for Rural Multilane Highway Intersections

(1)	(2)
	Predicted Average Crash Frequency (crashes/year)
Crash Severity Level	**(7) from Worksheet 2C**
Total	
Fatal and injury (FI)	
Fatal and injury[a] (FI[a])	
Property damage only (PDO)	

[a] Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Worksheet 3A. Predicted and Observed Crashes by Severity and Site Type Using the Site-Specific EB Method

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted Average Crash Frequency (crashes/year)			Observed Crashes,		Weighted Adjustment, w	Expected Average Crash Frequency, $N_{expected}$
Site Type	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$	$N_{observed}$ (crashes/year)	Overdispersion Parameter, k	Equation A-5	Equation A-4
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 3B. Site-Specific EB Method Summary Results

(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

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Predicted Average Crash Frequency (crashes/year)					N_{w0}	N_{w1}	w_0	N_0	w_1	N_1	$N_{expected/comb}$
Site Type	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$	Observed Crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, k	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

(1)	(2)	(3)
Crash Severity Level	$N_{predicted}$	$N_{expected}$
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	$(3)_{total}*(2)_{PDO}/(2)_{total}$

APPENDIX 11B. PREDICTIVE MODELS FOR SELECTED COLLISION TYPES

The main text of this chapter presents predictive models for crashes by severity level. Tables with crash proportions by collision type are also presented to allow estimates for crash frequencies by collision type to be derived from the crash predictions for specific severity levels. Safety prediction models are also available for some, but not all, collision types. These safety prediction models are presented in this appendix for application by HSM users, where appropriate. Users should generally expect that a more accurate safety prediction for a specific collision type can be obtained using a model developed specifically for that collision type than using a model for all collision types combined and multiplying the result by the proportion of that specific collision type of interest. However, prediction models are available only for selected collision types. And such models must be used with caution by HSM users because the results of a series of collision models for individual collision types will not necessarily sum to the predicted crash frequency for all collision types combined. In other words, when predicted crash frequencies for several collision types are used together, some adjustment of those predicted crash frequencies may be required to assure that their sum is consistent with results from the models presented in the main text of this chapter.

11B.1. UNDIVIDED ROADWAY SEGMENTS

Table 11B-1 summarizes the values for the coefficients used in prediction models that apply Equation 11-4 for estimating crash frequencies by collision type for undivided roadway segments. Two specific collision types are addressed: single-vehicle and opposite-direction collisions without turning movements (SvOdn) and same-direction collisions without turning movements (SDN). These models are assumed to apply for base conditions represented as the average value of the variables in a jurisdiction. There are no CMFs for use with these models; the crash predictions provided by these models are assumed to apply to average conditions for these variables for which CMFs are provided in Section 11.7.

Table 11B-1. SPFs for Selected Collision Types on Four-Lane Undivided Roadway Segments (Based on Equation 11-4)

Severity Level/Collision Type	a	b	Overdispersion Parameter (Fixed *k*)[a]
Total—SvOdn	–5.345	0.696	0.777
Fatal and Injury—SvOdn	–7.224	0.821	0.946
Fatal and Injury[b]—SvOdn	–7.244	0.790	0.962
Total—SDN	–14.962	1.621	0.525
Fatal and Injury—SDN	–12.361	1.282	0.218
Fatal and Injury[b]—SDN	–14.980	1.442	0.514

Note: SvOdn—Single Vehicle and Opposite Direction without Turning Movements Crashes (Note: These two crash types were modeled together)
SDN—Same Direction without Turning Movement (Note: This is a subset of all rear-end collisions)
[a] This value should be used directly as the overdispersion parameter; no further computation is required.
[b] Excluding crashes involving only possible injuries.

Divided Roadway Segments

No models by collision type are available for divided roadway segments on rural multilane highways.

Stop-Controlled Intersections

Table 11B-2 summarizes the values for the coefficients used in prediction models that apply Equation 11-4 for estimating crash frequencies by collision type for stop-controlled intersections on rural multilane highways. Four specific collision types are addressed:

- Single-vehicle collisions
- Intersecting direction collisions (angle and left-turn-through collisions)
- Opposing-direction collisions (head-on collisions)
- Same-direction collisions (rear-end collisions)

Table 11B-2 presents values for the coefficients a, b, c, and d used in applying Equations 11-11 and 11-12 for predicting crashes by collision type for three- and four-leg intersections with minor-leg stop-control. The intersection types and severity levels for which values are shown for coefficients a, b, and c are addressed with the SPF shown in Equation 11-11. The intersection types and severity levels for which values are shown for coefficients a and d are addressed with the SPF shown in Equation 11-12. The models presented in this exhibit were developed for intersections without specific base conditions. Thus, when using these models for predicting crash frequencies, no CMFs should be used, and it is assumed that the predictions apply to typical or average conditions for the CMFs presented in Section 11.7.

Table 11B-2. Collision Type Models for Stop-Controlled Intersections without Specific Base Conditions (Based on Equations 11-11 and 11-12)

Intersection Type/Severity Level/Collision Type	a	b	c	d	Overdispersion Parameter (Fixed *k*)[a]
4ST Total Single Vehicle	−9.999	—	—	0.950	0.452
4ST Fatal and Injury Single Vehicle	−10.259			0.884	0.651
4ST Fatal and Injury[b] Single Vehicle	−9.964	—	—	0.800	1.010
4ST Total Int. Direction	−7.095	0.458	0.462	—	1.520
4ST Fatal and Injury Int. Direction	−7.807	0.467	0.505		1.479
4ST Fatal and Injury[b] Int. Direction	−7.538	0.441	0.420	—	1.506
4ST Total Opp. Direction	−8.539	0.436	0.570	—	1.068
4ST Fatal and Injury Opp. Direction	10.274	0.465	0.529		1.453
4ST Fatal and Injury[b] Opp. Direction	−10.058	0.497	0.547	—	1.426
4ST Total Same Direction	−11.460	0.971	0.291	—	0.803
4ST Fatal and Injury Same Direction	−11.602	0.932	0.246		0.910
4ST Fatal and Injury[b] Same Direction	−13.223	1.032	0.184	—	1.283
3ST Total Single Vehicle	−10.986	—	—	1.035	0.641
3ST Fatal and Injury Single Vehicle	−10.835			0.934	0.741
3ST Fatal and Injury[b] Single Vehicle	−11.608	—	—	0.952	0.838
3ST Total Int. Direction	−10.187	0.671	0.529	—	1.184
3ST Fatal and Injury Int. Direction	−11.171	0.749	0.487		1.360
3ST Fatal and Injury[b] Int. Direction	−12.084	0.442	0.796	—	1.5375
3ST Total Opp. Direction	−13.808	1.043	0.425	—	1.571
3ST Fatal and Injury Opp. Direction	−14.387	1.055	0.432		1.629
3ST Fatal and Injury[b] Opp. Direction	−15.475	0.417	1.105		1.943
3ST Total Same Direction	−15.457	1.381	0.306		0.829
3ST Fatal and Injury Same Direction	−14.838	1.278	0.227		0.754
3ST Fatal and Injury[b] Same Direction	−14.736	1.199	0.147		0.654

Note: Int. Direction = Intersecting Direction (angle and left-turn-through crashes)
Opp. Direction = Opposing Direction (head-on)
[a] This value should be used directly as the overdispersion parameter; no further computation is required.
[b] Excluding crashes involving only possible injuries.

Signalized Intersections

No models by collision type are available for signalized intersections on rural multilane highways.

CHAPTER 12. Predictive Method for Urban and Suburban Arterials

12.1. Introduction

This chapter presents the predictive method for urban and suburban arterial facilities. 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 urban or suburban arterial facilities provides a structured methodology to estimate the expected average crash frequency, crash severity, and collision types for facilities 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 in a period of time that occurred in the past (i.e., what did or would have occurred) or in the future (i.e., what is expected to occur). The development of the SPFs in Chapter 12 is documented by Harwood et al. (8, 9). The CMFs used in this chapter have been reviewed and updated by Harkey et al. (6) and in related work by Srinivasan et al. (13). The SPF coefficients, default collision type distributions, and default nighttime crash proportions have been adjusted to a consistent basis by Srinivasan et al. (14). SPFs, default collision type distributions, default nighttime crash proportions, and default pedestrian and bicycle crash proportions for three- and four-leg all-way stop-controlled intersections, three-leg intersections where the through movements make turning maneuvers, five-leg signalized intersections, and intersections on high-speed arterials were added to Chapter 12 in the second edition of the *Highway Safety Manual* based on NCHRP Project 17-68 (*16*).

This chapter presents the following information about the predictive method for urban and suburban arterial facilities:

- A concise overview of the predictive method.
- The definitions of the facility types included in Chapter 12, and site types for which predictive models have been developed for Chapter 12.
- The steps of the predictive method in graphical and descriptive forms.
- Details for dividing an urban or suburban arterial facility into individual sites, consisting of intersections and roadway segments.
- Safety performance functions (SPFs) for urban and suburban arterials.
- Crash modification factors (CMFs) applicable to the SPFs in Chapter 12.
- Guidance for applying the Chapter 12 predictive method, and limitations of the predictive method specific to Chapter 12.
- Sample problems illustrating the application of the Chapter 12 predictive method for urban and suburban arterials.

12.2. 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 signalized and unsignalized 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 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 predictive models used within the Chapter 12 predictive method are described in detail in Section 12.3.

The predictive models used in Chapter 12 to predict average crash frequency, $N_{\text{predicted}}$, are of the general form shown in Equation 12-1.

$$N_{\text{predicted}} = (N_{spf\ x} \times (CMF_{1x} \times CMF_{2x} \times \ldots \times CMF_{yx}) + N_{pedx} + N_{bikex}) \times C_x \quad (12\text{-}1)$$

Where:

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

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

N_{pedx} = predicted average number of vehicle-pedestrian collisions per year for site type x;

N_{bikex} = predicted average number of vehicle-bicycle collisions per year for site type x;

CMF_{yx} = crash modification factors specific to site type x and specific geometric design and traffic control features y; and

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

The predictive models in Chapter 12 provide estimates of the crash severity and collision type distributions for roadway segments and intersections. The SPFs in Chapter 12 address two general crash severity levels: fatal-and-injury and property-damage-only crashes. Fatal-and-injury crashes include crashes involving all levels of injury severity including fatalities, incapacitating injuries, nonincapacitating injuries, and possible injuries. The relative proportions of crashes for the two severity levels are determined from separate SPFs for each severity level. The default estimates of the crash severity and crash type distributions are provided with the SPFs for roadway segments and intersections in Section 12.6.

12.3. Urban and Suburban Arterials—Definitions and Predictive Models in Chapter 12

This section provides the definitions of the facility and site types and the predictive models for each of the site types included in Chapter 12. These predictive models are applied following the steps of the predictive method presented in Section 12.4.

12.3.1. Definition of Chapter 12 Facility Types

The predictive method in Chapter 12 addresses the following urban and suburban arterial facilities: two- and four-lane undivided facilities, four-lane divided facilities, and three- and five-lane facilities with center two-way left-turn lanes. Divided arterials are nonfreeway facilities (i.e., facilities without full control of access) that have lanes in the two directions of travel separated by a raised or depressed median. Such facilities may have occasional grade-separated interchanges, but these are not the primary form of access. The predictive models do not apply to any section of an arterial within the limits of an interchange which has free-flow ramp terminals on the arterial of interest. Arterials with a flush separator (i.e., a painted median) between the lanes in the two directions of travel are considered undivided facilities, not divided facilities. Separate prediction models are provided for arterials with a flush separator that serves as a center two-way left-turn lane. Chapter 12 does not address arterial facilities with six or more lanes.

The terms "highway" and "road" are used interchangeably in this chapter and apply to all urban and suburban arterials 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 where the population is less 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. The term "arterial" refers to facilities the meet the FHWA definition of "roads serving major traffic movements (high-speed, high volume) for travel between major points" (5).

Table 12-1 identifies the specific site types on urban and suburban arterial highways that have predictive models. In Chapter 12, separate SPFs are used for each individual site to predict multiple-vehicle nondriveway collisions, single-vehicle collisions, driveway-related collisions, vehicle-pedestrian collisions, and vehicle-bicycle collisions for both roadway segments and intersections. These are combined to predict the total average crash frequency at an individual site. The five-leg signalized intersection models do not have base conditions and, therefore, can be used only for generalized predictions of crash frequencies.

Table 12-1. Urban and Suburban Arterial Site Type SPFs included in Chapter 12

Site Type	Site Types with SPFs in Chapter 12
Roadway Segments	Two-lane undivided arterials (2U)
	Three-lane arterials including a center two-way left-turn lane (TWLTL) (3T)
	Four-lane undivided arterials (4U)
	Four-lane divided arterials (i.e., including a raised or depressed median) (4D)
	Five-lane arterials including a center TWLTL (5T)
Intersections	Unsignalized three-leg intersection (stop control on minor-road approaches) (3ST)
	Unsignalized three-leg intersection on high-speed arterial (stop control on minor-road approaches) (3ST-HS)
	Unsignalized three-leg intersection (all-way stop control) (3aST)
	Three-leg intersection with stop control where through the movement makes a turning maneuver (i.e., turning intersection) (3STT)
	Signalized three-leg intersection~~s~~ (3SG)
	Signalized three-leg intersection on high-speed arterial (3SG-HS)
	Unsignalized four-leg intersection (stop control on minor-road approaches) (4ST)
	Unsignalized four-leg intersection on high-speed arterial (stop control on minor-road approaches) (4ST-HS)
	Unsignalized four-leg intersection (all-way stop control) (4aST)
	Signalized four-leg intersection (4SG)
	Signalized four-leg intersection on high-speed arterial (4SG-HS)
	Signalized five-leg intersection (5SG)

These specific site types are defined as follows:

- *Two-lane undivided arterial (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.
- *Three-lane arterials (3T)*—a roadway consisting of three lanes with a continuous cross-section providing two directions of travel in which center lane is a two-way left-turn lane (TWLTL).
- *Four-lane undivided arterials (4U)*—a roadway consisting of four 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.
- *Four-lane divided arterials (i.e., including a raised or depressed median) (4D)*—a roadway consisting of two lanes with a continuous cross-section providing two directions of travel in which the lanes are physically separated by either distance or a barrier.
- *Five-lane arterials including a center TWLTL (5T)*—a roadway consisting of five lanes with a continuous cross-section providing two directions of travel in which the center lane is a two-way left-turn lane (TWLTL).
- *Three-leg intersection with stop control (3ST)*—an intersection of an urban or suburban arterial and a minor road. A stop sign is provided on the minor road approach to the intersection only, and the posted speed limit of the arterial is 45 mph or less.
- *Three-leg intersection with stop control on high-speed arterial (3ST-HS)*—an intersection of an urban or suburban arterial and a minor road. A stop sign is provided on the minor road approach to the intersection only, and the posted speed limit of the arterial is 50 mph or greater.
- *Three-leg all-way stop-controlled intersection (3aST)*—an intersection of an urban or suburban arterial and a minor road. A stop sign is provided on all approaches to the intersection.
- *Three-leg intersection with stop control where the through movement makes a turning maneuver (3STT)*—an intersection of a two-lane undivided ~~n~~ urban or suburban arterial and a minor road. A stop sign is provided on the minor road approach to the intersection, and the major road turns at the intersection. A stop sign with an "Except Right Turn" message may be provided for one of the major road approaches.
- *Three-leg signalized intersection (3SG)*—an intersection of an urban or suburban arterial and one minor road. Signalized control is provided at the intersection by traffic lights, and the posted speed limit of the arterial is 45 mph or less.
- *Three-leg signalized intersection on high-speed arterial (3SG-HS)*—an intersection of an urban or suburban arterial and one minor road. Signalized control is provided at the intersection by traffic lights, and the posted speed limit of the arterial is 50 mph or greater.
- *Four-leg intersection with stop control (4ST)*—an intersection of an urban or suburban arterial and two minor roads. A stop sign is provided on both the minor road approaches to the intersection, and the posted speed limit of the arterial is 45 mph or less.
- *Four-leg intersection with stop control on high-speed arterial (4ST-HS)*—an intersection of an urban or suburban arterial and two minor roads. A stop sign is provided on both the minor road approaches to the intersection, and the posted speed limit of the arterial is 50 mph or greater.
- *Four-leg all-way stop-controlled intersection (4aST)*—an intersection of an urban or suburban arterial and two minor roads. A stop sign is provided on all approaches to the intersection.
- *Four-leg signalized intersection (4SG)*—an intersection of an urban or suburban arterial and two minor roads. Signalized control is provided at the intersection by traffic lights, and the posted speed limit of the arterial is 45 mph or less.
- *Four-leg signalized intersection on high-speed arterial (4SG-HS)*—an intersection of an urban or suburban arterial and two minor roads. Signalized control is provided at the intersection by traffic lights, and the posted speed limit of the arterial is 50 mph or greater.
- *Five-leg signalized intersection (5SG)*—an intersection of an urban or suburban arterial and three minor roads. Signalized control is provided at the intersection by traffic lights.

12.3.2. Predictive Models for Urban and Suburban Arterial Roadway Segments

The predictive models can be used to estimate total average crashes (i.e., all crash severities and collision types) or can be used to predict average frequency of specific crash severity types or specific collision types. The predictive model for an individual roadway segment or intersection combines the SPF, CMFs, and a calibration factor. Chapter 12 contains separate predictive models for roadway segments and for intersections.

The predictive models for roadway segments estimate the predicted average crash frequency of non-intersection-related crashes. Non-intersection-related crashes may include crashes that occur within the limits of an intersection but are not related to the intersection. The roadway segment predictive models estimate crashes that would occur regardless of the presence of the intersection.

The predictive models for roadway segments are presented in Equations 12-2 and 12-3 below.

$$N_{\text{predicted } rs} = C_r \times (N_{br} + N_{pedr} + N_{biker}) \tag{12-2}$$

$$N_{br} = N_{spf rs} \times (CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{nr}) \tag{12-3}$$

Where:

$N_{\text{predicted } rs}$ = predicted average crash frequency of an individual roadway segment for the selected year;

N_{br} = predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions);

$N_{spf\ rs}$ = predicted total average crash frequency of an individual roadway segment for base conditions (excluding vehicle-pedestrian and vehicle-bicycle collisions);

N_{pedr} = predicted average crash frequency of vehicle-pedestrian collisions for an individual roadway segment;

N_{biker} = predicted average crash frequency of vehicle-bicycle collisions for an individual roadway segment;

$CMF_{1r} \ldots CMF_{nr}$ = crash modification factors for roadway segments; and

C_r = calibration factor for roadway segments of a specific type developed for use for a particular geographical area.

Equation 12-2 shows that roadway segment crash frequency is estimated as the sum of three components: N_{br}, N_{pedr}, and N_{biker}. The following equation shows that the SPF portion of N_{br}, designated as $N_{spf\ rs}$, is further separated into three components by collision type shown in Equation 12-4:

$$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy} \tag{12-4}$$

Where:

N_{brmv} = predicted average crash frequency of multiple-vehicle nondriveway collisions for base conditions;

N_{brsv} = predicted average crash frequency of single-vehicle crashes for base conditions; and

N_{brdwy} = predicted average crash frequency of multiple-vehicle driveway-related collisions.

Thus, the SPFs and adjustment factors are applied to determine five components: N_{brmv}, N_{brsv}, N_{brdwy}, N_{pedr}, and N_{biker}, which together provide a prediction of total average crash frequency for a roadway segment.

Equations 12-2 through 12-4 are applied to estimate roadway segment crash frequencies for all crash severity levels combined (i.e., total crashes) or for fatal-and-injury or property-damage-only crashes.

12.3.3. Predictive Models for Urban and Suburban Arterial Intersections

The predictive models for intersections estimate the predicted total average crash frequency including those crashes that occur within the limits of an intersection and are a result of the presence of the intersection. The predictive model for an urban or suburban arterial intersection is given by:

$$N_{\text{predicted } int} = C_i \times (N_{bi} + N_{pedi} + N_{bikei}) \quad (12\text{-}5)$$

$$N_{bi} = N_{spf\ int} \times (CMF_{1i} \times CMF_{2i} \times \ldots \times CMF_{6i}) \quad (12\text{-}6)$$

Where:

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

N_{bi} = predicted average crash frequency of an intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions);

$N_{spf\ int}$ = predicted total average crash frequency of intersection-related crashes for base conditions (excluding vehicle-pedestrian and vehicle-bicycle collisions);

N_{pedi} = predicted average crash frequency of vehicle-pedestrian collisions of an intersection;

N_{bikei} = predicted average crash frequency of vehicle-bicycle collisions of an intersection;

$CMF_{1i} \ldots CMF_{6i}$ = crash modification factors for intersections; and

C_i = calibration factor for intersections developed for use for a particular geographical area.

The CMFs shown in Equation 12-6 do not apply to vehicle-pedestrian and vehicle-bicycle collisions. A separate set of CMFs that apply to vehicle-pedestrian collisions at signalized intersections is presented in Section 12.7.

Equation 12-5 shows that the intersection crash frequency is estimated as the sum of three components: N_{bi}, N_{pedi}, and N_{bikei}. The following equation shows that the SPF portion of N_{bi}, designated as $N_{spf\ int}$, is further separated into two components by collision type for minor-road stop-controlled and signalized intersections:

$$N_{spf\ int} = N_{bimv} + N_{bisv} \quad (12\text{-}7)$$

Where:

N_{bimv} = predicted average number of multiple-vehicle collisions of an intersection for base conditions; and

N_{bisv} = predicted average number of single-vehicle collisions of an intersection for base conditions.

For all-way stop-controlled intersections, the SPF portion of N_{bi} (i.e., $N_{spf\ int}$,) combines the estimates for multiple- and single-vehicle crashes as follows:

$$N_{spf\ int} = N_{bimv+sv} \quad (12\text{-}EA)$$

Where:

$N_{bimv + sv}$ = predicted average number of multiple-and single-vehicle collisions combined of an intersection for base conditions.

Thus, the SPFs and adjustment factors are applied to determine the different~~four~~ components of total intersection average crash frequency: N_{bimv}, N_{bisv}, $N_{bimv + sv}$, N_{pedi}, and N_{bikei}.

The SPFs for urban and suburban arterial highways are presented in Section 12.6. The associated CMFs for each of the SPFs are presented in Section 12.7 and summarized in Table 12-18. Only the specific CMFs associated with each SPF are applicable to that SPF (as these CMFs have base conditions which are identical to the base conditions of the SPF). The calibration factors, C_r and C_i, are determined in 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.

12.4. Predictive Method Steps for Urban and suburban arterials

The predictive method for urban and suburban arterials is shown in Figure 12-1. Applying the predictive method yields an estimate of the expected average crash frequency (and/or crash severity and collision types) for an urban or suburban arterial facility. The components of the predictive models in Chapter 12 are determined and applied in Steps 9, 10, and 11 of the predictive method. The information to apply each step is provided in the following sections and in Part C, Appendix A. In some situations, certain steps will not require any action. For example, a new facility will not have observed crash data and therefore steps relating to the EB Method require no action.

There are 18 steps in the predictive method. In some situations certain steps will not be needed because 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 urban and suburban arterials.

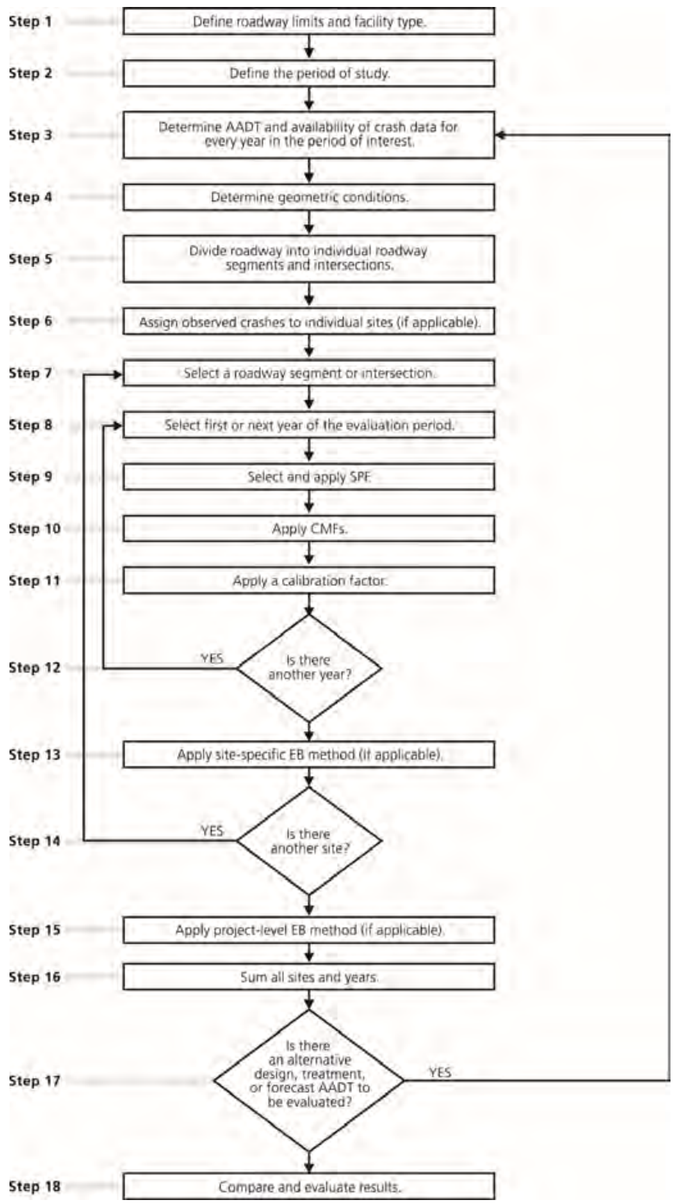


Figure 12-1. The HSM Predictive Method

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 an individual site. A site is either an intersection or a homogeneous roadway segment. Sites may consist of a number of types, such as signalized and unsignalized intersections. The definitions of urban and suburban arterials, intersections, and roadway segments and the specific site types included in Chapter 12 are provided in Section 12.3.

The predictive method can be undertaken for an existing roadway, a design alternative for an existing roadway, or a 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 very long corridor for the purposes of network screening which is discussed in Chapter 4.

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 ~~average annual daily traffic~~annual average daily traffic (AADT) volumes, 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, pedestrian crossing 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 CMFs in Step 10) include AADT volumes (vehicles per day) as a variable. For a past period the AADT may be determined by an automated recording or estimated by 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.

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.

For each intersection, two or three values are required in each predictive model. These are: the two-way AADT of the major street ($AADT_{maj}$), ~~and~~ the two-way AADT of the minor street ($AADT_{min}$), and, for five-leg intersections, the two-way AADT of the fifth-leg ($AADT_{fifth}$).

$AADT_{maj}$ 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. If the AADTs on the two minor road legs of a four-leg intersection differ, the larger of the AADTs for the two minor road legs is used. For a three-leg intersection, the AADT of the single minor road leg is used. For a five-leg intersection, the AADT of the fifth leg is used. Where needed, $AADT_{total}$ can be estimated as the sum of $AADT_{maj}$ and $AADT_{min}$ and total entering volume (TEV) at the intersection can be estimated as the sum of the two-way AADT for each intersection approach divided by two.

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 not an established procedure for doing this, the following 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.

For signalized intersections, the pedestrian volumes crossing each intersection leg are determined for each year of the period to be evaluated. The pedestrian crossing volumes for each leg of the intersection are then summed to determine the total pedestrian crossing volume for the intersection. Where pedestrian volume counts are not available, they may be estimated using the guidance presented in Table 12-15. Where pedestrian volume counts are not available for each year, they may be interpolated or extrapolated in the same manner as explained above for AADT data.

Determining Availability of Observed Crash Data

Where an existing site or alternative conditions for 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 crash 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 Part C, Appendix A.2.1.

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 cannot be assigned to individual roadway segments and intersections, the project level EB Method is applied (in Step 15).

If observed crash frequency 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 predictive 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 collection of data, it is necessary to understand the base conditions and CMFs in Step 9 and Step 10. The base conditions are defined in Section 12.6.1 for roadway segments and in Section 12.6.2 for intersections.

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

- Length of roadway segment (miles)
- AADT (vehicles per day)
- Number of through lanes
- Presence/type of median (undivided, divided by raised or depressed median, center TWLTL)
- Presence/type of on-street parking (parallel vs. angle; one side vs. both sides of street)
- Number of driveways for each driveway type (major commercial, minor commercial; major industrial/institutional; minor industrial/institutional; major residential; minor residential; other)
- Roadside fixed object density (fixed objects/mile, only obstacles 4-in or more in diameter that do not have a breakaway design are counted)
- Average offset to roadside fixed objects from edge of traveled way (feet)
- Presence/absence of roadway lighting
- Speed category (based on actual traffic speed or posted speed limit)
- Presence of automated speed enforcement

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

- Number of intersection legs (3, ~~or~~ 4, or 5)
- Type of traffic control (minor-road stop, all-way stop, or signal)
- Movements along uncontrolled approaches at three-leg intersection (i.e., straight or turning)
- Number of approaches with intersection left-turn lane (all approaches, 0, 1, 2, 3, or 4 for three- and four-leg signalized intersections; only major approaches, 0, 1, or 2, for minor-road stop-controlled intersections)
- Number of approaches with left-turn signal phasing (0, 1, 2, 3, or 4) (three- and four-leg signalized intersections only) and type of left-turn signal phasing (permissive, protected/permissive, permissive/protected, or protected)
- Number of approaches with intersection right-turn lane (all approaches, 0, 1, 2, 3, or 4 for three- and four-leg signalized intersections; only major approaches, 0, 1, or 2, for minor-road stop-controlled intersections)
- Number of approaches with right-turn-on-red operation prohibited (0, 1, 2, 3, or 4) (three- and four-leg signalized intersections only)
- Presence/absence of intersection lighting (not including five-leg intersections)
- Maximum number of traffic lanes to be crossed by a pedestrian in any crossing maneuver at the intersection considering the presence of refuge islands (for three- and four-leg signalized intersections only)
- Proportions of nighttime crashes for unlighted intersections (by total, fatal, injury, and property damage only) (not including three-leg turning intersections and five-leg intersections)
- Curve radius and length (three-leg turning intersections only)

For three- and four-leg signalized intersections, land use and demographic data used in the estimation of vehicle-pedestrian collisions include:

- Number of bus stops within 1,000 feet of the intersection
- Presence of schools within 1,000 feet of the intersection
- Number of alcohol sales establishments within 1,000 feet of the intersection
- Presence of red light camera
- Number of approaches on which right-turn-on-red is allowed
- Pedestrian volumes

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

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 12 predictive models are provided in Section 12.5. 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 crashes to individual roadway segments or intersections are presented in Part C, Appendix A.2.3.

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 has been 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 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 14

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 CMFs (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.

Steps 9 through 13, described below, 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 12 follow the general form shown in Equation 12-1. Each predictive model consists of a SPF, which is adjusted to site specific conditions using CMFs (in Step 10) and adjusted to local jurisdiction conditions (in Step 11) using a calibration factor (C). The SPFs, CMFs, 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 SPFs available for urban and suburban arterials are presented in Section 12.6.

The SPF (which is a regression model based on observed crash data for a set of similar sites) determines the predicted average crash frequency for a site with the same base conditions (i.e., a specific set of geometric design and traffic control features). The base conditions for each SPF are specified in Section 12.6. A detailed explanation and overview of the SPFs are provided in Section C.6.3.

The SPFs developed for Chapter 12 are summarized in Table 12-2. For the selected site, determine the appropriate SPF for the site type (intersection or roadway segment) and the geometric and traffic control features (undivided roadway, divided roadway, stop-controlled intersection, signalized intersection, and posted speed limit). The SPF for the selected site is calculated using the AADT determined in Step 3 ($AADT_{maj}$, ~~and~~ $AADT_{min}$, and/or $AADT_{fifth}$ for intersections) for the selected year.

Each SPF determined in Step 9 is provided with default distributions of crash severity and collision type (presented in Section 12.6). 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.

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.

In order to account for differences between the base conditions (Section 12.6) and the specific conditions of the site, CMFs are used to adjust the SPF estimate. An overview of CMFs and guidance for their use is provided in Section C.6.4, including the limitations of current knowledge related to the effects of simultaneous application of multiple CMFs. In using multiple CMFs, engineering judgment is required to assess the interrelationships and/or independence of individual elements or treatments being considered for implementation within the same project.

All CMFs used in Chapter 12 have the same base conditions as the SPFs used in Chapter 12 (i.e., when the specific site has the same condition as the SPF base condition, the CMF value for that condition is 1.00). Only the CMFs presented in Section 12.7 may be used as part of the Chapter 12 predictive method. Table 12-18 indicates which CMFs are applicable to the SPFs in Section 12.6.

The CMFs for roadway segments are those described in Section 12.7.1. These CMFs are applied as shown in Equation 12-3.

The CMFs for intersections are those described in Section 12.7.2, which apply to both three- and four-leg signalized and stop-controlled intersections, and in Section 12.7.3, which apply to three- and four-leg signalized intersections only. These CMFs are applied as shown in Equations 12-6 and 12-28. The five-leg signalized intersection models do not have base conditions so no CMFs are used with the five-leg signalized intersection models.

In Chapter 12, the multiple- and single-vehicle base crashes determined in Step 9 and the CMFs values calculated in Step 10 are then used to estimate the vehicle-pedestrian and vehicle-bicycle base crashes for roadway segments and intersections (present in Sections 12.6.1 and 12.6.2 respectively).

For three-leg turning intersections, Steps 9 and 10 are combined because the CMFs for three-leg turning intersections are calculated by severity level.

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 to local conditions will account for these 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 Section C.6.5. 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 12-2 through 12-7 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 12 predictive model estimate of predicted average crash frequency, $N_{\text{predicted}}$, 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, overdispersion parameter, *k*, for the SPF is also used. This is in addition to the material in Part C, Appendix A.2.4. 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 $N_{\text{predicted}}$ and N_{observed}. Overdispersion parameters are provided for each SPF in Section 12.6.

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. Part C, Appendix A.2.6 provides a method to convert the estimate of expected average crash frequency for a past time period to a future time period. In doing this, consideration is given to significant changes in geometric or roadway characteristics cause by the treatments considered for future time period.

Step 14—If there is another site to be evaluated, return to 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 cannot 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.

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 12-8:

$$N_{\text{total}} = \sum_{\substack{\text{all}\\ \text{roadway}\\ \text{segments}}} N_{rs} + \sum_{\substack{\text{all}\\ \text{intersections}}} N_{int} \tag{12-8}$$

Where:

N_{total} = total expected number of crashes within the limits of an urban or suburban arterial 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; and

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

Equation 12-8 represents the total expected number of crashes estimated to occur during the study period. Equation 12-9 is used to estimate the total expected average crash frequency within the network or facility limits during the study period.

$$N_{\text{total average}} = \frac{N_{\text{total}}}{n} \tag{12-9}$$

Where:

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

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 12.6. 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.

12.5. Roadway Segments and Intersections

Section 12.4 provides an explanation of the predictive method. Sections 12.5 through 12.8 provide the specific detail necessary to apply the predictive method steps. Detail regarding the procedure for determining a calibration factor to apply in Step 11 is provided in Part C, Appendix A.1. Detail regarding the EB Method, which is applied in Steps 6, 13, and 15, is provided in Part C, Appendix A.2.

In Step 5 of the predictive method, the roadway within the defined 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) (4).

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 Figure 12-2. When a roadway segment begins or ends at an intersection, the length of the roadway segment is measured from the center of the intersection.

Chapter 12 provides predictive models for ~~stop-controlled (~~three- and four-leg intersections with minor-road stop control; three- and four-leg intersections with all-way stop control; three-leg turning intersections with stop control; ~~) and signalized (~~three-, ~~and~~ four-, and five-leg~~)~~ intersections with signal control; and specific predictive models for three- and four-leg stop-controlled and signalized intersections on high-speed arterials with posted speed limits of 50 mph or greater. The intersection models estimate the predicted average frequency of crashes that occur within the limits of an intersection (Region A of Figure 12-2) and intersection-related crashes that occur on the intersection legs (Region B in Figure 12-2).

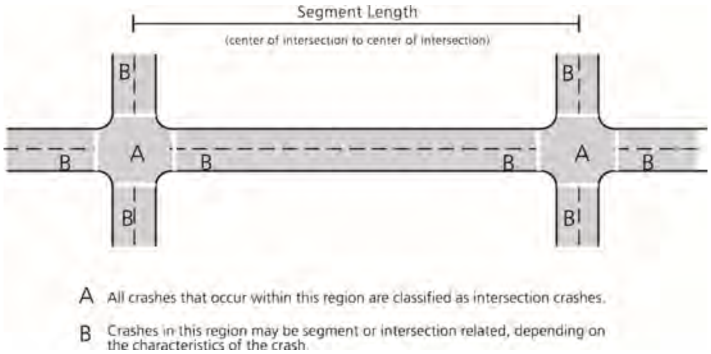


Figure 12-2. Definition of Roadway Segments and Intersections

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 and key roadway design characteristics and traffic control features. Figure 12-2 shows the segment length, *L*, for a single homogenous roadway segment occurring between two intersections. However, several homogenous roadway segments can occur between two intersections. A new (unique) homogeneous segment begins at the center of each intersection and where there is a change in at least one of the following characteristics of the roadway:

- Annual average daily traffic volume (AADT) (vehicles/day)
- Number of through lanes
- Presence/type of median
- Presence of TWLTL

The following rounded widths for medians without barriers are recommended before determining "homogeneous" segments:

Measured Median Width	Rounded Median Width
1 ft to 14 ft	10 ft
15 ft to 24 ft	20 ft
25 ft to 34 ft	30 ft
35 ft to 44 ft	40 ft
45 ft to 54 ft	50 ft
55 ft to 64 ft	60 ft
65 ft to 74 ft	70 ft
75 ft to 84 ft	80 ft
85 ft to 94 ft	90 ft
95 ft or more	100 ft

- Presence/type of on-street parking
- Roadside fixed object density
- Presence of lighting

- Speed category (based on actual traffic speed or posted speed limit)
- Automated enforcement

In addition, each individual intersection is treated as a separate site for which the intersection-related crashes are estimated using the predictive method.

There is no minimum roadway segment length, *L*, 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 assigning crashes to roadway segments and intersections for use in the site-specific EB Method is presented in Part C, Appendix A.2.3. In applying the EB Method for urban and suburban arterials, whenever the predicted average crash frequency for a specific roadway segment during the multiyear study period is less than 1/k (the inverse of the overdispersion parameter for the relevant SPF), consideration should be given to combining adjacent roadway segments and applying the project-level EB Method. This guideline for the minimum crash frequency for a roadway segment applies only to Chapter 12 which uses fixed-value overdispersion parameters. It is not needed in Chapters 10 or 11, which use length-dependent overdispersion parameters.

12.6. Safety Performance Functions

In Step 9 of the predictive method, the appropriate safety performance functions (SPFs) are used to predict crash frequencies 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, estimates 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 predicted crash frequencies for base conditions obtained with the SPFs are used in the predictive models in Equations 12-2 through ~~12-7~~12-EA. A detailed discussion of SPFs and their use in the HSM is presented in Sections 3.5.2 and 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 Part C, Appendix A. The SPFs in Chapter 12 are summarized in Table 12-2.

Table 12-2. Safety Performance Functions included in Chapter 12

Chapter 12 SPFs for Urban and Suburban Arterials	SPF Components by Collision Type	SPF Equations, Tables, and Figures
Roadway segments	multiple-vehicle nondriveway collisions	Equations 12-10, 12-11, 12-12, Figure 12-3, Tables 12-3, 12-4
	single-vehicle crashes	Equations 12-13, 12-14, 12-15, Figure 12-4, Tables 12-5, 12-6
	multiple-vehicle driveway-related collisions	Equations 12-16, 12-17, 12-18, Figures 12-5, 12-6, 12-7, 12-8, 12-9, Table 12-7
	vehicle-pedestrian collisions	Equation 12-19, Table 12-8
	vehicle-bicycle collisions	Equation 12-20, Table 12-9
Intersections	multiple-vehicle collisions	Equations 12-21, 12-EMVA, 12-EMVB, 12-EMVC, 12-EB, 12-22, 12-23, 12-EMVPROPA, 12-EMVPROPB, 12-EMVPROPC Figures 12-10, 12-XA, 12-XAi 12-11, 12-XB, 12-12, 12-XC, 12-13, 12-XD, 12-XE, Tables 12-10, 12-11
	single-vehicle crashes	Equations 12-24, 12-ESVA, 12-ESVB, 12-25, 12-26, 12-ESVTOTADJ, 12-ESVFIADJ, 12-ESVPDOADJ, 12-27, Figures 12-14, 12-XF, 12-XFi, 12-15, 12-XG, 12-16, 12-XH, 12-17, 12-XI, 12-XJ, Tables 12-12, 12-13
	multiple-and single-vehicle crashes combined	Equation 12-MV+SVA, 12-MV+SVB, Figures 12-XK, 12-XL, Tables 12-XA, 12-XB
	vehicle-pedestrian collisions	Equations 12-28, 12-29, 12-30, Tables 12-14, 12-15, 12-16
	vehicle-bicycle collisions	Equation 12-31, Table 12-17

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 Part C, Appendix A.

12.6.1. Safety Performance Functions for Urban and Suburban Arterial Roadway Segments

The predictive model for predicting average crash frequency on a particular urban or suburban arterial roadway segment was presented in Equation 12-2. The effect of traffic volume (AADT) on crash frequency is incorporated through the SPF, while the effects of geometric design and traffic control features are incorporated through the CMFs. The SPF for urban and suburban arterial roadway segments is presented in this section. Urban and suburban arterial roadway segments are defined in Section 12.3.

SPFs and adjustment factors are provided for five types of roadway segments on urban and suburban arterials:

- Two-lane undivided arterials (2U)
- Three-lane arterials including a center two-way left-turn lane (TWLTL) (3T)
- Four-lane undivided arterials (4U)
- Four-lane divided arterials (i.e., including a raised or depressed median) (4D)
- Five-lane arterials including a center TWLTL (5T)

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 12.4. The SPFs for roadway segments on urban and suburban arterials are applicable to the following AADT ranges:

- 2U: 0 to 32,600 vehicles per day
- 3T: 0 to 32,900 vehicles per day
- 4U: 0 to 40,100 vehicles per day
- 4D: 0 to 66,000 vehicles per day
- 5T: 0 to 53,800 vehicles per day

Application to sites with AADTs substantially outside these ranges may not provide reliable results.

Other types of roadway segments may be found on urban and suburban arterials but are not addressed by the predictive model in Chapter 12.

The procedure addresses five types of collisions. The corresponding equations, tables, and figures are indicated in Table 12-2 above:

- multiple-vehicle nondriveway collisions
- single-vehicle crashes
- multiple-vehicle driveway-related collisions
- vehicle-pedestrian collisions
- vehicle-bicycle collisions

The predictive model for estimating average crash frequency on roadway segments is shown in Equations 12-2 through 12-4. The effect of traffic volume on predicted crash frequency is incorporated through the SPFs, while the effects of geometric design and traffic control features are incorporated through the CMFs. SPFs are provided for multiple-vehicle nondriveway collisions and single-vehicle crashes. Adjustment factors are provided for multi-vehicle driveway-related, vehicle-pedestrian, and vehicle-bicycle collisions.

Multiple-Vehicle Nondriveway Collisions

The SPF for multiple-vehicle nondriveway collisions is applied as follows:

$$N_{brmv} = exp\left(a + b \times 1n\left(AADT\right) + 1n\left(L\right)\right) \quad (12\text{-}10)$$

Where:

AADT = ~~average annual daily traffic~~annual average daily traffic volume (vehicles/day) on roadway segment;

L = length of roadway segment (mi); and

a, *b* = regression coefficients.

Table 12-3 presents the values of the coefficients a and b used in applying Equation 12-10. The overdispersion parameter, *k*, is also presented in Table 12-3.

Table 12-3. SPF Coefficients for Multiple-Vehicle Nondriveway Collisions on Roadway Segments

	Coefficients Used in Equation 12-10		
Road Type	**Intercept (a)**	**AADT (b)**	**Overdispersion Parameter (*k*)**
Total crashes			
2U	−15.22	1.68	0.84
3T	−12.40	1.41	0.66
4U	−11.63	1.33	1.01
4D	−12.34	1.36	1.32
5T	−9.70	1.17	0.81
Fatal-and-injury crashes			
2U	−16.22	1.66	0.65
3T	−16.45	1.69	0.59
4U	−12.08	1.25	0.99
4D	−12.76	1.28	1.31
5T	−10.47	1.12	0.62
Property-damage-only crashes			
2U	−15.62	1.69	0.87
3T	−11.95	1.33	0.59
4U	−12.53	1.38	1.08
4D	−12.81	1.38	1.34
5T	−9.97	1.17	0.88

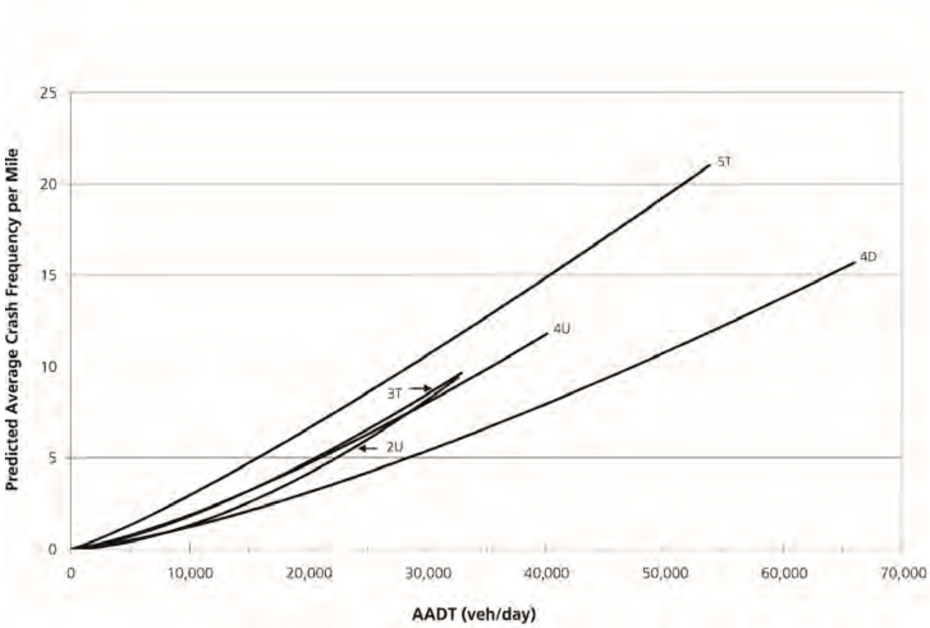


Figure 12-3. Graphical Form of the SPF for Multiple Vehicle Nondriveway collisions (from Equation 12-10 and Table 12-3)

Equation 12-10 is first applied to determine N_{brmv} using the coefficients for total crashes in Table 12-3. N_{brmv} is then divided into components by severity level, $N_{brmv(FI)}$ for fatal-and-injury crashes and $N_{brmv(PDO)}$ for property-damage-only crashes. These preliminary values of $N_{brmv(FI)}$ and $N_{brmv(PDO)}$, designated as $N'_{brmv(FI)}$ and $N'_{brmv(PDO)}$ in Equation 12-11, are determined with Equation 12-10 using the coefficients for fatal-and-injury and property-damage-only crashes, respectively, in Table 12-3. The following adjustments are then made to assure that $N_{brmv(FI)}$ and $N_{brmv(PDO)}$ sum to N_{brmv}:

$$N_{brmw(FI)} = N_{brmw(\text{total})} \left(\frac{N'_{brmv(FI)}}{N'_{brmv(FI)} + N'_{brmv(PDO)}} \right) \tag{12-11}$$

$$N_{brmv(PDO)} = N_{brmw(\text{total})} - N_{brmw(FI)} \tag{12-12}$$

The proportions in Table 12-4 are used to separate $N_{brmv(FI)}$ and $N_{brmv(PDO)}$ into components by collision type.

Table 12-4. Distribution of Multiple-Vehicle Nondriveway Collisions for Roadway Segments by Manner of Collision Type

	Proportion of Crashes by Severity Level for Specific Road Types									
	2U		3T		4U		4D		5T	
Collision Type	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Rear-end collision	0.730	0.778	0.845	0.842	0.511	0.506	0.832	0.662	0.846	0.651
Head-on collision	0.068	0.004	0.034	0.020	0.077	0.004	0.020	0.007	0.021	0.004
Angle collision	0.085	0.079	0.069	0.020	0.181	0.130	0.040	0.036	0.050	0.059
Sideswipe, same direction	0.015	0.031	0.001	0.078	0.093	0.249	0.050	0.223	0.061	0.248
Sideswipe, opposite direction	0.073	0.055	0.017	0.020	0.082	0.031	0.010	0.001	0.004	0.009
Other multiple-vehicle collisions	0.029	0.053	0.034	0.020	0.056	0.080	0.048	0.071	0.018	0.029

Source: HSIS data for Washington (2002–2006)

Single-Vehicle Crashes

SPFs for single-vehicle crashes for roadway segments are applied as follows:

$$N_{brsv} = exp\left(a + b \times \ln\left(AADT\right) + \ln\left(L\right)\right) \tag{12-13}$$

Table 12-5 presents the values of the coefficients and factors used in Equation 12-13 for each roadway type. Equation 12-13 is first applied to determine N_{brsv} using the coefficients for total crashes in Table 12-5. N_{brsv} is then divided into components by severity level; $N_{brsv(FI)}$ for fatal-and-injury crashes and $N_{brsv(PDO)}$ for property-damage-only crashes. Preliminary values of $N_{brsv(FI)}$ and $N_{brsv(PDO)}$, designated as $N'_{brsv(FI)}$ and $N'_{brsv(PDO)}$ in Equation 12-14, are determined with Equation 12-13 using the coefficients for fatal-and-injury and property-damage-only crashes, respectively, in Table 12-5. The following adjustments are then made to assure that $N_{brsv(FI)}$ and $N_{brsv(PDO)}$ sum to N_{brsv}:

$$N_{brsv(FI)} = N_{brsv(\text{total})} \left(\frac{N'_{brsv(FI)}}{N'_{brsv(FI)} + N'_{brsv(PDO)}} \right) \tag{12-14}$$

$$N_{brsv(PDO)} = N_{brsv(\text{total})} - N_{brsv(FI)} \tag{12-15}$$

The proportions in Table 12-6 are used to separate $N_{brsv(FI)}$ and $N_{brsv(PDO)}$ into components by crash type.

Table 12-5. SPF Coefficients for Single-Vehicle Crashes on Roadway Segments

Road Type	Coefficients Used in Equation 12-11 Intercept (a)	AADT (b)	Overdispersion Parameter (*k*)
Total crashes			
2U	−5.47	0.56	0.81
3T	−5.74	0.54	1.37
4U	−7.99	0.81	0.91
4D	−5.05	0.47	0.86
5T	−4.82	0.54	0.52
Fatal-and-injury crashes			
2U	−3.96	0.23	0.50
3T	−6.37	0.47	1.06
4U	−7.37	0.61	0.54
4D	−8.71	0.66	0.28
5T	−4.43	0.35	0.36
Property-damage-only crashes			
2U	−6.51	0.64	0.87
3T	−6.29	0.56	1.93
4U	−8.50	0.84	0.97
4D	−5.04	0.45	1.06
5T	−5.83	0.61	0.55

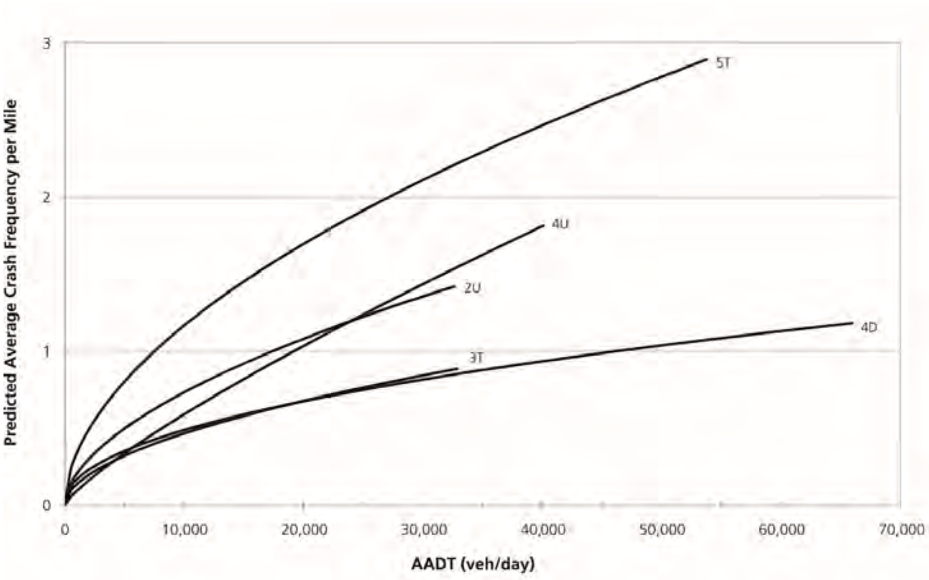


Figure 12-4. Graphical Form of the SPF for Single-Vehicle Crashes (from Equation 12-13 and Table 12-5)

Table 12-6. Distribution of Single-Vehicle Crashes for Roadway Segments by Collision Type

	Proportion of Crashes by Severity Level for Specific Road Types									
	2U		3T		4U		4D		5T	
Collision Type	FI	PDO	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Collision with animal	0.026	0.066	0.001	0.001	0.001	0.001	0.001	0.063	0.016	0.049
Collision with fixed object	0.723	0.759	0.688	0.963	0.612	0.809	0.500	0.813	0.398	0.768
Collision with other object	0.010	0.013	0.001	0.001	0.020	0.029	0.028	0.016	0.005	0.061
Other single-vehicle collision	0.241	0.162	0.310	0.035	0.367	0.161	0.471	0.108	0.581	0.122

Source: HSIS data for Washington (2002–2006)

Multiple-Vehicle Driveway-Related Collisions

The model presented above for multiple-vehicle collisions addressed only collisions that are not related to driveways. Driveway-related collisions also generally involve multiple vehicles, but are addressed separately because the frequency of driveway-related collisions on a roadway segment depends on the number and type of driveways. Only unsignalized driveways are considered; signalized driveways are analyzed as signalized intersections.

The total number of multiple-vehicle driveway-related collisions within a roadway segment is determined as:

$$N_{brdwy} = \sum_{\substack{\text{all} \\ \text{driveway} \\ \text{types}}} n_j \times N_j \times \left(\frac{AADT}{15,500} \right)^{(t)} \qquad (12\text{-}16)$$

Where:

N_j = Number of driveway-related collisions per driveway per year for driveway type *j* from Table 12-7;

n_j = number of driveways within roadway segment of driveway type j including all driveways on both sides of the road; and

t = coefficient for traffic volume adjustment from Table 12-7.

The number of driveways of a specific type, n_j, is the sum of the number of driveways of that type for both sides of the road combined. The number of driveways is determined separately for each side of the road and then added together.

Seven specific driveway types have been considered in modeling. These are:

- Major commercial driveways
- Minor commercial driveways
- Major industrial/institutional driveways
- Minor industrial/institutional driveways
- Major residential driveways
- Minor residential driveways
- Other driveways

Major driveways are those that serve sites with 50 or more parking spaces. Minor driveways are those that serve sites with less than 50 parking spaces. It is not intended that an exact count of the number of parking spaces be made for each site. Driveways can be readily classified as major or minor from a quick review of aerial photographs that show parking areas or through user judgment based on the character of the establishment served by the driveway. Commercial driveways provide access to establishments that serve retail customers. Residential driveways serve single- and multiple-family dwellings. Industrial/institutional driveways serve factories, warehouses, schools, hospitals, churches, offices, public facilities, and other places of employment. Commercial sites with no restriction on access along an entire property frontage are generally counted as two driveways.

Table 12-7. SPF Coefficients for Multiple-Vehicle Driveway Related Collisions

	Coefficients for Specific Roadway Types				
Driveway Type (*j*)	**2U**	**3T**	**4U**	**4D**	**5T**
Number of Driveway-Related Collisions per Driveway per Year (N_j)					
Major commercial	0.158	0.102	0.182	0.033	0.165
Minor commercial	0.050	0.032	0.058	0.011	0.053
Major industrial/institutional	0.172	0.110	0.198	0.036	0.181
Minor industrial/institutional	0.023	0.015	0.026	0.005	0.024
Major residential	0.083	0.053	0.096	0.018	0.087
Minor residential	0.016	0.010	0.018	0.003	0.016
Other	0.025	0.016	0.029	0.005	0.027
Regression Coefficient for AADT (*t*)					
All driveways	1.000	1.000	1.172	1.106	1.172
Overdispersion Parameter (*k*)					
All driveways	0.81	1.10	0.81	1.39	0.10
Proportion of Fatal-and-Injury Crashes (f_{dwy})					
All driveways	0.323	0.243	0.342	0.284	0.269
Proportion of Property-Damage-Only Crashes					
All driveways	0.677	0.757	0.658	0.716	0.731

Note: Includes only unsignalized driveways; signalized driveways are analyzed as signalized intersections. Major driveways serve 50 or more parking spaces; minor driveways serve less than 50 parking spaces.

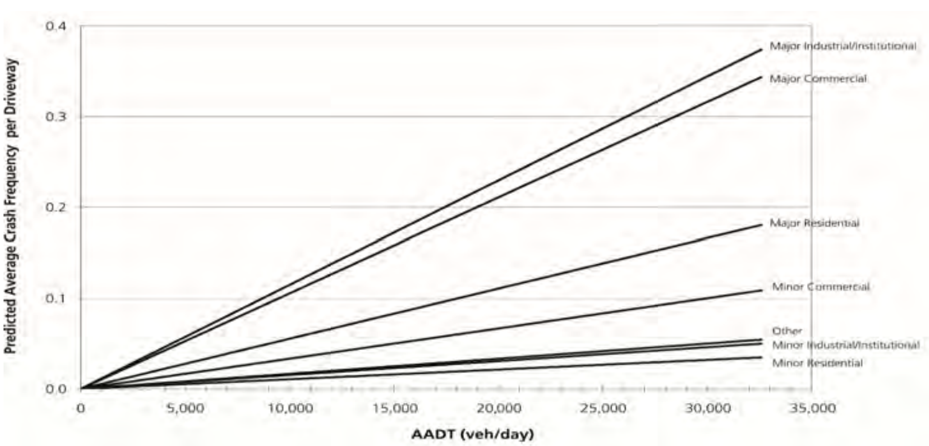


Figure 12-5. Graphical Form of the SPF for Multiple Vehicle Driveway Related Collisions on Two-Lane Undivided Arterials (2U) (from Equation 12-16 and Table 12-7)

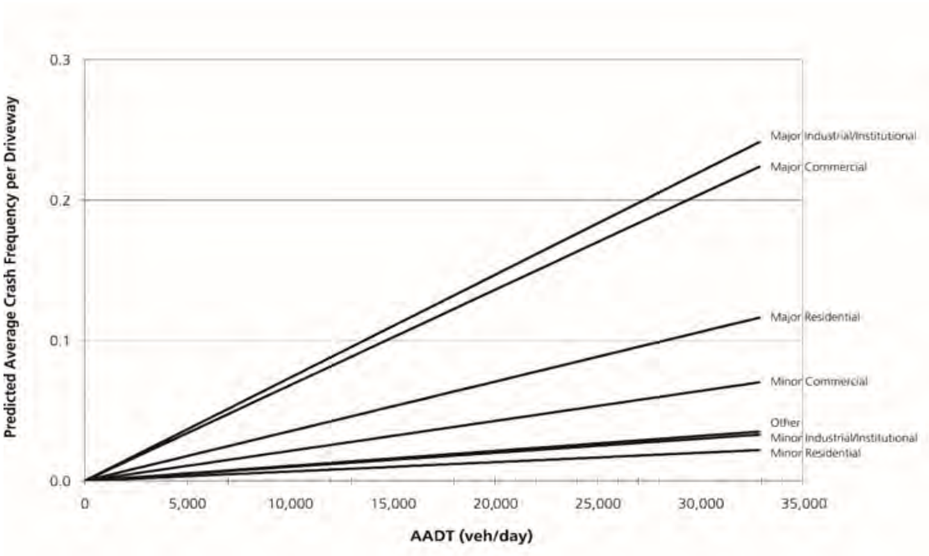


Figure 12-6. Graphical Form of the SPF for Multiple Vehicle Driveway Related Collisions on Three-Lane Undivided Arterials (3T) (from Equation 12-16 and Table 12-7)

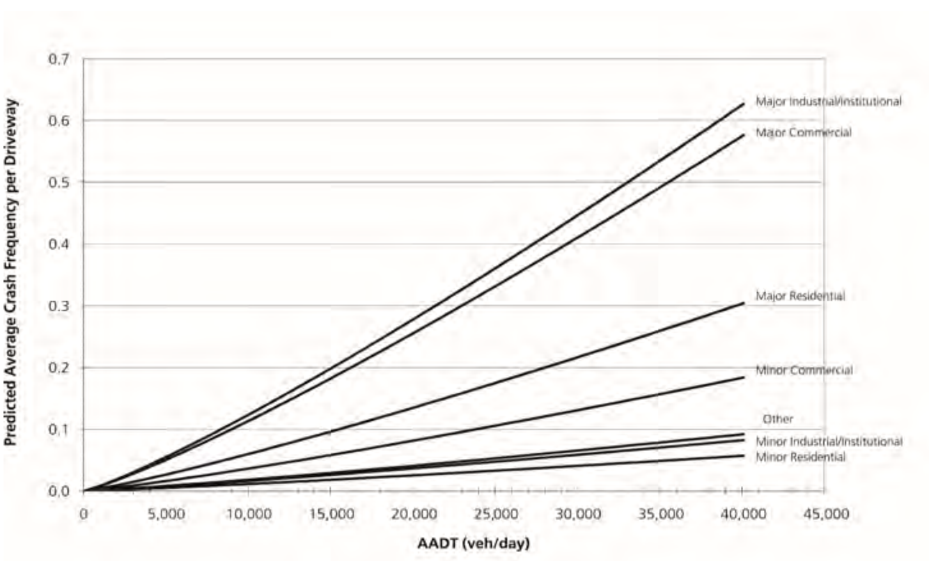


Figure 12-7. Graphical Form of the SPF for Multiple Vehicle Driveway Related Collisions on Four-Lane Undivided Arterials (4U) (from Equation 12-16 and Table 12-7)

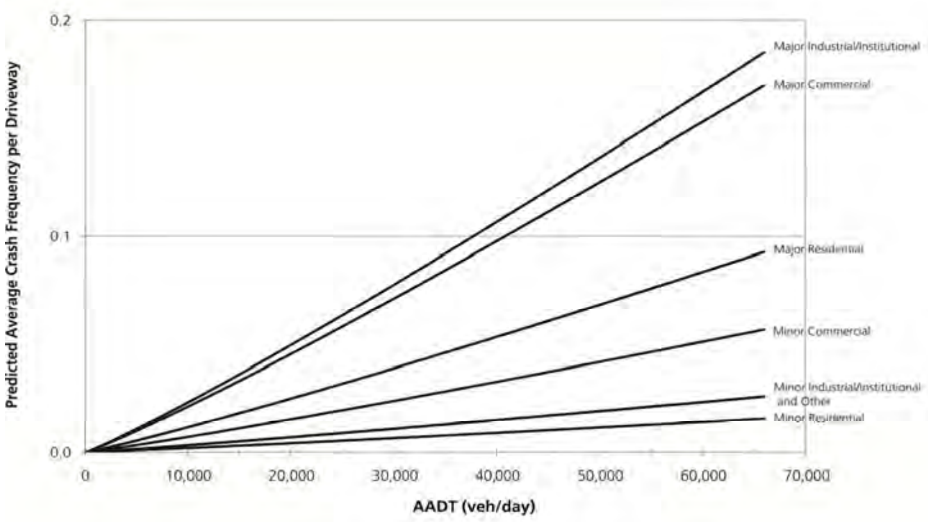


Figure 12-8. Graphical Form of the SPF for Multiple Vehicle Driveway Related Collisions on Four-Lane Divided Arterials (4D) (from Equation 12-16 and Table 12-7)

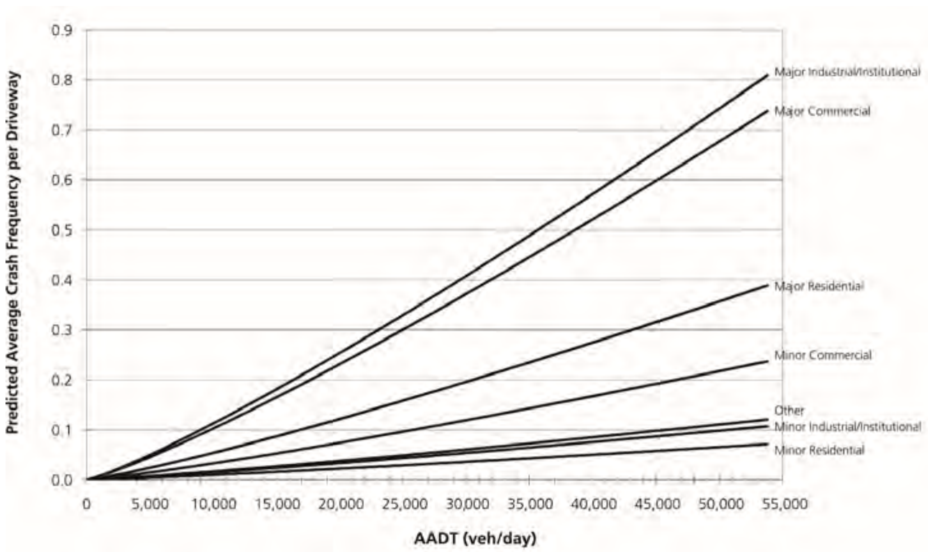


Figure 12-9. Graphical Form of the SPF for Multiple Vehicle Driveway Related Collisions on Five-Lane Arterials Including a Center Two-Way Left-Turn Lane (from Equation 12-16 and Table 12-7)

Driveway-related collisions can be separated into components by severity level as follows:

$$N_{brdwy(FI)} = N_{brdwy(\text{total})} \times f_{dwy} \tag{12-17}$$

$$N_{brdwy(PDO)} = N_{brdwy(\text{total})} - N_{brdwy(FI)} \tag{12-18}$$

Where:

f_{dwy} = proportion of driveway-related collisions that involve fatalities or injuries

The values of N_j and f_{dwy} are shown in Table 12-7.

Vehicle-Pedestrian Collisions

The number of vehicle-pedestrian collisions per year for a roadway segment is estimated as:

$$N_{pedr} = N_{br} \times f_{pedr} \tag{12-19}$$

Where:

f_{pedr} = pedestrian crash adjustment factor.

The value N_{br} used in Equation 12-19 is that determined with Equation 12-3.

Table 12-8 presents the values of f_{pedr} for use in Equation 12-19. All vehicle-pedestrian collisions are considered to be fatal-and-injury crashes. The values of f_{pedr} are likely to depend on the climate and the walking environment in particular states or communities. HSM users are encouraged to replace the values in Table 12-8 with suitable values for their own state or community through the calibration process (see Part C, Appendix A).

Table 12-8. Pedestrian Crash Adjustment Factor for Roadway Segments

	Pedestrian Crash Adjustment Factor (f_{pedr})	
Road Type	**Posted Speed 30 mph or Lower**	**Posted Speed Greater than 30 mph**
2U	0.036	0.005
3T	0.041	0.013
4U	0.022	0.009
4D	0.067	0.019
5T	0.030	0.023

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All pedestrian collisions resulting from this adjustment factor are treated as fatal-and-injury crashes and none as property-damage-only crashes.
Source: HSIS data for Washington (2002–2006)

Vehicle-Bicycle Collisions

The number of vehicle-bicycle collisions per year for a roadway segment is estimated as:

$$N_{biker} = N_{br} \times f_{biker} \tag{12-20}$$

Where:

f_{biker} = bicycle crash adjustment factor.

The value of N_{br} used in Equation 12-20 is determined with Equation 12-3.

Table 12-9 presents the values of fbiker for use in Equation 12-18. All vehicle-bicycle collisions are considered to be fatal-and-injury crashes. The values of fbiker are likely to depend on the climate and bicycling environment in particular states or communities. HSM users are encouraged to replace the values in Table 12-9 with suitable values for their own state or community through the calibration process (see Part C, Appendix A).

Table 12-9. Bicycle Crash Adjustment Factors for Roadway Segments

	Bicycle Crash Adjustment Factor (f_{biker})	
Road type	**Posted Speed 30 mph or Lower**	**Posted Speed Greater than 30 mph**
2U	0.018	0.004
3T	0.027	0.007
4U	0.011	0.002
4D	0.013	0.005
5T	0.050	0.012

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All bicycle collisions resulting from this adjustment factor are treated as fatal-and-injury crashes and none as property-damage-only crashes.
Source: HSIS data for Washington (2002–2006)

12.6.2. Safety Performance Functions for Urban and Suburban Arterial Intersections

The predictive models for predicting the frequency of crashes related to an intersection are~~is~~ presented in Equations 12-5 through 12-EA~~12-7~~. The structure of the predictive models for intersections is similar to the predictive models for roadway segments.

The effect of traffic volume on predicted crash frequency for intersections is incorporated through SPFs, while the effect of geometric and traffic control features are incorporated through CMFs. Most~~Each~~ of the SPFs for intersections incorporate~~s~~ separate effects for the AADTs on the major- and minor-road legs, respectively. However, several of the SPFs for intersections include a variable for total entering volume or AADT$_{total}$. ~~,~~For five-leg intersections, sometimes the AADT of the fifth-leg is a separate term in the model and sometimes it is included in a term that combines all non-major road AADTs.

SPFs and adjustment factors have been developed for ~~four~~ twelve types of intersections on urban and suburban arterials. These are:

- Three-leg intersections with stop control on the minor-road approach (3ST)
- Three-leg intersections with stop control on the minor-road approach on high-speed arterials (3ST-HS)
- Three-leg all-way stop-controlled intersections (3aST)
- Three-leg turning intersections with stop control (3STT)
- Three-leg signalized intersections (3SG)
- Three-leg signalized intersections on high-speed arterials (3SG-HS)
- Four-leg intersections with stop control on the minor-road approaches (4ST)
- Four-leg intersections with stop control on the minor-road approaches on high-speed arterials (4ST-HS)
- Four-leg all-way stop-controlled intersections (4aST)
- Four-leg signalized intersections (4SG)

- Four-leg signalized intersections on high-speed arterials (4SG-HS)
- Five-leg signalized intersections (5SG)

Other types of intersections may be found on urban and suburban arterials but are not addressed by the Chapter 12 SPFs.

As indicated above, several of the intersection SPFs have been developed specifically for intersections located on high-speed arterials with posted speed limits of 50 mph or greater. The intersection SPFs that are not designated specifically for high-speed arterials can be used to predict crash frequencies at intersections located on high-speed arterials, but use of models that have been developed specifically for intersections located on high-speed arterials is recommended when analyzing intersections located on urban and suburban arterials with posted speed limits of 50 mph or greater.

The SPFs for each of the ~~four~~twelve intersection types identified above predict total crash frequency per year for crashes that occur within the limits of the intersection and intersection-related crashes. The SPFs and adjustment factors address the following four types of collisions, (the corresponding equations, tables, and figures are indicated in Table 12-2):

- multiple-vehicle collisions
- single-vehicle crashes
- vehicle-pedestrian collisions
- vehicle-bicycle collisions

Multiple-vehicle and single-vehicle crashes are modeled together for all-way stop-controlled intersections.

The SPFs for three- and four-leg minor-road stop-controlled intersections (3ST, 3ST-HS, 4ST, and 4ST-HS) on all urban and suburban arterials are applicable to the following base conditions:

- Intersection left-turn lanes 0, except on stop-controlled approaches
- Intersection right-turn lanes 0, except on stop-controlled approaches
- Lighting None

The SPFs for three- and four-leg all-way stop-controlled intersections (3aST and 4aST) on urban and suburban arterials are applicable to the following base conditions:

- Lighting None

The SPFs for three-leg turning intersections (3STT) on urban and suburban arterials are applicable to the following base conditions:

- Curve radius 84 ft
- Curve length 100 ft

The SPFs for three- and four-leg signalized intersections (3SG and 4SG) on urban and suburban arterials are applicable to the following base conditions:

- Intersection left-turn lanes None
- Intersection left-turn signal phasing Permissive left-turn signal phasing
- Intersection right-turn lanes None
- Right-turn-on-red Right-turn-on-red permitted at all approaches
- Lighting None

- Red-light cameras None
- Bus stops 0 bus stops present within 1,000 ft of the intersection
- Schools 0 schools present within 1,000 ft of the intersection
- Alcohol sales establishments 0 alcohol sales establishments present within 1,000 ft of the intersection

The SPFs for three- and four-leg signalized intersections (3SG-HS and 4SG-HS) on urban and suburban arterials with posted speed limits of 50 mph or greater are applicable to the following base conditions:

- Intersection left-turn lanes None
- Intersection right-turn lanes None
- Lighting None

The SPFs for five-leg signalized intersections (5SG) do not have base conditions and, therefore, can be used only for generalized predictions of crash frequencies.

Guidance on the estimation of traffic volumes for the major, ~~and~~ minor, and fifth road approach legs for use in the SPFs is presented in Step 3. The AADT(s) used in the SPF are the AADT(s) for the selected year of the evaluation period. The SPFs for intersections are applicable to the following AADT ranges:

3ST Intersections	$AADT_{maj}$: 0 to 45,700 vehicles per day and	$AADT_{min}$: 0 to 9,300 vehicles per day	
3ST-HS Intersections	$AADT_{maj}$: 0 to 58,494 vehicles per day and	$AADT_{min}$: 0 to 11,335 vehicles per day	
3aST Intersections	$AADT_{maj}$: 0 to 15,000 vehicles per day and	$AADT_{min}$: 0 to 11,000 vehicles per day	
3STT Intersections	$AADT_{maj}$: 0 to 17,688 vehicles per day and	$AADT_{min}$: 0 to 5,787 vehicles per day	
3SG Intersections	$AADT_{maj}$: 0 to 58,100 vehicles per day and	$AADT_{min}$: 0 to 16,400 vehicles per day	
3SG-HS Intersections	$AADT_{maj}$: 0 to 47,200 vehicles per day and	$AADT_{min}$: 0 to 11,282 vehicles per day	
4ST Intersections	$AADT_{maj}$: 0 to 46,800 vehicles per day and	$AADT_{min}$: 0 to 5,900 vehicles per day	
4ST-HS Intersections	$AADT_{maj}$: 0 to 59,000 vehicles per day and	$AADT_{min}$: 0 to 29,800 vehicles per day	
4aST Intersections	$AADT_{maj}$: 0 to 12,955 vehicles per day and	$AADT_{min}$: 0 to 11,982 vehicles per day	
4SG Intersections	$AADT_{maj}$: 0 to 67,700 vehicles per day and	$AADT_{min}$: 0 to 33,400 vehicles per day	
4SG-HS Intersections	$AADT_{maj}$: 0 to 59,800 vehicles per day and	$AADT_{min}$: 0 to 30,029 vehicles per day	
5SG Intersections	$AADT_{maj}$: 0 to 29,630 vehicles per day and	$AADT_{min}$: 0 to 21,865 vehicles per day and	$AADT_{fifth}$: 0 to 24,340 vehicles per day

4SG Intersections Pedestrian Models:

- $AADT_{maj}$: 80,200 vehicles per day
- $AADT_{min}$: 49,100 vehicles per day
- PedVol: 34,200 pedestrians per day crossing all four legs combined

Application to sites with AADTs substantially outside this range may not provide reliable results.

Multiple-Vehicle Collisions

SPFs for multiple-vehicle intersection-related collisions are applied as follows:

$$N_{bimv} = exp\left(a + b \times \ln\left(AADT_{maj}\right) + c \times \ln\left(AADT_{min}\right)\right) \tag{12-21}$$

$$N_{bimv} = exp\left(a + b \times \ln\left(AADT_{maj}\right) + c \times \ln\left(AADT_{min}\right) + d \times \ln\left(AADT_{fifth}\right)\right) \tag{12-EMVA}$$

$$N_{bimv} = exp\left(a + b \times \ln\left(AADT_{maj}\right) + e \times \ln\left(AADT_{min + fifth}\right)\right) \tag{12-EMVB}$$

$$N_{bimv} = exp\left(a + f \times ln(TEV_3)\right) \tag{12-EMVC}$$

Where:

$AADT_{maj}$ = average daily traffic volume (vehicles/day) for major road (both directions of travel combined);

$AADT_{min}$ = average daily traffic volume (vehicles/day) for minor road (both directions of travel combined); ~~and~~

$AADT_{fifth}$ = average daily traffic volume (vehicles/day) for fifth road (both directions of travel combined);

$AADT_{min+fifth}$ = average daily traffic volume (vehicles/day) for minor road and fifth road approaches combined (both directions of travel combined) (= $AADT_{min}$ + $AADT_{fifth}$); ~~and~~

TEV_3 = total entering volume at a three-leg intersection, see Equation 12-EB~~10-ED~~ (vehicles per day); ~~and~~

$$TEV_3 = 0.5 \times \left(AADT_{maj,1} + AADT_{maj,2} + AADT_{min}\right) \tag{12-EB}$$

$AADT_{maj,1}$ = AADT (vehicles per day) on one major road approach (both directions of travel combined);

$AADT_{maj,2}$ = AADT (vehicles per day) on second major road approach (both directions of travel combined); and

a, *b*, *c*, *d*, *e*, *f* = regression coefficients.

Table 12-10 presents the values of the coefficients *a*, *b*, ~~and~~ *c*, *d*, ~~*and*~~ *e*, *and f* used in applying Equations 12-21, 12-EMVA, ~~and~~12-EMVB, and 12-EMVC for total, FI, and PDO severity levels. ~~.~~The SPF overdispersion parameter, *k*, is also presented in Table 12-10. Predicted crash frequencies for the three different severity levels can be estimated using the coefficients in Table 12-10. However, because the SPFs were developed independently, it is unlikely that the sum of the FI and PDO crash frequencies will equal the total crash frequency. To obtain consistency between the estimated values requires adjustments as follows.

For 3ST, 3ST-HS, 3SG, 3SG-HS, 4ST, 4ST-HS, 4SG, 4SG-HS, and 5SG intersection types, Equations 12-21, 12-EMVA, and ~~and~~ 12-EMVB~~, and 12-EMVC~~ are~~is~~ first applied to determine N_{bimv} using the coefficients for total crashes in Table 12-10. N_{bimv} is then divided into components by crash severity level, $N_{bimv(FI)}$ for fatal-and-injury crashes and $N_{bimv(PDO)}$ for property-damage-only crashes. Preliminary values of $N_{bimv(FI)}$ and $N_{bimv(PDO)}$, designated as $N'_{bimv(FI)}$ and $N'_{bimv(PDO)}$ in Equations 12-22~~ and 12-EMVPROPA~~, are determined with Equations 12-21, 12-EMVA, and ~~and~~ 12-EMVB~~, 12-EMVC~~ using the coefficients for fatal-and-injury and property-damage-only crashes, respectively, in Table 12-10. ~~Equations 12-EMVPROPA and 12-EMVPROPB are used only for 3STT intersections, while Equations 12-22 and 12-23 are used for all other intersection types~~ Using Equations 12-22 and 12-23,~~. The following~~ adjustments are then made to assure that $N_{bimv(FI)}$ and $N_{bimv(PDO)}$ sum to $N_{bimv(total)}$:

$$N_{bimv(FI)} = N_{bimv(\text{total})} \times \left(\frac{N'_{bimv(FI)}}{N'_{bimv(FI)} + N'_{bimv(PDO)}}\right) \tag{12-22}$$

$$N_{bimv(PDO)} = N_{bimv(\text{total})} - N_{bimv(FI)} \tag{12-23}$$

For 3STT, Equation 12-EMVC is first applied to determine N_{bimv} using the coefficients for total crashes in Table 12-10. N_{bimv} is then divided into components by crash severity level, $N_{bimv(FI)}$ for fatal-and-injury crashes and $N_{bimv(PDO)}$ for property-damage-only crashes. Preliminary values of $N_{bimv(FI)}$ and $N_{bimv(PDO)}$, designated as $N'_{bimv(FI)}$ and $N'_{bimv(PDO)}$ in Equation 12-EMVPROPA, are determined with Equation 12-EMVC using the coefficients for fatal-and-injury and property-damage-only crashes, respectively, in Table 12-10. Because CMF values for horizontal curves (see Table 12-CMF) are by severity level for use with Equation 12-EMVC, CMFs are used in conjunction with Equations 12-EMVPROPA and 12-EMVPROPB to adjust for actual conditions. Using Equations 12-EMVPROPA, 12-EMVPROPB, and 12-EMVPROPC adjustments are then made to assure that $N_{bimv(FI),adj}$ and $N_{bimv(PDO),adj}$ sum to $N_{bimv(total),adj}$:

$$N_{bimv(total),adj} = N_{bimv(total)} CMF_{7i,mv,tot} \tag{12-EMVPROPA}$$

$$N_{bimv(FI),adj} = N_{bimv(total),adj} \times \left(\frac{N'_{bimv(FI)} CMF_{7i,mv,fi}}{N'_{bimv(FI)} CMF_{7i,mv,fi} + N'_{bimv(PDO)} CMF_{7i,mv,pdo}} \right) \tag{12-EMVPROPB}$$

$$N_{bimv(PDO),adj} = N_{bimv(total),adj} - N_{bimv(FI),adj} \tag{12-EMVPROPC}$$

The proportions in Table 12-11 are used to separate $N_{bimv(FI)}$ and $N_{bimv(PDO)}$ into components by manner of collision.

Table 12-10. SPF Coefficients for Multiple-Vehicle Collisions at Intersections

	Coefficients Used in Equations 12-21, 12-EMVA, ~~and~~ 12-EMVB, 12-EMVC						Overdispersion Parameter (k)
Intersection Type	**Intercept (a)**	**$AADT_{maj}$ (b)**	**$AADT_{min}$ (c)**	**$AADT_{fifth}$ (d)**	**$AADT_{min+fifth}$ (e)**	**TEV_3 (f)**	
Total Crashes							
3ST	−13.36	1.11	0.41				0.80
3ST-HS	-8.26	0.58	0.49				0.85
3STT	-8.49					0.87	0.32
3SG	−12.13	1.11	0.26				0.33
3SG-HS	-4.41	0.43	0.19				0.21
4ST	−8.90	0.82	0.25				0.40
4ST-HS	-5.78	0.48	0.36				0.91
4SG	−10.99	1.07	0.23				0.39
4SG-HS	-9.65	0.98	0.28				0.31
5SG	-11.23	0.87	0.36	0.19			0.46
Fatal-and-Injury Crashes							
3ST	−14.01	1.16	0.30				0.69
3ST-HS	-6.84	0.40	0.38				0.76
3STT	-9.53					0.81	0.02
3SG	−11.58	1.02	0.17				0.30
3SG-HS	-7.28	0.64	0.17				0.09
4ST	−11.13	0.93	0.28				0.48
4ST-HS	-7.93	0.55	0.45				0.89
4SG	−13.14	1.18	0.22				0.33
4SG-HS	-9.61	0.86	0.29				0.31
5SG	-15.22	1.24			0.40		0.63
Property-Damage-Only Crashes							
3ST	−15.38	1.20	0.51				0.77
3ST-HS	-9.89	0.65	0.56				1.11
3STT	-8.12					0.79	0.14
3SG	−13.24	1.14	0.30				0.36
3SG-HS	-3.08	0.25	0.19				0.34
4ST	−8.74	0.77	0.23				0.40
4ST-HS	-5.46	0.42	0.32				0.94
4SG	−11.02	1.02	0.24				0.44
4SG-HS	-10.70	1.04	0.29				0.38
5SG	-10.92	0.75	0.39	0.23			0.48

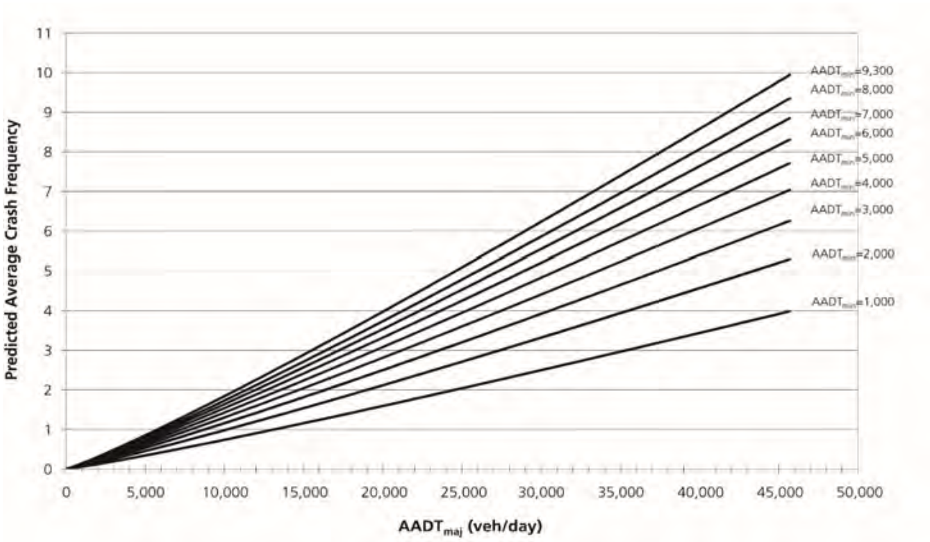


Figure 12-10. Graphical Form of the Intersection SPF for Total Multiple-~~-~~Vehicle Collisions at~~on~~ Three-Leg Intersections with Minor-Road Stop Control (3ST) (from Equation 12-21 and Table 12-10)

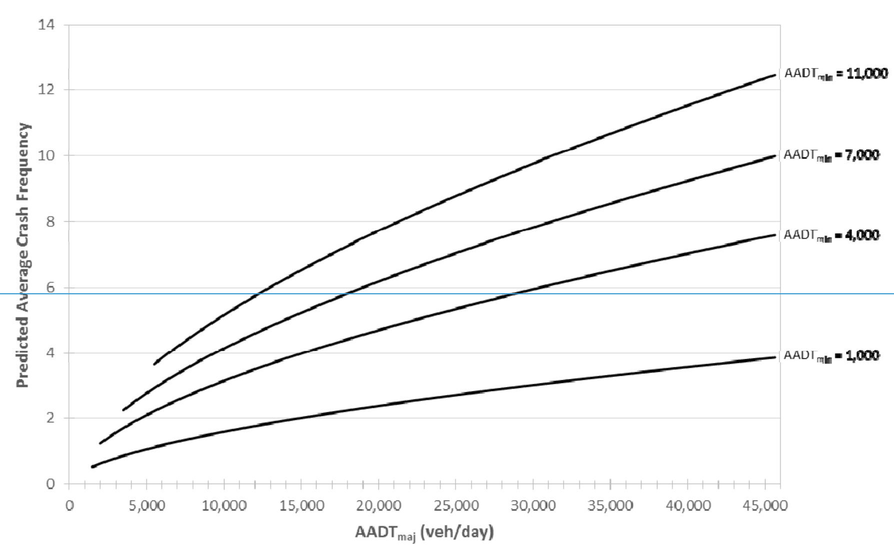


Figure 12-XA. Graphical Form of the Intersection SPF for Total Multiple-Vehicle Collisions at Three-Leg Intersections on High-Speed Arterials with Minor-Road Stop Control (3ST-HS) (from Equation 12-21 and Table 12-10)

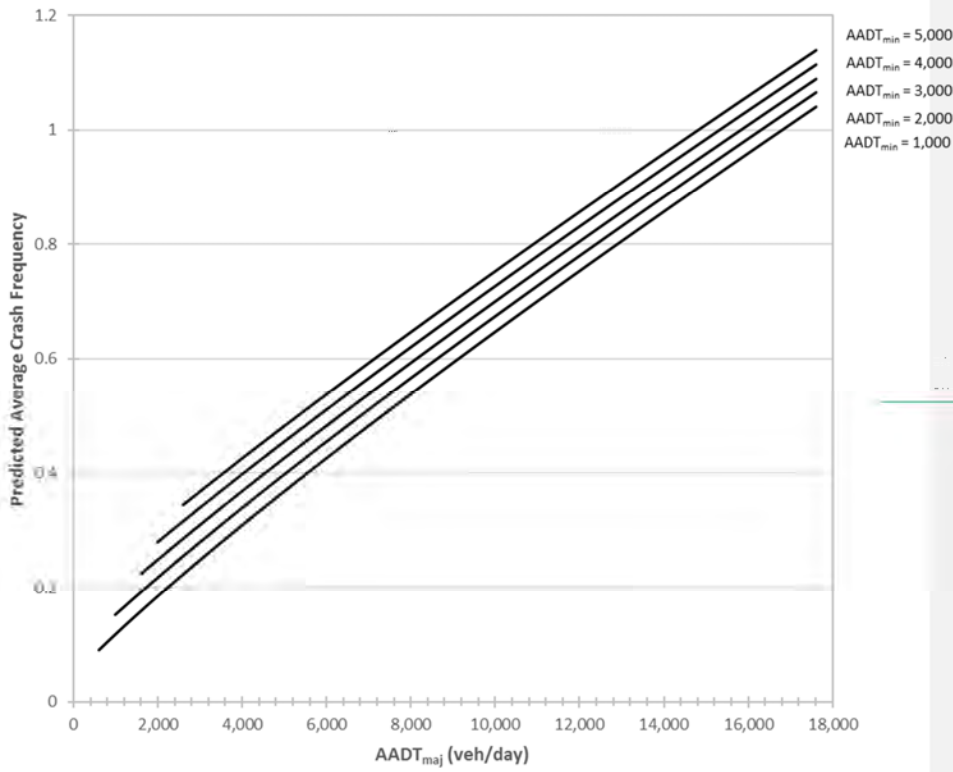


Figure 12-XAi. Graphical Form of the Intersection SPF for Total Multiple-Vehicle Collisions at Three-Leg Turning Intersections (3STT) (from Equation 12-EMVC and Table 12-10)

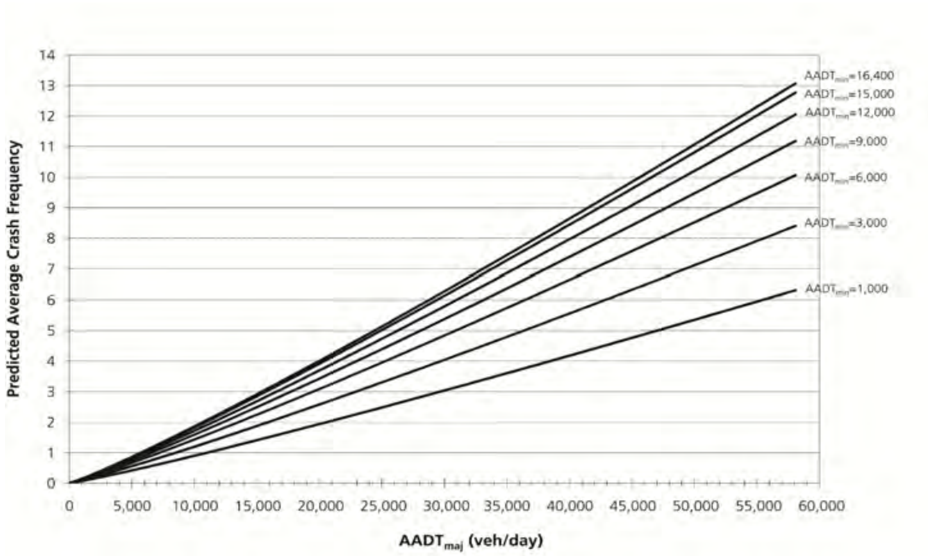


Figure 12-11. Graphical Form of the Intersection SPF for Total Multiple-~~-~~Vehicle Collisions at~~on~~ Three-Leg Signalized Intersections (3SG) (from Equation 12-21 and Table 12-10)

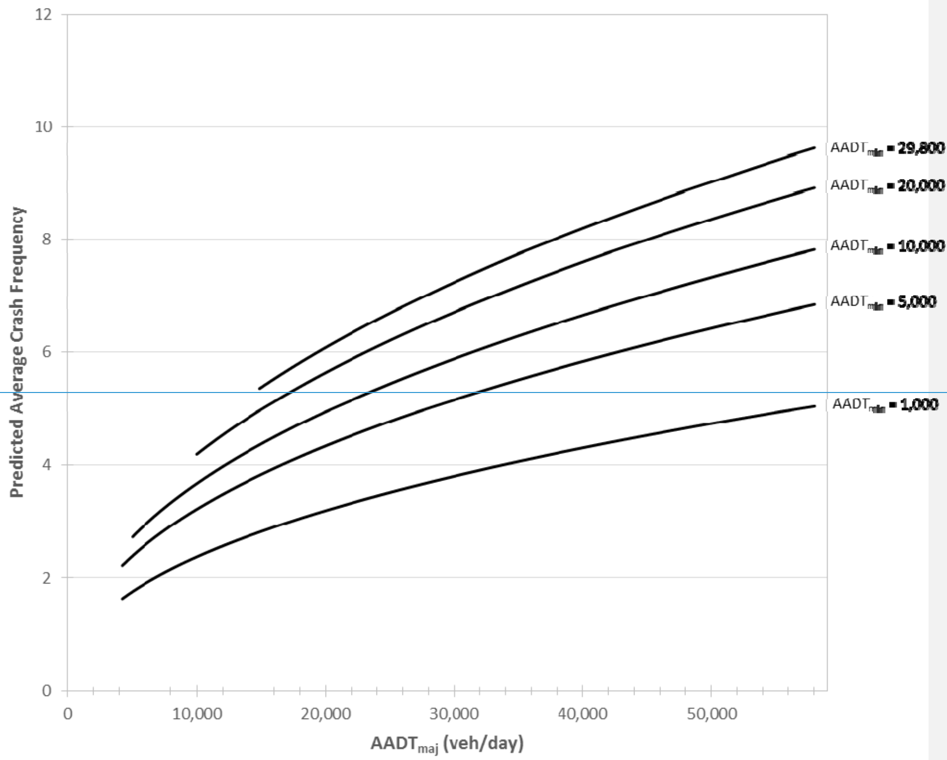


Figure 12-XB. Graphical Form of the Intersection SPF for Total Multiple-Vehicle Collisions at Three-Leg Signalized Intersections on High-Speed Arterials (3SG-HS) (from Equation 12-21 and Table 12-10)

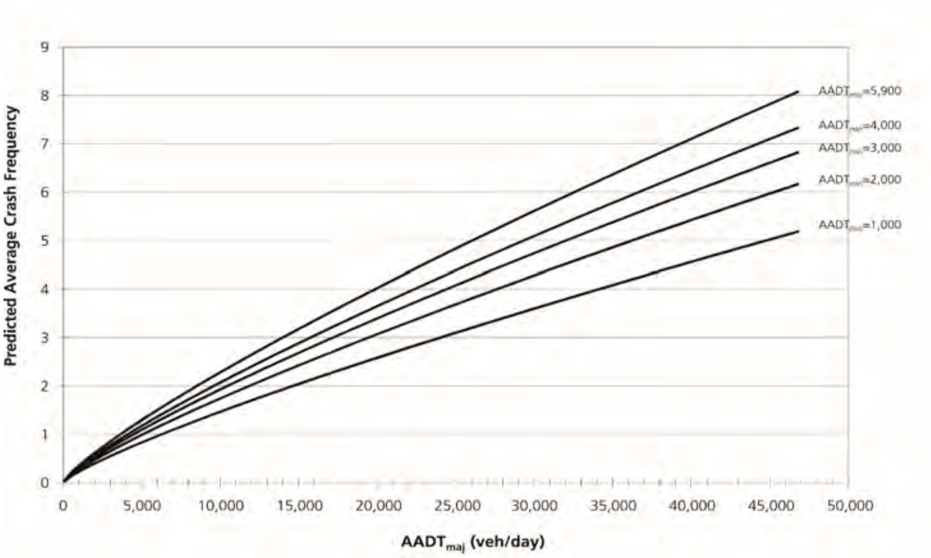


Figure 12-12. Graphical Form of the Intersection SPF for Total Multiple-~~-~~Vehicle Collisions at~~on~~ Four-Leg Intersections with Minor-Road Stop Control (4ST) (from Equation 12-21 and Table 12-10)

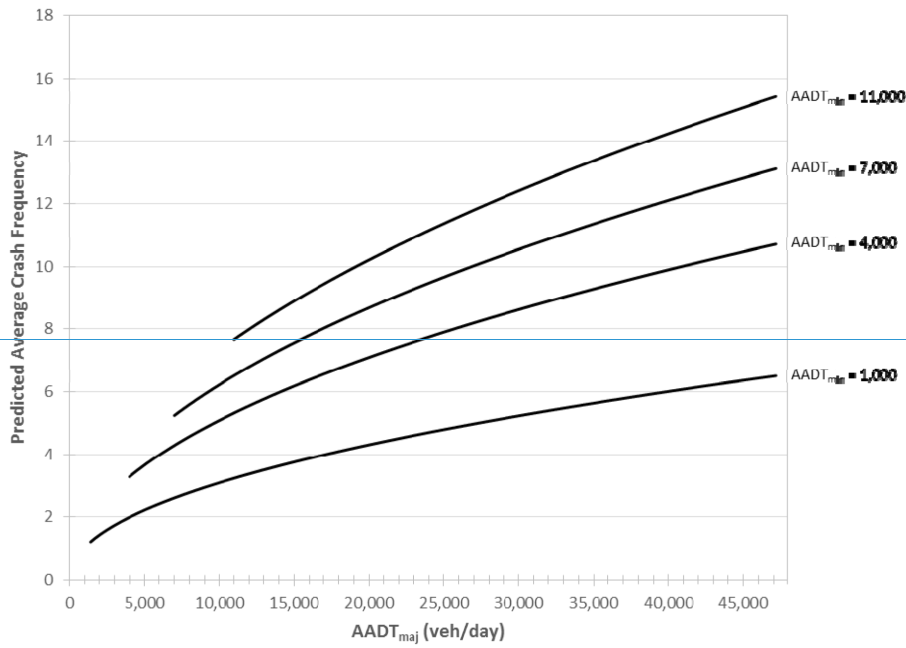


Figure 12-XC. Graphical Form of the Intersection SPF for Total Multiple-Vehicle Collisions at Four-Leg Intersections on High-Speed Arterials with Minor-Road Stop Control (4ST-HS) (from Equation 12-21 and Table 12-10)

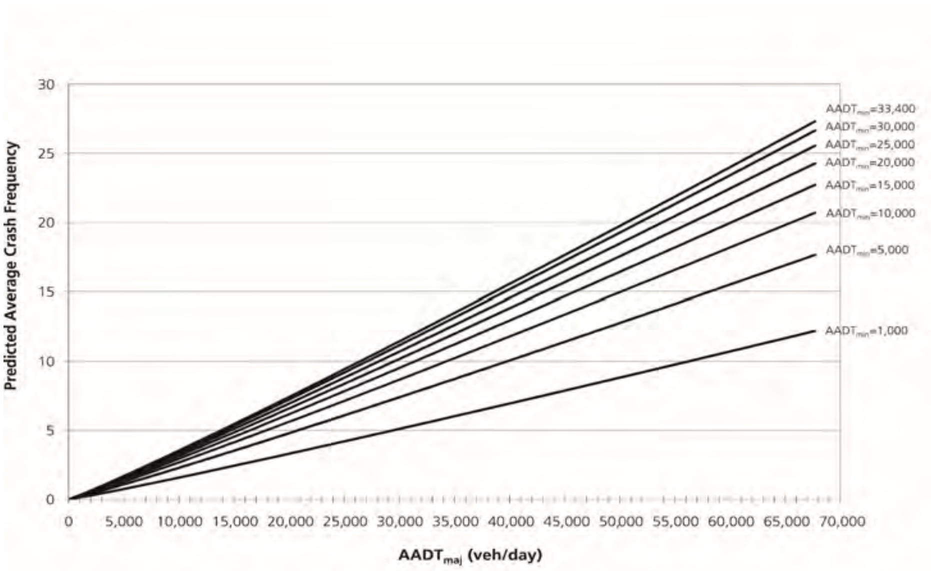


Figure 12-13. Graphical Form of the Intersection SPF for Total Multiple-Vehicle Collisions at~~on~~ Four-Leg Signalized Intersections (4SG) (from Equation 12-21 and Table 12-10)

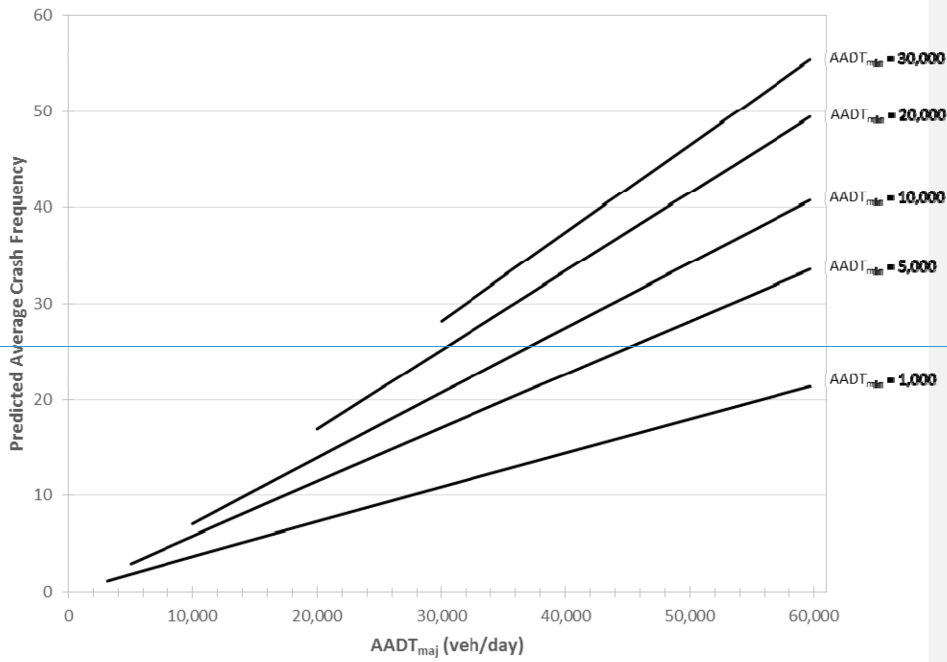
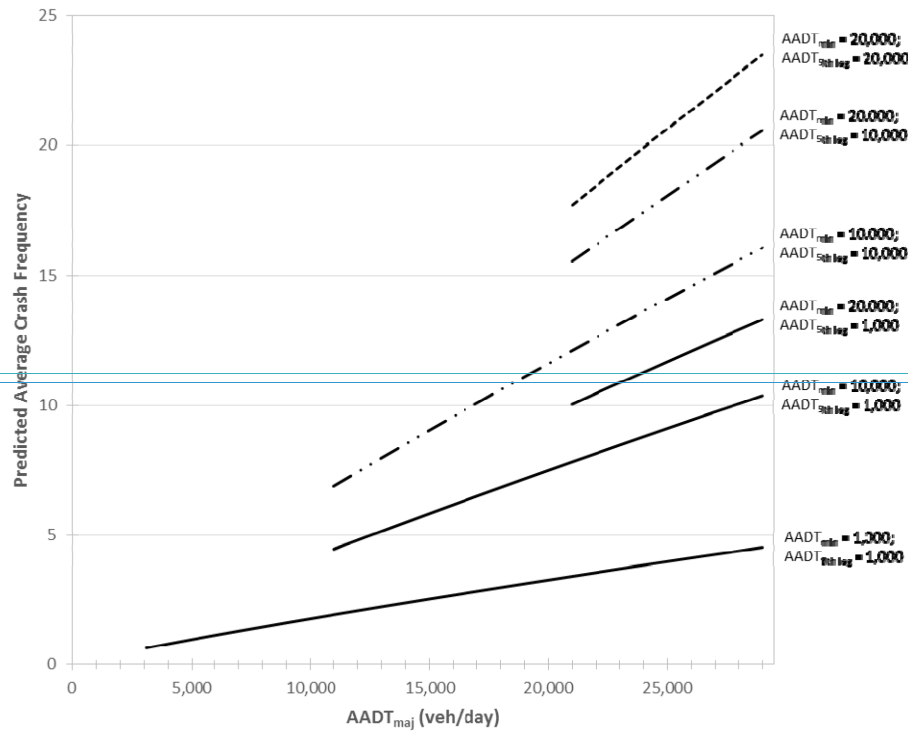


Figure 12-XD. Graphical Form of the Intersection SPF for Total Multiple-Vehicle Collisions at Four-Leg Signalized Intersections on High-Speed Arterials (4SG-HS) (from Equation 12-21 and Table 12-10)


25
20
15
10
5
0
0
5,000
10,000
15,000
20,000
25,000
Predicted Average Crash Frequency
AADT$_{maj}$ (veh/day)
AADT$_{min}$ = 20,000;
AADT$_{5th\ leg}$ = 20,000
AADT$_{min}$ = 20,000;
AADT$_{5th\ leg}$ = 10,000
AADT$_{min}$ = 10,000;
AADT$_{5th\ leg}$ = 10,000
AADT$_{min}$ = 20,000;
AADT$_{5th\ leg}$ = 1,000
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AADT$_{5th\ leg}$ = 1,000
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AADT$_{5th\ leg}$ = 1,000

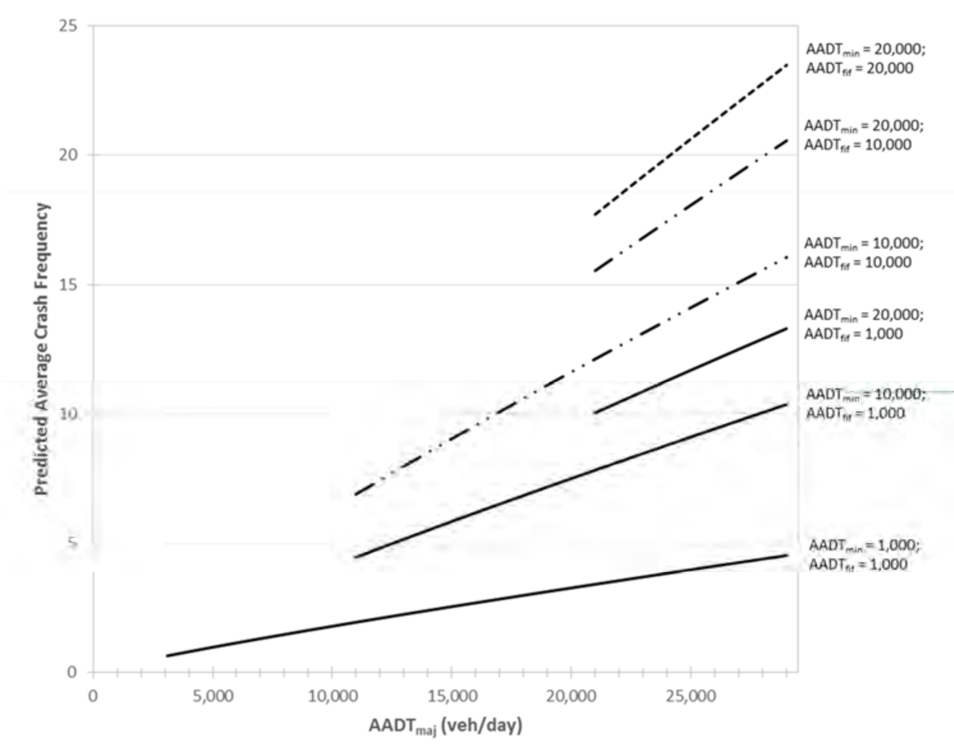


Figure 12-XE. Graphical Form of the Intersection SPF for Total Multiple-Vehicle Collisions at Five-Leg Signalized Intersections (5SG) (from Equation 12-EMVA and Table 12-10)

Table 12-11. Distribution of Multiple-Vehicle Collisions for Intersections by Collision Type

	Proportion of Crashes by Severity Level for Specific Intersections Types									
	3ST[a]		3ST-HS[b]		3STT[b]		3SG[a]		3SG-HS[b]	
Manner of Collision	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Rear-end collision	0.421	0.440	0.360	0.485	0.115	0.178	0.549	0.546	0.634	0.648
Head-on collision	0.045	0.023	0.023	0.021	0.115	0.068	0.038	0.020	0.029	0.004
Angle collision	0.343	0.262	0.473	0.317	0.577	0.411	0.280	0.204	0.232	0.165
Sideswipe	0.126	0.040	0.077	0.113	0.115	0.288	0.076	0.032	0.036	0.114
Other multiple-vehicle collisions	0.065	0.235	0.068	0.064	0.077	0.055	0.057	0.198	0.069	0.069

Source: [a] Based on HSIS data for California (2002–2006). [b] Based on data from NCHRP Project 17-68.

Table 12-11. Distribution of Multiple-Vehicle Collisions for Intersections by Collision Type (Continued)

	Proportion of Crashes by Severity Level for Specific Intersections Types									
	4ST[a]		4ST-HS[b]		4SG[a]		4SG-HS[b]		5SG[b]	
Manner of Collision	FI	PDO	FI	PDO	FI	PDO	FI	PDO	FI	PDO
Rear-end collision	0.338	0.374	0.167	0.315	0.450	0.483	0.560	0.6576 ~~1~~	0.425	0.431
Head-on collision	0.041	0.030	0.051	0.019	0.049	0.030	0.028	0.009	0.065	0.024
Angle collision	0.440	0.335	0.653	0.426	0.347	0.244	0.303	0.1762 ~~07~~	0.321	0.238
Sideswipe	0.121	0.044	0.028	0.142	0.099	0.032	0.026	0.094	0.049	0.169
Other multiple-vehicle collisions	0.060	0.217	0.102	0.098	0.055	0.211	0.083	0.0642 ~~9~~	0.139	0.139

Source: [a] Based on HSIS data for California (2002–2006). [b] Based on data from NCHRP Project 17-68.

Single-Vehicle Crashes
SPFs for single-vehicle crashes are applied as follows:

$$N_{bisv} = exp\left(a + b \times \ln\left(AADT_{maj}\right) + c \times \ln\left(AADT_{min}\right)\right) \qquad (12\text{-}24)$$

$$N_{bisv} = exp\ (\ a + f \times \ln(AADT_{total})\ ) \qquad (12\text{-ESVA})$$

$$N_{bisv} = exp\left(a + g \times ln(TEV_3)\right) \qquad (12\text{-ESVB})$$

Where:

$AADT_{total}$ = average daily traffic volume (vehicles/day) for major road and minor road approaches combined for three- and four-leg intersections (both directions of travel combined, = $AADT_{maj} + AADT_{min}$) or for major road, minor road, and fifth road approaches combined for five-leg intersections (both directions of travel combined, = $AADT_{maj} + AADT_{min} + AADT_{fifth}$);

TEV_3 = total entering volume at a three-leg intersection, see Equation 12-EB (vehicles per day); and

f and g = regression coefficient.

Table 12-12 presents the values of the coefficients *a, b, c, f, and g* used in applying Equations 12-24, 12-ESVA, and 12-ESVB for total, FI, and PDO severity levels. The SPF overdispersion parameter, *k*, is also presented in Table 12-12. Predicted crash frequencies for the three different severity levels can be estimated using the coefficients in Table 12-12. However, because the SPFs were developed independently, it is unlikely that the sum of the FI and PDO crash frequencies will equal the total crash frequency. To obtain consistency between the estimated values requires adjustments as follows.

For 3ST, 3ST-HS, 3SG, 3SG-HS, 4ST, 4ST-HS, 4SG, 4SG-HS, and 5SG intersection types, Table 12-12 presents the values of the coefficients and factors used in Equations 12-24~~,~~ and 12-ESVA~~, and 12-ESVB~~ for each roadway type. Equations 12-24 and ~~,~~12-ESVA~~, and 12-ESVB~~ are~~is~~ first applied to determine N_{bisv} using the coefficients for total crashes in Table 12-12. N_{bisv} is then divided into components by severity level, $N_{bisv(FI)}$ for fatal-and-injury crashes and $N_{bisv(PDO)}$ for property-damage-only crashes. Preliminary values of $N_{bisv(FI)}$ and $N_{bisv(PDO)}$, designated as $N'_{bisv(FI)}$ and $N'_{bisv(PDO)}$ in Equations 12-25 ~~and 12-ESVPROPA~~, are determined with Equations 12-24~~,~~ and 12-ESVA~~, and 12-ESVB~~ using the coefficients for fatal-and-injury and property-damage-only crashes, respectively, in Table 12-12. Using Equations 12-25 and 12-26, ~~Equations 12-ESVPROPA and 12-ESVPROPB are used only for~~

~~3STT intersections, while Equations 12-22 and 12-23 are used for all other intersection types. The following~~ adjustments are then made to assure that $N_{bisv(FI)}$ and $N_{bisv(PDO)}$ sum to $N_{bisv(total)}$.

$$N_{bisv(FI)} = N_{bisv(\text{total})} \times \left(\frac{N'_{bisv(FI)}}{N'_{bisv(FI)} + N'_{bisv(PDO)}} \right) \tag{12-25}$$

$$N_{bisv(PDO)} = N_{bisv(\text{total})} - N_{bisv(FI)} \tag{12-26}$$

For 3STT, since there are no models for fatal-and-injury single-vehicle crashes, using the coefficients for total crashes in Table 12-12, Equation 12-ESVB is applied to determine $N_{bisv(total)}$. $N_{bisv(total)}$ is then multiplied by the CMF value for horizontal curves for total single-vehicle crashes ($CMF_{7i,sv,total}$) to adjust for actual conditions (see Equation ESVTOTADJ). $N_{bisv(total),adj}$ is then multiplied by the proportion of fatal-and-injury crashes to obtain an estimate for fatal-and-injury single-vehicle crashes $N_{bisv(FI),adj}$ (see Equation 12-ESVFIADJ) for actual conditions. Using Equations 12-ESVTOTADJ, 12-ESVFIADJ, and 12-ESVPDOADJ, adjustments are made so that $N_{bisv(FI),adj}$ and $N_{bisv(PDO),adj}$ sum to $N_{bisv(total),adj}$:

$$N_{bisv(total),adj} = N_{bisv(total)} \times CMF_{7i,sv,tot} \tag{12-ESVTOTADJ}$$

$$N_{bisv(FI),adj} = N_{bisv(total),adj} \times f_{bisv} \tag{12-ESVFIADJ}$$

$$N_{bisv(PDO),adj} = N_{bisv(total),adj} - N_{bisv(FI),adj} \tag{12-ESVPDOADJ}$$

Where:

f_{bisv} = proportion of fatal-and-injury crashes for combined sites

The default value of f_{bisv} in Equation 12-ESVFIADJ is 0.33 for 3STT intersections. It is recommended that these default values be updated based on locally available data.

Table 12-12. SPF Coefficients for Single-Vehicle Crashes at Intersections

	Coefficients Used in Equations 12-24, 12-ESVA, 12-ESVB					
Intersection Type	**Intercept (a)**	**AADT$_{maj}$ (b)**	**AADT$_{min}$ (c)**	**AADT$_{total}$ (f)**	**TEV$_3$ (g)**	**Overdispersion Parameter (*k*)**
Total Crashes						
3ST	−6.81	0.16	0.51			1.14
3ST-HS	-12.28	0.92	0.36			0.69
3STT	-5.40				0.46	0.50
3SG	−9.02	0.42	0.40			0.36
3SG-HS	-6.77	0.60	0.04[a]			0.57
4ST	−5.33	0.33	0.12			0.65
4ST-HS	-7.63	0.44	0.39			1.12
4SG	−10.21	0.68	0.27			0.36
4SG-HS	-6.04	0.52	0.10			0.55
5SG	-13.94			1.23		0.34
Fatal-and-Injury Crashes						
3ST[b]						
3ST-HS	-14.00	0.79[a]	0.53			2.10
3STT[b]						
3SG	−9.75	0.27	0.51			0.24
3SG-HS	-7.41	0.63	-0.09 [a]			1.04
4ST[b]						
4ST-HS	-13.96	0.91	0.45			1.64
4SG	-9.25	0.43	0.29			0.09
4SG-HS	-9.89	0.83	0.04 [a]			0.98
5SG	-20.72			1.76		0.15
Property-Damage-Only Crashes						
3ST	−8.36	0.25	0.55			1.29
3ST-HS	-12.07	0.92	0.31			0.75
3STT	-6.68				0.57	0.61
3SG	−9.08	0.45	0.33			0.53
3SG-HS	-7.54	0.61	0.08[a]			0.74
4ST	−7.04	0.36	0.25			0.54
4ST-HS	-6.15	0.24[a]	0.41			1.40
4SG	−11.34	0.78	0.25			0.44
4SG-HS	-5.10	0.37	0.11			0.84
5SG	-12.25			1.03		0.27

[a] Coefficients are not statistically significant.

[b] ~~Note:~~ Where no models are available, Equation 12-27 is used for 3ST and 3ST and Equation 12-ESVFI is used for 3STT.

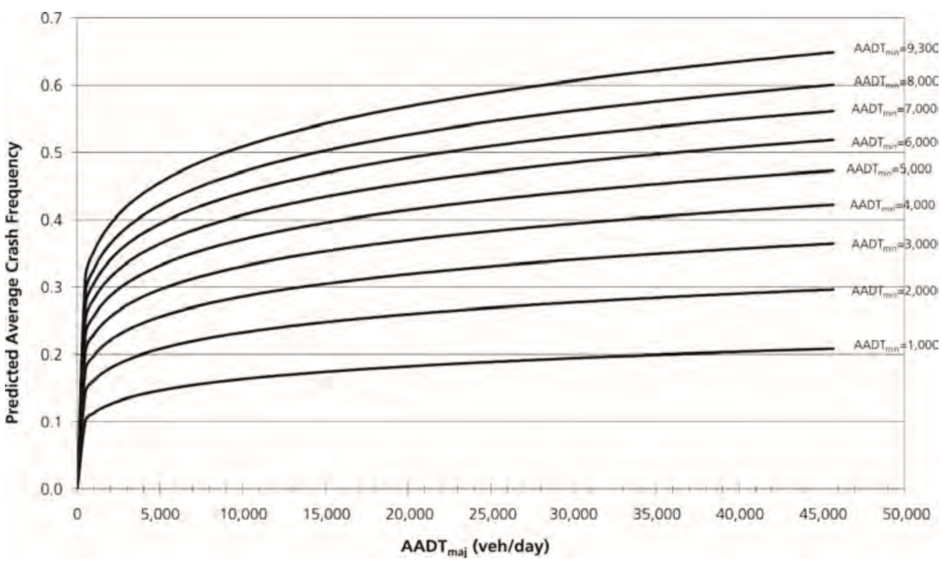


Figure 12-14. Graphical Form of the Intersection SPF for Total Single-Vehicle Crashes at~~on~~ Three-Leg Intersections with Minor-Road Stop Control (3ST) (from Equation 12-24 and Table 12-12)

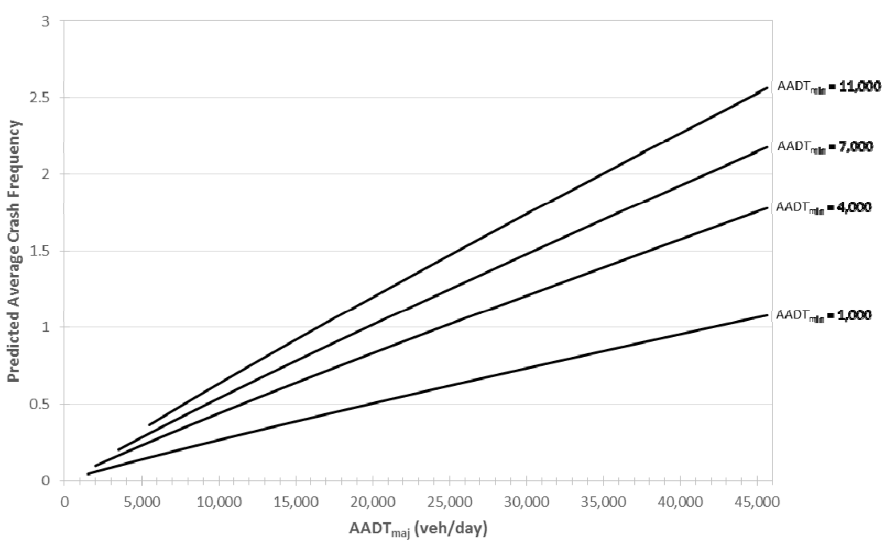


Figure 12-XF. Graphical Form of the Intersection SPF for Total Single-Vehicle Crashes at Three-Leg Intersections on High-Speed Arterials with Minor-Road Stop Control (3ST-HS) (from Equation 12-24 and Table 12-12)

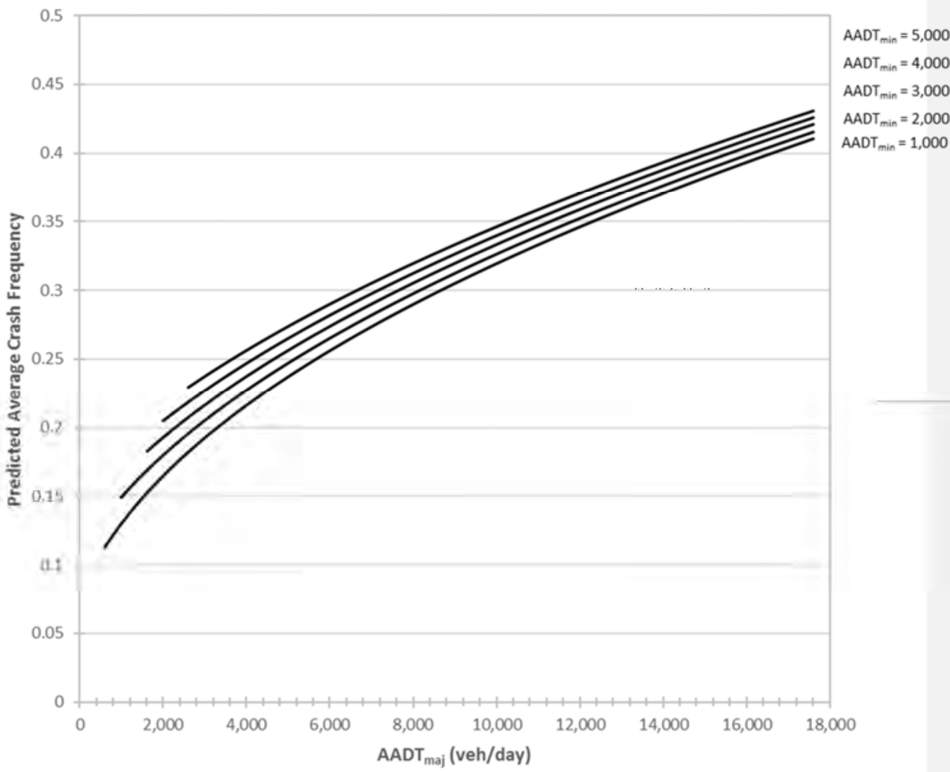


Figure 12-XFi. Graphical Form of the Intersection SPF for Total Single-Vehicle Crashes at Three-Leg Turning Intersections (3STT) (from Equation 12-ESVB and Table 12-12)

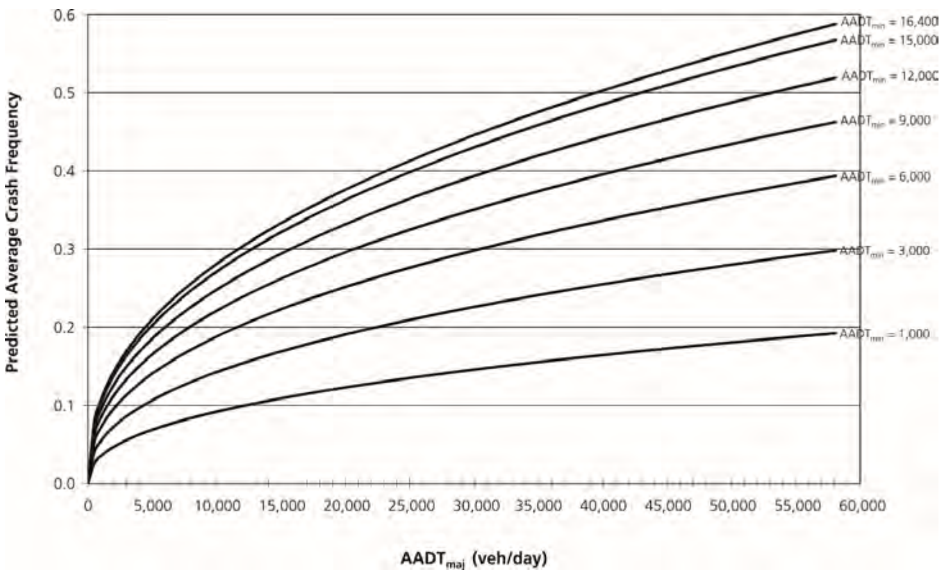


Figure 12-15. Graphical Form of the Intersection SPF for Total -Single-Vehicle Crashes at~~on~~ Three-Leg Signalized Intersections (3SG) (from Equation 12-24 and Table 12-12)

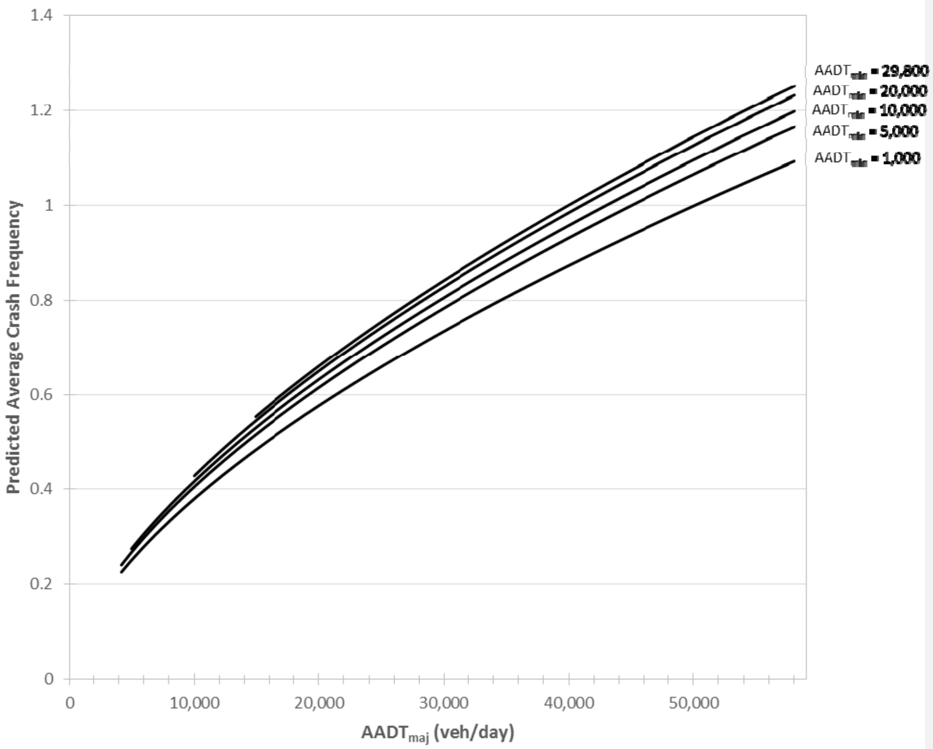


Figure 12-XG. Graphical Form of the Intersection SPF for Total Single-Vehicle Crashes at Three-Leg Signalized Intersections on High-Speed Arterials (3SG-HS) (from Equation 12-24 and Table 12-12)

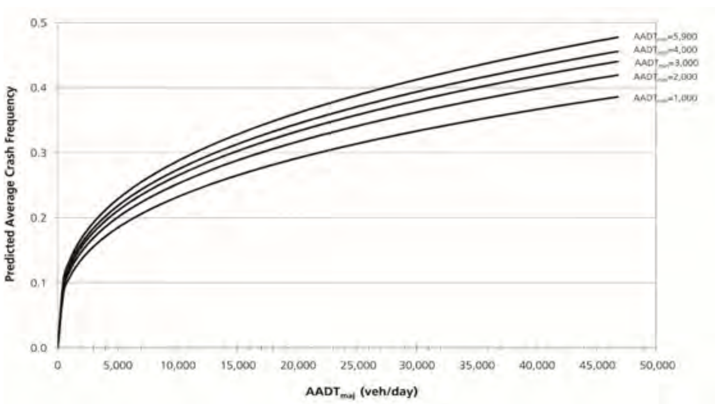


Figure 12-16. Graphical Form of the Intersection SPF for Total Single-Vehicle Crashes at~~on~~ Four-Leg Stop Controlled Intersections (4ST) (from Equation 12-24 and Table 12-12)

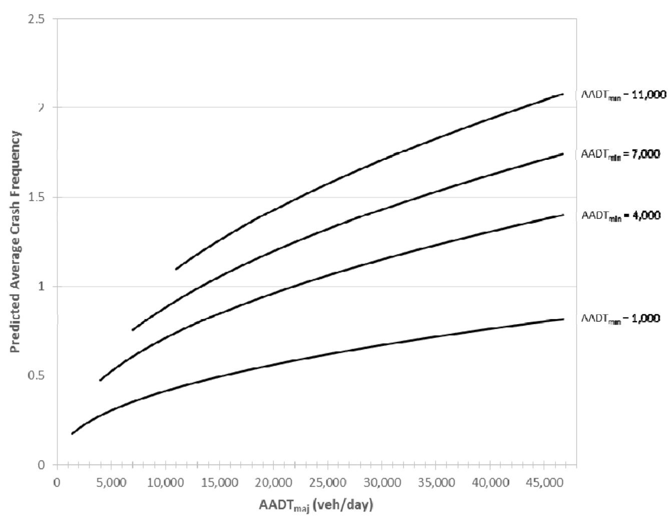


Figure 12-XH. Graphical Form of the Intersection SPF for Total Single-Vehicle Crashes at Four-Leg Intersections on High-Speed Arterials with Minor-Road Stop Control (4ST-HS) (from Equation 12-24 and Table 12-12)

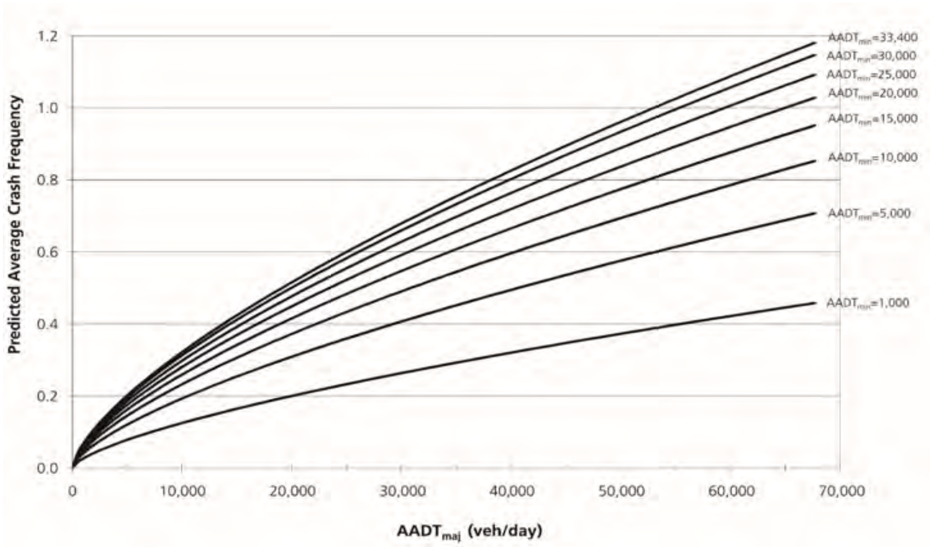


Figure 12-17. Graphical Form of the Intersection SPF for Total Single-Vehicle Crashes at~~on~~ Four-Leg Signalized Intersections (4SG) (from Equation 12-24 and Table 12-12)

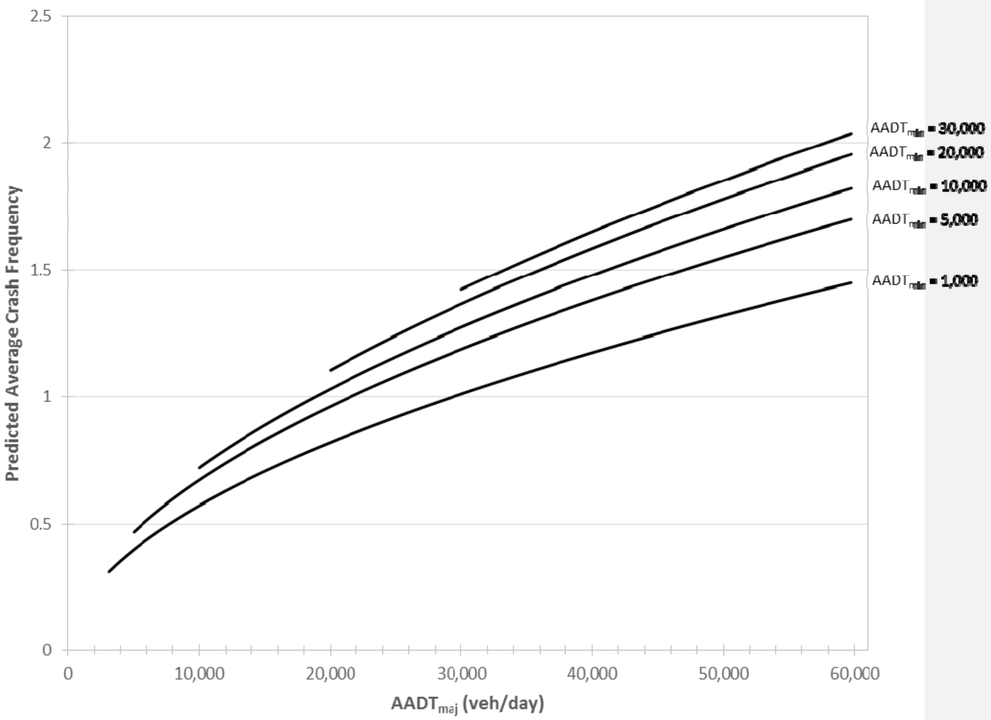
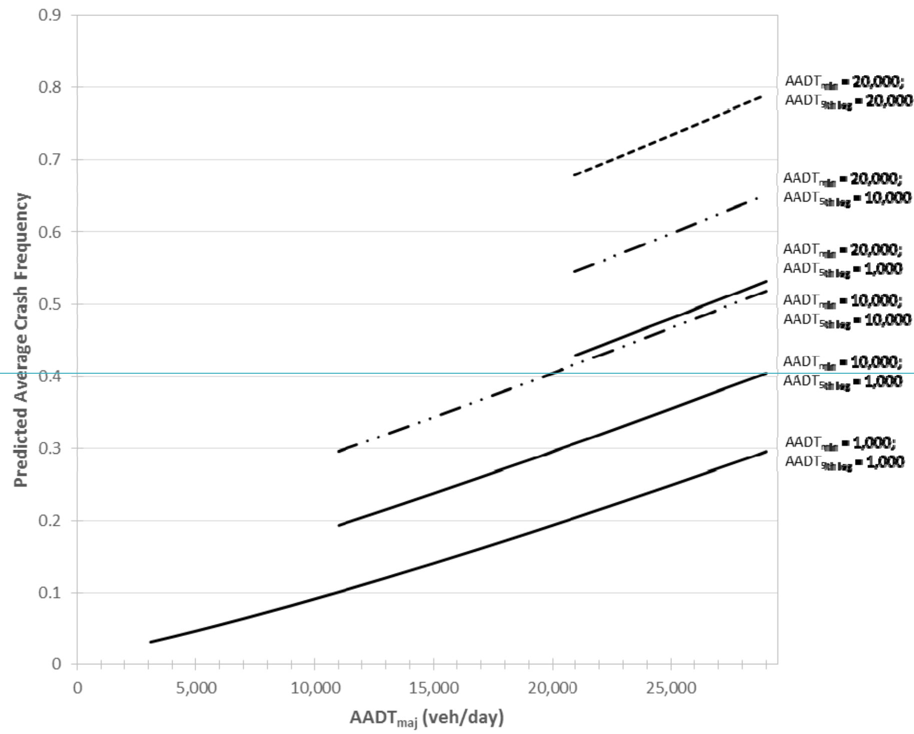


Figure 12-XI. Graphical Form of the Intersection SPF for Total Single-Vehicle Crashes at Four-Leg Signalized Intersections on High-Speed Arterials (4SG-HS) (from Equation 12-24 and Table 12-12)


0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Predicted Average Crash Frequency
0
5,000
10,000
15,000
20,000
25,000
$AADT_{maj}$ (veh/day)
$AADT_{min}$ = 20,000; $AADT_{5th\ leg}$ = 20,000
$AADT_{min}$ = 20,000; $AADT_{5th\ leg}$ = 10,000
$AADT_{min}$ = 20,000; $AADT_{5th\ leg}$ = 1,000
$AADT_{min}$ = 10,000; $AADT_{5th\ leg}$ = 10,000
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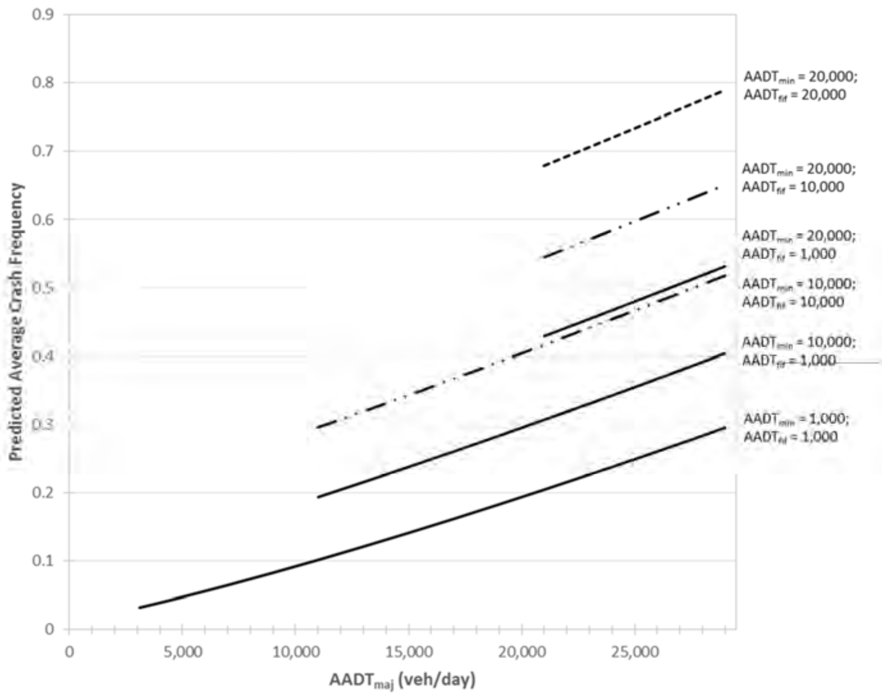

Figure 12-XJ. Graphical Form of the Intersection SPF for Total Single-Vehicle Crashes at Five-Leg Signalized Intersections (5SG) (from Equation 12-ESVA and Table 12-12)

The proportions in Table 12-13 are used to separate $N_{bisv(FI)}$ and $N_{bisv(PDO)}$ into components by crash type.

Table 12-13. Distribution of Single-Vehicle Crashes for Intersection by Collision Type

	Proportion of Crashes by Severity Level for Specific Road Types									
	3ST[a]		3ST-HS[b]		3STT[b]		3SG[a]		3SG-HS[b]	
Crash Type	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Collision with parked vehicle	0.001	0.003	0	0	0	0	0.001	0.001	0	0
Collision with animal	0.003	0.018	0	0.009	0	0.038	0.001	0.003	0	0
Collision with fixed object	0.762	0.834	0.186	0.257	0.750	0.846	0.653	0.895	0.552	0.411
Collision with other object	0.090	0.092	0	0	0	0.058	0.091	0.069	0	0
Other single-vehicle collision	0.039	0.023	0.674	0.681	0.167	0.058	0.045	0.018	0.310	0.534
Noncollision	0.105	0.030	0.140	0.053	0.083	0	0.209	0.014	0.138	0.055
~~Collision with parked vehicle~~	~~0.001~~	~~0.001~~	~~0~~	~~0~~	~~0.001~~	~~0.001~~	~~0~~	~~0~~	~~0~~	~~0.055~~
~~Collision with animal~~	~~0.001~~	~~0.026~~	~~0~~	~~0.019~~	~~0.002~~	~~0.002~~	~~0~~	~~0.003~~	~~0~~	~~0~~
~~Collision with fixed object~~	~~0.679~~	~~0.847~~	~~0.109~~	~~0.243~~	~~0.744~~	~~0.870~~	~~0.240~~	~~0.422~~	~~0.310~~	~~0.205~~
~~Collision with other object~~	~~0.089~~	~~0.070~~	~~0~~	~~0.019~~	~~0.072~~	~~0.070~~	~~0~~	~~0.006~~	~~0~~	~~0.027~~
~~Other single-vehicle collision~~	~~0.051~~	~~0.007~~	~~0.739~~	~~0.701~~	~~0.040~~	~~0.023~~	~~0.620~~	~~0.520~~	~~0.621~~	~~0.712~~
~~Noncollision~~	~~0.179~~	~~0.049~~	~~0.152~~	~~0.019~~	~~0.141~~	~~0.034~~	~~0.140~~	~~0.049~~	~~0.069~~	~~0~~

Source: [a] Based on HSIS data for California (2002–2006). [b] Based on data from NCHRP Project 17-68.

Table 12-13. Distribution of Single-Vehicle Crashes for Intersection by Collision Type (Continued)

	Proportion of Crashes by Severity Level for Specific Road Types									
	4ST[a]		4ST-HS[b]		4SG[a]		4SG-HS[b]		5SG[b]	
Crash Type	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Collision with parked vehicle	0.001	0.001	0	0	0.001	0.001	0	0	0	0.055
Collision with animal	0.001	0.026	0	0.019	0.002	0.002	0	0.003	0	0
Collision with fixed object	0.679	0.847	0.109	0.243	0.744	0.870	0.240	0.422	0.310	0.205
Collision with other object	0.089	0.070	0	0.019	0.072	0.070	0	0.006	0	0.027
Other single-vehicle collision	0.051	0.007	0.739	0.701	0.040	0.023	0.620	0.520	0.621	0.712
Noncollision	0.179	0.049	0.152	0.019	0.141	0.034	0.140	0.049	0.069	0

Source: [a] Based on HSIS data for California (2002–2006). [b] Based on data from NCHRP Project 17-68.

Since there are no models for fatal-and-injury crashes at three- and four-leg stop-controlled intersections ~~and three-leg turning intersections~~ in Table 12-12, Equation 12-25 is replaced with Equation 12-27 ~~for three- and four-leg~~

~~stop-controlled intersections and is replaced with Equation 12-ESVFI for three-leg turning intersections.~~ ~~the following equation in these cases:~~

$$N_{bisv(FI)} = N_{bisv(\text{total})} \times f_{bisv} \quad (12\text{-}27)$$

~~Where:~~

~~f_{bisv} = proportion of fatal-and-injury crashes for combined sites.~~

~~$N_{bisv(FI)} = N_{bisv(total)} \times CMF_{7i,sv,tot} \times f_{bisv}$ (12-ESVFI)~~

The default value of f_{bisv} in Equation 12-27 is 0.31 for 3ST and, ~~and~~ 0.28 for 4ST~~, and 0.33 for 3STT~~ intersections. It is recommended that these default values be updated based on locally available data.

Multiple- and Single-Vehicle Crashes (aST Only)

SPFs for multiple- and single-vehicle crashes are applied for three- and four-leg all-way stop-controlled intersections as follows:

$$N_{bi\ mv+sv} = exp\,[a + b \times ln(AADT_{maj}) + c \times ln(AADT_{min})] \quad (12\text{-MV+SVA})$$

$$N_{bi\ mv+sv} = exp\,[a + f \times ln(AADT_{total})] \quad (12\text{- MV+SVB})$$

Where:

$N_{bi\ mv+sv}$ = predicted average number of multiple-and single-vehicle collisions combined for base conditions.

Table 12-XA presents the values of the coefficients and factors used in Equations 12-MV+SVA and 12-MV+SVB for each intersection type.

Table 12-XA. SPF Coefficients for Multiple- and Single-Vehicle Crashes at Three- and Four-Leg All-Way Stop-Controlled Intersections

Intersection Type	Coefficients Used in Equations 12-MV+SVA and 12-MV+SVB~~24~~ Intercept (a)	AADT$_{maj}$ (b)	AADT$_{min}$ (c)	AADT$_{total}$ (f)	Overdispersion Parameter (*k*)
Fatal-and-Injury Crashes					
3aST	-8.19	--	--	0.77	0.07
4aST	-11.62	0.92	0.32	--	0.66
Property-Damage-Only Crashes					
3aST	-7.94	--	--	0.85	0.37
4aST	-8.58	0.64	0.36	--	0.78

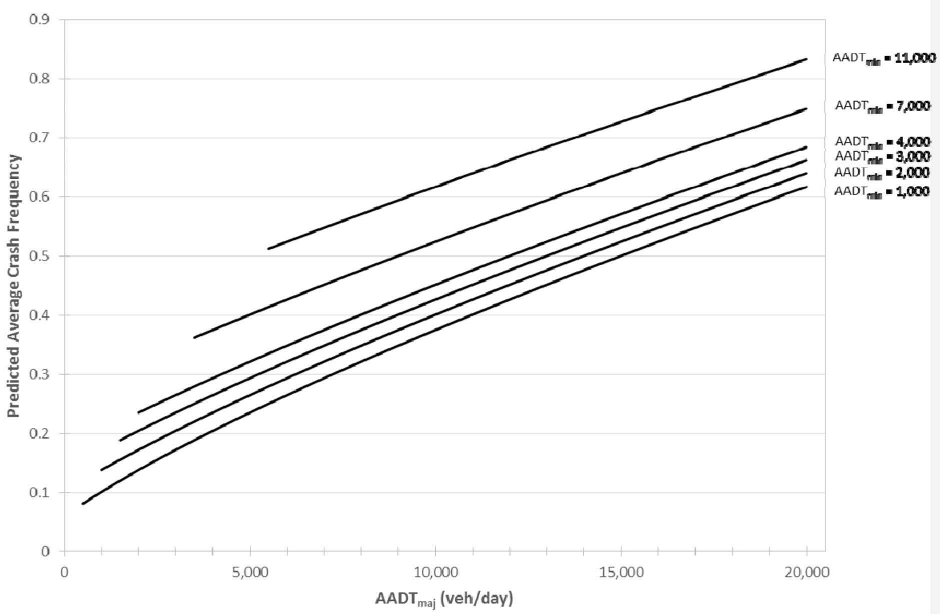

Figure 12-XK. Graphical Form of the Intersection SPF for FI Multiple- and Single-Vehicle Crashes at Three-Leg Intersections with All-Way Stop Control (3aST) (from Equation 12-MV+SVB and Table 12-XA)

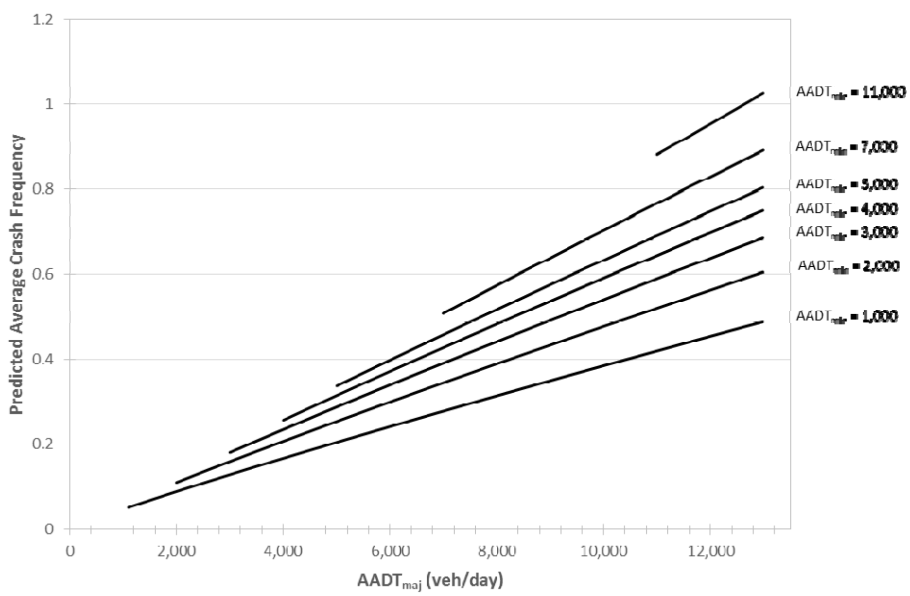

Figure 12-XL. Graphical Form of the Intersection SPF for FI Multiple- and Single-Vehicle Crashes at Four-Leg Intersections with All-Way Stop Control (4aST) (from Equation 12-MV+SVA and Table 12-XA)

The proportions in Table 12-XB are used to separate $N_{bi\ mv+sv\ (FI)}$ and $N_{bi\ mv+sv\ (PDO)}$ into components by crash type.

Table 12-XB. Distribution of Multiple- and Single-Vehicle Crashes for Three- and Four-Leg All-Way Stop-Controlled Intersection by Collision Type

	Proportion of Crashes by Severity Level for Specific Road Types			
	3aST		4aST	
Crash Type	FI	PDO	FI	PDO
Multiple-vehicle crashes				
Angle collision	16.7	24.1	53.6	48.1
Head-on collision	2.4	0.0	1.1	0.4
Rear-end collision	42.9	38.3	23.3	30.2
Sideswipe collision	2.4	6.0	1.5	4.6
Other multiple-vehicle collision	4.8	11.3	12.4	8.5
Single-vehicle crashes				
Single-vehicle noncollision	4.8	0.0	0.4	0.1
Other single-vehicle collision	26.2	20.3	7.8	8.1

Source: Based on data from NCHRP Project 17-68.

SPFs for Vehicle-Pedestrian Collisions

Separate SPFs are provided for estimation of the number of vehicle-pedestrian collisions at signalized and unsignalized intersections.

SPFs for Three- and Four-Leg Signalized Intersections

The number of vehicle-pedestrian collisions per year at a three- or four-leg signalized intersection is estimated with a SPF and a set of CMFs that apply specifically to vehicle-pedestrian collisions. The model for estimating vehicle-pedestrian collisions at three- and four-leg signalized intersections is:

$$N_{pedi} = N_{pedbase} \times CMF_{1p} \times CMF_{2p} \times CMF_{3p} \quad (12\text{-}28)$$

Where:

$N_{pedbase}$ = predicted number of vehicle-pedestrian collisions per year for base conditions at signalized intersections; and

$CMF_{1p}...CMF_{3p}$ = crash modification factors for vehicle-pedestrian collisions at signalized intersections.

The SPF for vehicle-pedestrian collisions at signalized intersections is:

$$N_{pedbase} = \exp\left(a + b \times \ln\left(AADT_{\text{total}}\right) + c \times \ln\left(\frac{AADT_{min}}{AADT_{maj}}\right) + d \times \ln\left(PedVol\right) + e \times n_{lanesx}\right) \quad (12\text{-}29)$$

Where:

$AADT_{\text{total}}$ = sum of the average daily traffic volumes (vehicles per day) for the major and minor roads ($= AADT_{maj} + AADT_{min}$);

$PedVol$ = sum of daily pedestrian volumes (pedestrians/day) crossing all intersection legs;

n_{lanesx} = maximum number of traffic lanes crossed by a pedestrian in any crossing maneuver at the intersection considering the presence of refuge islands; and

a, b, c, d, e = regression coefficients.

Determination of values for $AADT_{maj}$ and $AADT_{min}$ is addressed in the discussion of Step 3. Only pedestrian crossing maneuvers immediately adjacent to the intersection (e.g., at a marked crosswalk or along the extended path of any sidewalk present) are considered in determining the pedestrian volumes. Table 12-14 presents the values of the coefficients *a*, *b*, *c*, *d*, and *e* used in applying Equation 12-29.

The coefficient values in Table 12-14 are intended for estimating total vehicle-pedestrian collisions. All vehicle-pedestrian collisions are considered to be fatal-and-injury crashes.

The application of Equation 12-29 requires data on the total pedestrian volumes crossing the intersection legs. Reliable estimates will be obtained when the value of PedVol in Equation 12-29 is based on actual pedestrian volume counts. Where pedestrian volume counts are not available, they may be estimated using Table 12-15. Replacing the values in Table 12-15 with locally derived values is encouraged.

The value of n_{lanesx} in Equation 12-29 represents the maximum number of traffic lanes that a pedestrian must cross in any crossing maneuver at the intersection. Both through and turning lanes that are crossed by a pedestrian along the crossing path are considered. If the crossing path is broken by an island that provides a suitable refuge for the pedestrian so that the crossing may be accomplished in two (or more) stages, then the number of lanes crossed in each stage is considered separately. To be considered as a suitable refuge, an island must be raised or depressed; a flush or painted island is not treated as a refuge for purposes of determining the value of nlanesx.

Table 12-14. SPFs for Vehicle-Pedestrian Collisions at Three- and Four-Leg Signalized Intersections

	Coefficients used in Equation 12-29					
Intersection Type	Intercept (a)	AADTtotal (b)	$AADT_{min}/AADT_{maj}$ (c)	PedVol (d)	n_{lanesx} (e)	Overdispersion Parameter (*k*)
Total crashes						
3SG	–6.60	0.05	0.24	0.41	0.09	0.52
4SG	–9.53	0.40	0.26	0.45	0.04	0.24

Table 12-15. Estimates of Pedestrian Crossing Volumes Based on General Level of Pedestrian Activity

	Estimate of PedVol (pedestrians/day) for Use in Equation 12-29	
General Level of Pedestrian Activity	3SG Intersections	4SG Intersections
High	1,700	3,200
Medium-high	750	1,500
Medium	400	700
Medium-low	120	240
Low	20	50

SPFs for Minor Road Stop-Controlled Intersections, All-Way Stop-Controlled Intersections, Three-Leg Stop-Controlled Turning Intersections, Intersections on High-Speed Arterials, and Five-Leg Signalized Intersections

The number of vehicle-pedestrian collisions per year for a minor road stop-controlled intersection, an all-way stop-controlled intersection, a three-leg stop-controlled turning intersection, an intersection on a high-speed arterial, or a five-leg signalized intersection is estimated as:

$$N_{pedi} = N_{bi} \times f_{pedi} \tag{12-30}$$

Where:

f_{pedi} = pedestrian crash adjustment factor for intersections.

The value of N_{bi} used in Equation 12-30 is that determined with Equation 12-6.

Table 12-16 presents the values of f_{pedi} for use in Equation 12-30. All vehicle-pedestrian collisions are considered to be fatal-and-injury crashes. The values of f_{pedi} are likely to depend on the climate and walking environment in particular states or communities. HSM users are encouraged to replace the values in Table 12-16 with suitable values for their own state or community through the calibration process (see Part C, Appendix A).

Table 12-16. Pedestrian Crash Adjustment Factors for Minor Road Stop-Controlled Intersections, All-Way Stop-Controlled Intersections, Three-Leg Stop-Controlled Turning Intersections, Intersections on High-Speed Arterials, and Five-Leg Signalized Intersections

Intersection Type	Pedestrian Crash Adjustment Factor (f_{pedi})
3ST [a]	0.021
3ST-HS[b]	0.004
3aST[b]	0.017
3STT	0.011
3SG-HS[b]	0.002
4ST [a]	0.022
4ST-HS[b]	0.004
4aST[b]	0.015
4SG-HS[b]	0.003
5SG[b]	0.031

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All pedestrian collisions resulting from this adjustment factor are treated as fatal-and-injury crashes and none as property-damage-only crashes.
Source: [a] Based on HSIS data for California (2002–2006). [b] Based on data from NCHRP Project 17-68.

Vehicle-Bicycle Collisions

The number of vehicle-bicycle collisions per year for an intersection is estimated as:

$$N_{bikei} = N_{bi} \times f_{bikei} \tag{12-31}$$

Where:

f_{bikei} = bicycle crash adjustment factor for intersections.

The value of N_{bi} used in Equation 12-31 is determined with Equation 12-6.

Table 12-17 presents the values of f_{bikei} for use in Equation 12-31. All vehicle-bicycle collisions are considered to be fatal-and-injury crashes. The values of f_{bikei} are likely to depend on the climate and bicycling environment in particular states or communities. HSM users are encouraged to replace the values in Table 12-17 with suitable values for their own state or community through the calibration process (see Part C, Appendix A).

Table 12-17. Bicycle Crash Adjustment Factors for Minor Road Stop-Controlled Intersections, All-Way Stop-Controlled Intersections, Three-Leg Stop-Controlled Turning Intersections, Intersections on High-Speed Arterials, and Five-Leg Signalized Intersections~~for Intersections~~

Intersection Type	Bicycle Crash Adjustment Factor (f_{bikei})
3ST[a]	0.016
3ST-HS[b]	0
3aST[b]	0.011
3STT	0
3SG[a]	0.011
3SG-HS[b]	0.001
4ST[a]	0.018
4ST-HS[b]	0
4aST[b]	0.011
4SG[a]	0.015
4SG-HS[b]	0.001
5SG[b]	0.031

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All bicycle collisions resulting from this adjustment factor are treated as fatal-and-injury crashes and none as property-damage-only crashes. Source: [a] Based on HSIS data for California (2002–2006). [b] Based on data from NCHRP Project 17-68.

12.7. Crash Modification Factors

In Step 10 of the predictive method shown in Section 12.4, crash modification factors are applied to the selected safety performance function (SPF), which was selected in Step 9. SPFs provided in Chapter 12 are presented in Section 12.6. A general overview of crash modification factors (CMFs) is presented in Section 3.5.3. The Part C—Introduction and Applications Guidance provides further discussion on the relationship of CMFs to the predictive method. This section provides details of the specific CMFs applicable to the SPFs presented in Section 12.6.

Crash modification factors (CMFs) 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 12 shown in Equation 12-1. The CMF 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 a CMF with a value greater than 1.00; any feature associated with lower crash frequency than the base condition has a CMF with a value less than 1.00.

The CMFs used in Chapter 12 are consistent with the CMFs in Part D, although they have, in some cases, been expressed in a different form to be applicable to the base conditions of the SPFs. The CMFs presented in Chapter 12 and the specific SPFs which they apply to are summarized in Table 12-18.

Table 12-18. Summary of CMFs in Chapter 12 and the Corresponding SPFs

Applicable SPF	CMF	CMF Description	CMF Equations and Tables
Roadway Segments	CMF_{1r}	On-Street Parking	Equation 12-32 and Table 12-19
	CMF_{2r}	Roadside Fixed Objects	Equation 12-33 and Tables 12-20 and 12-21
	CMF_{3r}	Median Width	Table 12-22
	CMF_{4r}	Lighting	Equation 12-34 and Table 12-23
	CMF_{5r}	Automated Speed Enforcement	See text
Multiple-Vehicle Collisions and Single-Vehicle Crashes at Intersections	CMF_{1i}	Intersection Left-Turn Lanes	Table 12-24
	CMF_{2i}	Intersection Left-Turn Signal Phasing	Table 12-25
	CMF_{3i}	Intersection Right-Turn Lanes	Table 12-26
	CMF_{4i}	Right-Turn-on-Red	Equation 12-35
	CMF_{5i}	Lighting	Equation 12-36 and Table 12-27
	CMF_{6i}	Red-Light Cameras	Equations 12-37, 12-38, 12-39
	~~CMF_{6i}~~ CMF_{7i}	~~Red-Light Cameras~~Horizontal Curve	Equation~~s~~ 12-~~37, 12-38, 12-39~~CMF and Table 12-CMF
Vehicle-Pedestrian Collisions at Signalized Intersections	CMF_{1p}	Bus Stops	Table 12-28
	CMF_{2p}	Schools	Table 12-29
	CMF_{3p}	Alcohol Sales Establishments	Table 12-30

12.7.1. Crash Modification Factors for Roadway Segments

The CMFs for geometric design and traffic control features of urban and suburban arterial roadway segments are presented below. These CMFs are determined in Step 10 of the predictive method and used in Equation 12-3 to adjust the SPF for urban and suburban arterial roadway segments to account for differences between the base conditions and the local site conditions.

***CMF_{1r}*—On-Street Parking**
The CMF for on-street parking, where present, is based on research by Bonneson (1). The base condition is the absence of on-street parking on a roadway segment. The CMF is determined as:

$$CMF_{1r} = 1 + p_{pk} \times \left(f_{pk} - 1.0 \right) \tag{12-32}$$

Where:

CMF_{1r} = crash modification factor for the effect of on-street parking on total crashes;

f_{pk} = factor from Table 12-19;

p_{pk} = proportion of curb length with on-street parking = (0.5 L_{pk}/L); and

L_{pk} = sum of curb length with on-street parking for both sides of the road combined (miles); and

L = length of roadway segment (miles).

This CMF applies to total roadway segment crashes.

The sum of curb length with on-street parking (L_{pk}) can be determined from field measurements or video log review to verify parking regulations. Estimates can be made by deducting from twice the roadway segment length allowances for intersection widths, crosswalks, and driveway widths.

Table 12-19. Values of f_{pk} Used in Determining the Crash Modification Factor for On-Street Parking

	Type of Parking and Land Use			
	Parallel Parking		Angle Parking	
Road Type	Residential/Other	Commercial or Industrial/Institutional	Residential/Other	Commercial or Industrial/Institutional
2U	1.465	2.074	3.428	4.853
3T	1.465	2.074	3.428	4.853
4U	1.100	1.709	2.574	3.999
4D	1.100	1.709	2.574	3.999
5T	1.100	1.709	2.574	3.999

CMF_{2r}—Roadside Fixed Objects

The base condition is the absence of roadside fixed objects on a roadway segment. The CMF for roadside fixed objects, where present, has been adapted from the work of Zegeer and Cynecki (15) on predicting utility pole crashes. The CMF is determined with the following equation:

$$CMF_{2r} = f_{\text{offset}} \times D_{fo} \times p_{fo} + (1.0 - p_{fo}) \qquad (12\text{-}33)$$

Where:

CMF_{2r} = crash modification factor for the effect of roadside fixed objects on total crashes;

f_{offset} = fixed-object offset factor from Table 12-20;

D_{fo} = fixed-object density (fixed objects/mi) for both sides of the road combined; and

p_{fo} = fixed-object collisions as a proportion of total crashes from Table 12-21.

This CMF applies to total roadway segment crashes. If the computed value of CMF_{2r} is less than 1.00, it is set equal to 1.00. This can only occur for very low fixed object densities.

In estimating the density of fixed objects (D_{fo}), only point objects that are 4 inches or more in diameter and do not have breakaway design are considered. Point objects that are within 70 ft of one another longitudinally along the road are counted as a single object. Continuous objects that are not behind point objects are counted as one point object for each 70 ft of length. The offset distance (O_{fo}) shown in Table 12-20 is an estimate of the average distance from the edge of the traveled way to roadside objects over an extended roadway segment. If the average offset to fixed objects exceeds 30 ft, use the value of foffset for 30 ft. Only fixed objects on the roadside on the right side of the roadway in each direction of travel are considered; fixed objects in the roadway median on divided arterials are not considered.

Table 12-20. Fixed-Object Offset Factor

Offset to Fixed Objects (O_{fo}) (ft)	Fixed-Object Offset Factor (f_{offset})
2	0.232
5	0.133
10	0.087
15	0.068
20	0.057
25	0.049
30	0.044

Table 12-21. Proportion of Fixed-Object Collisions

Road Type	Proportion of Fixed-Object Collisions (p_{fo})
2U	0.059
3T	0.034
4U	0.037
4D	0.036
5T	0.016

CMF_{3r}—Median Width

A CMF for median widths on divided roadway segments of urban and suburban arterials is presented in Table 12-22 based on the work of Harkey et al. (6). The base condition for this CMF is a median width of 15 ft. The CMF applies to total crashes and represents the effect of median width in reducing cross-median collisions; the CMF assumes that nonintersection collision types other than cross-median collisions are not affected by median width. The CMF in Table 12-22 has been adapted from the CMF in Table 13-12 based on the estimate by Harkey et al. (6) that cross-median collisions represent 12.0 percent of crashes on divided arterials.

This CMF applies only to traversable medians without traffic barriers; it is not applicable to medians serving as TWLTLs (a CMF for TWLTLs is provided in Chapter 16). The effect of traffic barriers on safety would be expected to be a function of barrier type and offset, rather than the median width; however, the effects of these factors on safety have not been quantified. Until better information is available, a CMF value of 1.00 is used for medians with traffic barriers. The value of this CMF is 1.00 for undivided facilities.

Table 12-22. CMFs for Median Widths on Divided Roadway Segments without a Median Barrier (CMF_{3r})

Median Width (ft)	CMF
10	1.01
15	1.00
20	0.99
30	0.98
40	0.97
50	0.96
60	0.95
70	0.94
80	0.93
90	0.93
100	0.92

CMF_{4r}—Lighting

The base condition for lighting is the absence of roadway segment lighting ($CMF_{4r} = 1.00$). The CMF for lighted roadway segments is determined, based on the work of Elvik and Vaa (3), as:

$$CMF_{4r} = 1.0 - \left(p_{nr} \times \left(1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr}\right)\right) \tag{12-34}$$

Where:

CMF_{4r} = crash modification factor for the effect of roadway segment lighting on total crashes;

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

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

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

CMF_{4r} applies to total roadway segment crashes. Table 12-23 presents default values for the nighttime crash proportions p_{inr}, p_{pnr}, and p_{nr}. Replacement of the estimates in Table 12-23 with locally derived values is encouraged. If lighting installation increases the density of roadside fixed objects, the value of CMF_{2r} is adjusted accordingly.

Table 12-23. Nighttime Crash Proportions for Unlighted Roadway Segments

	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occur at Night
Roadway Segment Type	Fatal and Injury p_{inr}	PDO p_{pnr}	p_{nr}
2U	0.424	0.576	0.316
3T	0.429	0.571	0.304
4U	0.517	0.483	0.365
4D	0.364	0.636	0.410
5T	0.432	0.568	0.274

CMF_{5r}—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. Chapter 17 presents a CMF of 0.83 for the reduction of all types of fatal-and-injury crashes from implementation of automated speed enforcement. This CMF is assumed to apply to roadway segments between intersections with fixed camera sites where the camera is always present or where drivers have no way of knowing whether the camera is present or not. No information is available on the effect of automated speed enforcement on noninjury crashes. With the conservative assumption that automated speed enforcement has no effect on noninjury crashes, the value of the CMF for automated speed enforcement would be 0.95.

12.7.2. Crash Modification Factors for Intersections

The effects of individual geometric design and traffic control features of intersections are represented in the predictive models by CMFs. CMF_{1i} through CMF_{6i} are applied to multiple-vehicle collisions and single-vehicle crashes at intersections, but not to vehicle-pedestrian and vehicle-bicycle collisions, and are applicable to all severity levels. CMF_{7i} is only applicable to three-leg stop-controlled turning intersections and values differ by crash type (i.e., multiple- and single-vehicle collisions) and by severity. CMF_{1p} through CMF_{3p} are applied to vehicle-pedestrian collisions at three- and four-leg signalized intersections (3SG and 4SG), but not to multiple-vehicle collisions and single-vehicle crashes and not to other intersection types.

CMF_{1i}—Intersection Left-Turn Lanes

The base condition for intersection left-turn lanes is the absence of left-turn lanes on the intersection approaches. The CMFs for presence of left-turn lanes are presented in Table 12-24. These CMFs apply to installation of left-turn lanes on any approach to a signalized intersection but only on uncontrolled major-road approaches to stop-controlled intersections. These CMFs apply to intersections on arterials covering all speed ranges. The CMFs for installation of left-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF for 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 change in crash frequency for 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 Table 12-24. The CMFs in the table apply to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions). The CMFs for installation of left-turn lanes are based on research by Harwood et al. (7). A CMF of 1.00 is always used when no left-turn lanes are present. The CMFs in Table 12-24 are applicable to the following intersection types: 3ST, 3ST-HS, 3SG, 3SG-HS, 4ST, 4ST-HS, 4SG, and 4SG-HS.

Table 12-24. Crash Modification Factor (*CMF1i*) for Installation of Left-Turn Lanes on Intersection Approaches

		Number of Approaches with Left-Turn Lanes[a]			
Intersection Type	**Intersection Traffic Control**	**One Approach**	**Two Approaches**	**Three Approaches**	**Four Approaches**
Three-leg intersection	Minor-road stop control[b]	0.67	0.45	—	—
	Traffic signal	0.93	0.86	0.80	—
Four-leg intersection	Minor-road stop control[b]	0.73	0.53	—	—
	Traffic signal	0.90	0.81	0.73	0.66

[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.

CMF2i—Intersection Left-Turn Signal Phasing

The CMF for left-turn signal phasing is based on the results of work by Hauer (10), as modified in a study by Lyon et al. (11). Types of left-turn signal phasing considered include permissive, protected, protected/permissive, and permissive/protected. Protected/permissive operation is also referred to as a leading left-turn signal phase; permissive/protected operation is also referred to as a lagging left-turn signal phase. The CMF values are presented in Table 12-25. The base condition for this CMF is permissive left-turn signal phasing. This CMF applies to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions) and is applicable only to signalized intersections. A CMF value of 1.00 is always used for unsignalized intersections. The CMFs in Table 12-25 are applicable to 3SG and 4SG intersection types.

If several approaches to a signalized intersection have left-turn phasing, the values of *CMF2i* for each approach are multiplied together.

Table 12-25. Crash Modification Factor (*CMF2i*) for Type of Left-Turn Signal Phasing

Type of Left-Turn Signal Phasing	***CMF2i***
Permissive	1.00
Protected/permissive or permissive/protected	0.99
Protected	0.94

Note: Use $CMF_{2i} = 1.00$ for all unsignalized intersections and in conjuction with ~~all intersections~~SPFs ~~on~~for intersections on high-speed arterials. If several approaches to a signalized intersection have left-turn phasing, the values of *CMF2i* for each approach are multiplied together.

CMF3i—Intersection Right-Turn Lanes

The base condition for intersection right-turn lanes is the absence of right-turn lanes on the intersection approaches. The CMFs for presence of right-turn lanes based on research by Harwood et al. (7) are presented in Table 12-26. These CMFs 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. These CMFs apply to intersections on arterials covering all speed ranges. The CMFs for installation of right-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF 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 change in crash frequency 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 Table 12-26.

The CMFs in Table 12-26 apply to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions). A CMF value of 1.00 is always used when no right-turn lanes are present. This CMF applies only to right-turn lanes that are identified by marking or signing. The CMF is not applicable to long tapers, flares, or paved shoulders that may be used informally by right-turn traffic. The CMFs in Table 12-26 are applicable to the following intersection types: 3ST, 3ST-HS, 3SG, 3SG-HS, 4ST, 4ST-HS, 4SG, and 4SG-HS.

Table 12-26. Crash Modification Factor (CMF_{3i}) for Installation of Right-Turn Lanes on Intersection Approaches

		Number of Approaches with Right-Turn Lanes[a]			
Intersection Type	**Type of Traffic Control**	**One Approach**	**Two Approaches**	**Three Approaches**	**Four Approaches**
Three-leg intersection	Minor-road stop control[b]	0.86	0.74	—	—
	Traffic signal	0.96	0.92	—	
Four-leg intersection	Minor-road stop control[b]	0.86	0.74	—	—
	Traffic signal	0.96	0.92	0.88	0.85

[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.

CMF$_{4i}$—Right-Turn-on-Red

The CMF for prohibiting right-turn-on-red on one or more approaches to a signalized intersection has been derived from a study by Clark (2) and from the CMFs for right-turn-on-red operation shown in Chapter 14. The base condition for CMF_{4i} is permitting a right-turn-on-red at all approaches to a signalized intersection. The CMF is determined as:

$$CMF_{4i} = 0.98^{(n_{prohib})} \quad (12\text{-}35)$$

Where:

CMF_{4i} = crash modification factor for the effect of prohibiting right turns on red on total crashes; and

n_{prohib} = number of signalized intersection approaches for which right-turn-on-red is prohibited.

This CMF applies to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions) and is applicable only to signalized intersections. A CMF value of 1.00 is used for unsignalized intersections and- in conjuction with SPFs for intersections on~~all intersections on~~ high-speed arterials. CMF values based on Equation 12-35 are applicable to the following intersection types: 3SG and 4SG.

CMF_{5i}—Lighting

The base condition for lighting is the absence of intersection lighting. The CMF for lighted intersections is adapted from the work of Elvik and Vaa (3), as:

$$CMF_{5i} = 1 - 0.38 \times p_{ni} \quad (12\text{-}36)$$

Where:

CMF_{5i} = crash modification factor for the effect of intersection lighting on total crashes; and

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

This CMF applies to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions). Table 12-27 presents default values for the nighttime crash proportion, p_{ni}. HSM users are encouraged to replace the estimates in Table 12-27 with locally derived values. CMF values based on Equation 12-36 are applicable to the following intersection types: 3ST, 3ST-HS, 3aST, 3SG, 3SG-HS, 4ST, 4ST-HS, 4aST, 4SG, and 4SG-HS.

Table 12-27. Nighttime Crash Proportions for Unlighted Intersections

	Proportion of Crashes that Occur at Night
Intersection Type	p_{ni}
3ST	0.238
3ST-HS	0.291
3aST	0.187
3SG ~~and 4SG~~	0.235
3SG-HS	0.206
4ST	0.229
4ST-HS	0.256
4aST	0.277
4SG	0.235
4SG-HS	0.245

CMF$_{6i}$—Red-Light Cameras

The base condition for red light cameras is their absence. The CMF for installation of a red light camera for enforcement of red signal violations at a signalized intersection is based on an evaluation by Persaud et al. (12). As shown in Chapter 14, this study indicates a CMF for red light camera installation of 0.74 for right-angle collisions and a CMF of 1.18 for rear-end collisions. In other words, red light cameras would typically be expected to reduce right-angle collisions and increase rear-end collisions. There is no evidence that red light camera installation affects other collision types. Therefore, a CMF for the effect of red light camera installation on total crashes can be computed with the following equations:

$$CMF_{6i} = 1 - p_{ra} \times (1 - 0.74) - p_{re} \times (1 - 1.18) \tag{12-37}$$

$$p_{ra} = \frac{p_{ramv(FI)} \times N_{bimv(FI)} + p_{ramv(PDO)} \times N_{bimv(PDO)}}{\left(N_{bimv(FI)} + N_{bimv(PDO)} + N_{bisv}\right)} \tag{12-38}$$

$$p_{re} = \frac{p_{remv(FI)} \times N_{bimv(FI)} + p_{remv(PDO)} \times N_{bimv(PDO)}}{\left(N_{bimv(FI)} + N_{bimv(PDO)} + N_{bisv}\right)} \tag{12-39}$$

Where:

CMF_{6i} = crash modification factor for installation of red light cameras at signalized intersections;

p_{ra} = proportion of crashes that are multiple-vehicle, right-angle collisions;

p_{re} = proportion of crashes that are multiple-vehicle, rear-end collisions;

$p_{ramv(FI)}$ = proportion of multiple-vehicle fatal-and-injury crashes represented by right-angle collisions;

$p_{ramv(PDO)}$ = proportion of multiple-vehicle property-damage-only crashes represented by right-angle collisions;

$p_{remv(FI)}$ = proportion of multiple-vehicle fatal-and-injury crashes represented by rear-end collisions; and

$p_{remv(PDO)}$ = proportion of multiple-vehicle property-damage-only crashes represented by rear-end collisions.

The values of $N_{bimv(FI)}$ is available from Equation 12-22, the value of $N_{bimv(PDO)}$ is available from Equation 12-23, and the value of N_{bisv} is available from Equation 12-24. The values of $p_{ramv(FI)}$, $p_{ramv(PDO)}$, $p_{remv(FI)}$, and $p_{remv(PDO)}$ can be determined from data for the applicable intersection type in Table 12-11. The values in Table 12-11 may be updated with data for a particular jurisdiction as part of the calibration process presented in Part C, Appendix A. The data in Table 12-11, by definition, represent average values for a broad range of signalized intersections. Because jurisdictions are likely to implement red-light cameras at intersections with higher than average proportions of right-angle collisions, it is acceptable to replace the values in Table 12-11 with estimate based on data for a specific intersection when determining the value of the red light camera CMF. CMF values based on Equation 12-37 are applicable to the following intersection types: 3SG and 4SG.

CMF_{7i}—Horizontal Curves

The base condition for this CMF is a curve radius of 84 ft and length of 100 ft. This CMF only applies to three-leg turning intersections (3STT). The CMFs for horizontal curves at three-leg turning intersections is based on research by Torbic et al. (*16*). Equation 12-CMF is used to compute the CMF values for horizontal curve for multiple- and single-vehicle collisions by severity level. For multiple-vehicle crashes, both curve length and radius influence the horizontal curve CMF value. For single-vehicle crashes, only curve length influences the horizontal curve CMF value.

$$CMF_i = e^{a(R-84)+b(L_c-100)} \qquad (12\text{-CMF})$$

Where:

CMF_{7i} = crash modification factor for horizontal curves at three-leg turning intersections;

R = curve radius (ft);

L_c = curve length (ft); and

a, b = regression coefficients

Table 12-CMF. Coefficients for Horizontal Curve CMF

			CMF Coefficients	
Intersection Type	**Crash Type**	**Crash Severity**	**a**	**b**
Three-leg Turning	Multiple vehicle	Total	-0.014	0.017
		Fatal and Injury	-0.014	0.01~~9~~8
		Property damage only	-0.017	0.020
	Single vehicle[a]	Total	0	0.009
		Property damage only	0	0.008

[a] Curve radius is not a statistically significant predictor of single-vehicle crashes.

This CMF was developed based on horizontal curves with radii ranging from 25 to 269 ft and lengths ranging from 41 to 239 ft.

12.7.3. Crash Modification Factors for Vehicle-Pedestrian Collisions at Signalized Intersections

The CMFs for vehicle-pedestrian collisions at signalized intersections are presented below.

CMF_{1p}—Bus Stops

The CMFs for the number of bus stops within 1,000 ft of the center of the intersection are presented in Table 12-28. The base condition for bus stops is the absence of bus stops near the intersection. These CMFs apply to total vehicle-pedestrian collisions and are based on research by Harwood et al. (8). The CMFs in Table 12-28 are applicable to 3SG and 4SG intersection types.

Table 12-28. Crash Modification Factor (CMF_{1p}) for the Presence of Bus Stops near the Intersection

Number of Bus Stops within 1,000 ft of the Intersection	CMF_{1p}
0	1.00
1 or 2	2.78
3 or more	4.15

In applying Table 12-28, multiple bus stops at the same intersection (i.e., bus stops in different intersection quadrants or located some distance apart along the same intersection leg) are counted separately. Bus stops located at adjacent intersections would also be counted as long as any portion of the bus stop is located within 1,000 ft of the intersection being evaluated.

CMF_{2p}—Schools

The base condition for schools is the absence of a school near the intersection. The CMF for schools within 1,000 ft of the center of the intersection is presented in Table 12-29. A school may be counted if any portion of the school grounds is within 1,000 ft of the intersection. Where one or more schools are located near the intersection, the value of the CMF is independent of the number of schools present. This CMF applies to total vehicle-pedestrian collisions and is based on research by Harwood et al. (8). The CMFs in Table 12-29 are applicable to 3SG and 4SG intersection types.

This CMF indicates that an intersection with a school nearby is likely to experience more vehicle-pedestrian collisions than an intersection without schools even if the traffic and pedestrian volumes at the two intersections are identical. Such increased crash frequencies indicate that school children are at higher risk than other pedestrians.

Table 12-29. Crash Modification Factor (CMF_{2p}) for the Presence of Schools near the Intersection

Presence of Schools within 1,000 ft of the Intersection	CMF_{2p}
No school present	1.00
School present	1.35

CMF_{3p}—Alcohol Sales Establishments

The base condition for alcohol sales establishments is the absence of alcohol sales establishments near the intersection. The CMF for the number of alcohol sales establishments within 1,000 ft of the center of an intersection is presented in Table 12-30. Any alcohol sales establishment wholly or partly within 1,000 ft of the intersection may be counted. The CMF applies to total vehicle-pedestrian collisions and is based on research by Harwood et al. (8). The CMFs in Table 12-30 are applicable to 3SG and 4SG intersection types.

This CMF indicates that an intersection with alcohol sales establishments nearby is likely to experience more vehicle-pedestrian collisions than an intersection without alcohol sales establishments even if the traffic and pedestrian volumes at the two intersections are identical. This indicates the likelihood of higher risk behavior on the part of either pedestrians or drivers near alcohol sales establishments. The CMF includes any alcohol sales establishment which may include liquor stores, bars, restaurants, convenience stores, or grocery stores. Alcohol sales establishments are counted if they are on any intersection leg or even on another street, as long as they are within 1,000 ft of the intersection being evaluated.

Table 12-30. Crash Modification Factor (CMF_{3p}) for the Number of Alcohol Sales Establishments near the Intersection

Number of Alcohol Sales Establishments within 1,000 ft of the Intersection	CMF_{3p}
0	1.00
1–8	1.12
9 or more	1.56

12.8. Calibration of the SPFs to Local Conditions

In Step 10 of the predictive method, presented in Section 12.4, the predictive model is calibrated to local state or geographic conditions. Crash 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, crash reporting threshold, and crash reporting practices. These variations may result in some jurisdictions experiencing a different number of reported traffic crashes on urban and suburban arterial highways than others. Calibration factors are included in the methodology to allow highway agencies to adjust the SPFs to match actual local conditions.

The calibration factors for roadway segments and intersections (defined below as C_r and C_i, respectively) will have values greater than 1.0 for roadways that, on average, experience more crashes than the roadways used in the development of the SPFs. The calibration factors for roadways that experience fewer crashes 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 Part C, Appendix A.

Calibration factors provide one method of incorporating local data to improve estimated crash frequencies for individual agencies or locations. Several other default values used in the methodology, 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 Part C, Appendix A.

12.9. Interim Predictive Method for Roundabouts

Sufficient research has not yet been conducted to form the basis for development of a predictive method for roundabouts. Since many jurisdictions are planning projects to convert existing intersections into modern roundabouts, an interim predictive method is presented here. This interim procedure is applicable to a location at which a modern roundabout has been constructed or is being planned to replace an existing intersection with minor-road stop control or an existing signalized intersection. The interim procedure is:

1. Apply the predictive method from Chapter 12 to estimate the crash frequency, N_{int}, for the existing intersection.

2. Multiply N_{int} by the appropriate CMF from Chapter 12 for conversion on an existing intersection to a modern roundabout. The applicable CMFs are:

   - 0.56 for conversion of a two-way stop-controlled intersection to a modern roundabout.
   - 0.52 for conversion of a signalized intersection to a modern roundabout.

These CMFs are applicable to all crash severities and collision types for both one- and two-lane roundabouts in all settings.

At present, there are no available SPFs to determine predicted average crash frequency of an existing or newly constructed roundabout where no intersection currently exists.

12.10. Limitations of Predictive Method in Chapter 12

The limitations of the predictive method which apply generally across all of the Part C chapters are discussed in Section C.8. This section discusses limitations of the specific predictive models and the application of the predictive method in Chapter 12.

Where urban and suburban arterials intersect access-controlled facilities (i.e., freeways), the grade-separated interchange facility, including the arterial facility within the interchange area, cannot be addressed with the predictive method for urban and suburban arterials.

12.11. Application of Chapter 12 Predictive method

The predictive method presented in Chapter 12 applies to urban and suburban arterials. The predictive method is applied to by following the 18 steps presented in Section 12.4. Appendix 12A 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 computation, rounding the final estimate expected average crash frequency to one decimal place.

12.12. Summary

The predictive method is used to estimate the expected average crash frequency for a series of contiguous sites (entire urban or suburban arterial facility), or a single individual site. An urban or suburban facility is defined in Section 12.3.

The predictive method for urban and suburban arterial highways is applied by following the 18 steps of the predictive method presented in Section 12.4. Predictive models, developed for urban and suburban arterial facilities, are applied in Steps 9, 10, and 11 of the method. These models have been developed to estimate the predicted average crash frequency of an individual intersection or homogenous roadway segment. The facility is divided into these individual sites in Step 5 of the predictive method.

Where observed data are available, the EB Method may be applied in Step 13 or 15 of the predictive method to improve the reliability of the estimate. The EB Method can be applied at the site-specific level or at the project specific level. It may also be applied to a future time period if site conditions will not change in the future period. The EB Method is described in Part C, Appendix A.2.

Each predictive model in Chapter 12 consists of a safety performance function (SPF), crash modification factors (CMFs), a calibration factor, and pedestrian and bicyclist factors. The SPF is selected in Step 9 and is used to estimate the predicted average crash frequency for a site with base conditions. This estimate can be for either total crashes or organized by crash-severity or collision-type distribution. In order to account for differences between the base conditions of the SPF and the actual conditions of the local site, CMFs are applied in Step 10 which adjust the predicted number of crashes according the geometric conditions of the site.

In order to account for the differences in state or regional crash frequencies, the SPF is calibrated to the specific state and or geographic region to which they apply. The process for determining calibration factors for the predictive models is described in Part C, Appendix A.1.

Section 12.13 presents ten~~six~~ sample problems which detail the application of the predictive method. A series of template worksheets have been developed to assist with applying the predictive method in Chapter 12. These worksheets are utilized to solve the sample problems in Section 12.13, and Appendix 12A contains blank versions of the worksheets.

12.13. Sample Problems

In this section, ten~~six~~ sample problems are presented using the predictive method steps for urban and suburban arterials. Sample Problems 1 and 2 illustrate how to calculate the predicted average crash frequency for urban and suburban arterial 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 Problems XA, XB, XC, and XD illustrate similar calculations for a three-leg all-way stop-controlled intersection, a three-leg turning intersection, a four-leg signalized intersection on a high-speed arterial, and a five-leg signalized intersection. Sample Problem 5 illustrates how to combine the results from Sample Problems 1 through 4 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 4 in a case where site-specific observed crash data are not available (i.e., using the project-level EB Method).

Table 12-31. List of Sample Problems in Chapter 12

Problem No.	Page No.	Description
1	12-49	Predicted average crash frequency for a three-lane TWLTL arterial roadway segment
2	12-63	Predicted average crash frequency for a four-lane divided arterial roadway segment
3	12-74	Predicted average crash frequency for a three-leg stop-controlled intersection
4	12-86	Predicted average crash frequency for a four-leg signalized intersection
XA		Predicted average crash frequency for a three-leg all-way stop-controlled intersection
XD		Predicted average crash frequency for a three-leg turning intersection
XB		Predicted average crash frequency for a four-leg signalized intersection on a high-speed arterial
XC		Predicted average crash frequency for a five-leg signalized intersection
5	12-97	Expected average crash frequency for a facility when site-specific observed crash data are available
6	12-101	Expected average crash frequency for a facility when site-specific observed crash data are not available

12.13.1. Sample Problem 1

The Site/Facility
A three-lane urban arterial roadway segment with a center two-way left-turn lane (TWLTL).

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

The Facts
- 1.5-mi length
- 11,000 veh/day
- 1.0 mi of parallel on-street commercial parking on each side of street
- 30 driveways (10 minor commercial, 2 major residential, 15 minor residential, 3 minor industrial/institutional)
- 10 roadside fixed objects per mile

- 6-ft offset to roadside fixed objects
- Lighting present
- 35-mph posted speed

Assumptions

Collision type distributions used are the default values presented in Tables 12-4 and 12-6 and Equations 12-19 and 12-20.

The calibration factor is assumed to be 1.00.

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 7.0 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.

For a three-lane urban arterial roadway segment with TWLTL, SPF values for multiple-vehicle nondriveway, single-vehicle, multiple-vehicle driveway-related, vehicle-pedestrian, and vehicle-bicycle collisions are determined. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these models.

Multiple-Vehicle Nondriveway Collisions

The SPF for multiple-vehicle nondriveway collisions for the roadway segment is calculated from Equation 12-10 and Table 12-3 as follows:

$$N_{brmv} = exp\left(a + b \times \ln\left(AADT\right) + \ln\left(L\right)\right)$$

$$N_{brmv(\text{total})} = exp\left(-12.40 + 1.41 \times \ln\left(11{,}000\right) + \ln\left(1.5\right)\right)$$

$$= 3.805 \text{ crashes/year}$$

$$N_{brmv(FI)} = \exp\left(-16.45 + 1.69 \times \ln\left(11{,}000\right) + \ln\left(1.5\right)\right)$$

$$= 0.728 \text{ crashes/year}$$

$$N_{brmv(PDO)} = exp\left(-11.95 + 1.33 \times \ln\left(11{,}000\right) + \ln\left(1.5\right)\right)$$

$$= 2.298 \text{ crashes/year}$$

These initial values for fatal-and-injury (FI) and property-damage-only (PDO) crashes are then adjusted using Equations 12-11 and 12-12 to assure that they sum to the value for total crashes as follows:

$$N_{brmv(FI)} = N_{brmv(\text{total})}\left(\frac{N'_{brmv(FI)}}{N'_{brmv(FI)} + N'_{brmv(PDO)}}\right)$$
$$= 3.085\left(\frac{0.728}{0.728+2.298}\right)$$
$$= 0.742 \text{ crashes/year}$$

$$N_{brmv(PDO)} = N_{brmv(\text{total})} - N_{brmv(FI)}$$
$$= 3.085 - 0.742$$
$$= 2.343 \text{ crashes/year}$$

Single-Vehicle Crashes

The SFP for single-vehicle crashes for the roadway segments is calculated from Equation 12-13 and Table 12-5 as follows:

$$N_{brsv} = exp\left(a + b \times \ln\left(AADT\right) + \ln\left(L\right)\right)$$
$$N_{brsv(\text{total})} = exp\left(-5.74 + 0.54 \times \ln\left(11,000\right) + \ln\left(1.5\right)\right)$$
$$= 0.734 \text{ crashes/year}$$
$$N_{brsv(FI)} = exp\left(-6.37 + 0.47 \times \ln\left(11,000\right) + \ln\left(1.5\right)\right)$$
$$= 0.204 \text{ crashes/year}$$
$$N_{brsv(PDO)} = exp\left(-6.29 + 0.56 \times \ln\left(11,000\right) + \ln\left(1.5\right)\right)$$
$$= 0.510 \text{ crashes/year}$$

These initial values for fatal-and-injury (FI) and property-damage-only (PDO) crashes are then adjusted using Equations 12-14 and 12-15 to assure that they sum to the value for total crashes as follows:

$$N_{brsv(FI)} = N_{brsv(\text{total})}\left(\frac{N'_{brsv(FI)}}{N'_{brsv(FI)} + N'_{brsv(PDO)}}\right)$$
$$= 0.734 \times \left(\frac{0.204}{0.204+0.510}\right)$$
$$= 0.210 \text{ crashes/year}$$

$$N_{brsv(PDO)} = N_{brsv(\text{total})} - N_{brsv(FI)}$$
$$= 0.734 - 0.210$$
$$= 0.524 \text{ crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

The SPF for multiple-vehicle driveway-related collisions for the roadway segment is calculated from Equation 12-16 as follows:

$$N_{brdwy(\text{total})} = \sum_{\substack{\text{all} \\ \text{driveway} \\ \text{types}}} n_j \times N_j \times \left(\frac{AADT}{15,000}\right)^{(t)}$$

The number of driveways within the roadway segment, n_j, for Sample Problem 1 is 10 minor commercial, two major residential, 15 minor residential, and three minor industrial/institutional.

The number of driveway-related collisions, N_j, and the regression coefficient for AADT, t, for a three-lane arterial are provided in Table 12-7.

$$N_{brdwy(\text{total})} = 10 \times 0.032 \times \left(\frac{11,000}{15,000}\right)^{(1.0)} + 2 \times 0.053 \times \left(\frac{11,000}{15,000}\right)^{(1.0)}$$
$$+15 \times 0.010 \times \left(\frac{11,000}{15,000}\right)^{(1.0)} + 3 \times 0.015 \times \left(\frac{11,000}{15,000}\right)^{(1.0)}$$
$$= 0.455 \text{ crashes/year}$$

Driveway-related collisions can be separated into components by severity level using Equations 12-17 and 12-18 as follows:

From Table 12-7, for a three-lane arterial the proportion of driveway-related collisions that involve fatalities and injuries, $f_{dwy} = 0.243$

$$\begin{aligned} N_{brdwy(FI)} &= N_{brdwy(\text{total})} \times f_{dwy} \\ &= 0.455 \times 0.243 \\ &= 0.111 \text{ crashes/year} \end{aligned}$$

$$\begin{aligned} N_{brdwy(PDO)} &= N_{brdwy(\text{total})} - N_{brdwy(FI)} \\ &= 0.455 - 0.111 \\ &= 0.344 \text{ crashes/year} \end{aligned}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.

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

On-Street Parking (CMF_{1r})

CMF_{1r} is calculated from Equation 12-32 as follows:

$$CMF_{1r} = 1 + p_{pk} \times (f_{pk} - 1.0)$$

The proportion of curb length with on-street parking, p_{pk}, is determined as follows:

$$p_{pk} = 0.5 \times \frac{L_{pk}}{L}$$

Since 1.0 mile of on-street parking on each side of the road is provided, the sum of curb length with on-street parking for both sides of the road combined, $L_{pk} = 2$.

$$p_{pk} = 0.5 \times \frac{2}{1.5} = 0.66$$

From Table 12-19, $f_{pk} = 2.074$.

$$\begin{aligned} CMF_{1r} &= 1 + 0.66 \times (2.074 - 1.0) \\ &= 1.71 \end{aligned}$$

Roadside Fixed Objects (CMF_{2r})

CMF_{2r} is calculated from Equation 12-33 as follows:

$$CMF_{2r} = f_{\text{offset}} \times D_{fo} \times p_{fo} + \left(1.0 - p_{fo}\right)$$

From Table 12-20, for a roadside fixed object with a 6-ft offset, the fixed-object offset factor, f_{offset}, is interpolated as 0.124.

From Table 12-21, for a three-lane arterial the proportion of total crashes, $p_{fo} = 0.034$.

$$\begin{aligned} CMF_{2r} &= 0.124 \times 10 \times 0.034 + (1.0 - 0.034) \\ &= 1.01 \end{aligned}$$

Median Width (CMF_{3r})

The value of CMF_{3r} is 1.00 for undivided facilities (see Section 12.7.1). It is assumed that a roadway with TWLTL is undivided.

Lighting (CMF_{4r})

CMF_{4r} is calculated from Equation 12-34 as follows:

$$CMF_{4r} = 1.0 - \left(p_{nr} \times \left(1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr}\right)\right)$$

For a three-lane arterial, $p_{inr} = 0.429$, $p_{pnr} = 0.571$, and $p_{nr} = 0.304$ (see Table 12-23).

$$\begin{aligned} CMF_{4r} &= 1.0 - \left(0.304 \times (1.0 - 0.72 \times 0.429 - 0.83 \times 0.571)\right) \\ &= 0.93 \end{aligned}$$

Automated Speed Enforcement (CMF_{5r})

Since there is no automated speed enforcement in Sample Problem 1, $CMF_{5r} = 1.00$ (i.e., the base condition for CMF_{5r} is the absent of automated speed enforcement).

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

$$\begin{aligned} CMF_{comb} &= 1.71 \times 1.01 \times 0.93 \\ &= 1.61 \end{aligned}$$

Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions) for SPF base conditions, N_{br}, is calculated first in order to determine vehicle-pedestrian and vehicle-bicycle crashes. N_{br} is determined from Equation 12-3 as follows:

$$N_{br} = N_{spf\ rs} \times \left(CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{nr}\right)$$

From Equation 12-4, $N_{spf\ rs}$ can be calculated as follows:

$$\begin{aligned} N_{spf\ rs} &= N_{brmv} + N_{brsv} + N_{brdwy} \\ &= 3.085 + 0.734 + 0.455 \\ &= 4.274 \text{ crashes/year} \end{aligned}$$

The combined CMF value for Sample Problem 1 is 1.61.

$$N_{br} = 4.274 \times (1.61)$$
$$= 6.881 \text{ crashes/year}$$

The SPF for vehicle-pedestrian collisions for the roadway segment is calculated from Equation 12-19 as follows:

$$N_{pedr} = N_{br} \times f_{pedr}$$

From Table 12-8, for a posted speed greater than 30 mph on three-lane arterials the pedestrian crash adjustment factor, $f_{pedr} = 0.013$.

$$N_{pedr} = 6.881 \times 0.013$$
$$= 0.089 \text{ crashes/year}$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-20 as follows:

$$N_{biker} = N_{br} \times f_{biker}$$

From Table 12-9, for a posted speed greater than 30 mph on three-lane arterials the bicycle crash adjustment factor, $f_{biker} = 0.007$.

$$N_{biker} = 6.881 \times 0.007$$
$$= 0.048 \text{ crashes/year}$$

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

It is assumed in that a calibration factor, C_r, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency

The predicted average crash frequency is calculated using Equation 12-2 based on the results obtained in Steps 9 through 11 as follows:

$$N_{\text{predicted } rs} = C_r \times (N_{br} + N_{pedr} + N_{biker})$$
$$= 1.00 \times (6.881 + 0.089 + 0.048)$$
$$= 7.018 \text{ crashes/year}$$

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 12 worksheets are provided for determining the predicted average crash frequency. The 12 worksheets include:

- *Worksheet SP1A (Corresponds to Worksheet 1A)*—General Information and Input Data for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1B (Corresponds to Worksheet 1B)*—Crash Modification Factors for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1C (Corresponds to Worksheet 1C)*—Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Arterial Roadway Segments

- *Worksheet SP1D (Corresponds to Worksheet 1D)*—Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1E (Corresponds to Worksheet 1E)*—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1F (Corresponds to Worksheet 1F)*—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1G (Corresponds to Worksheet 1G)*—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1H (Corresponds to Worksheet 1H)*—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1I (Corresponds to Worksheet 1I)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1J (Corresponds to Worksheet 1J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1K (Corresponds to Worksheet 1K)*—Crash Severity Distribution for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1L (Corresponds to Worksheet 1L)*—Summary Results for Urban and Suburban Arterial Roadway Segments

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheet SP1A—General Information and Input Data for Urban and Suburban Roadway Segments

Worksheet SP1A is a summary of general information about the roadway segment, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 1.

Worksheet SP1A. General Information and Input Data for Urban and Suburban Roadway Segments

General Information		Location Information	
Analyst		Roadway	
Agency or Company		Roadway Section	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		**Base Conditions**	**Site Conditions**
Road type (2U, 3T, 4U, 4D, 5T)		—	3T
Length of segment, L (mi)		—	1.5
AADT (veh/day)		—	11,000
Type of on-street parking (none/parallel/angle)		none	parallel-commercial
Proportion of curb length with on-street parking		—	0.66
Median width (ft)		15	not present
Lighting (present/not present)		not present	present
Auto speed enforcement (present/not present)		not present	not present
Major commercial driveways (number)		—	0
Minor commercial driveways (number)		—	10
Major industrial/institutional driveways (number)		—	0
Minor industrial/institutional driveways (number)		—	3
Major residential driveways (number)		—	2
Minor residential driveways (number)		—	15
Other driveways (number)		—	0
Speed Category		—	intermediate or high speed (>30 mph)
Roadside fixed object density (fixed objects/mi)		not present	10
Offset to roadside fixed objects (ft)		not present	6
Calibration Factor, C_r		1.0	1.0

Worksheet SP1B. Crash Modification Factors for Urban and Suburban Roadway Segments

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 6 of Worksheet SP1B which indicates the combined CMF value.

Worksheet SP1B. Crash Modification Factors for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
CMF for On-Street Parking	**CMF for Roadside Fixed Objects**	**CMF for Median Width**	**CMF for Lighting**	**CMF for Auto Speed Enforcement**	**Combined CMF**
CMF_{1r}	CMF_{2r}	CMF_{3r}	CMF_{4r}	CMF_{5r}	CMF_{comb}
from Equation 12-32	from Equation 12-33	from Table 12-22	from Equation 12-34	from Section 12.7.1	(1)*(2)*(3)*(4)*(5)
1.71	1.01	1.00	0.93	1.00	1.61

Worksheet SP1C—Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Roadway Segments

The SPF for multiple-vehicle nondriveway collisions along the roadway segment in Sample Problem 1 is calculated using Equation 12-10 and entered into Column 4 of Worksheet SP1C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 6 in Worksheet SP1B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle nondriveway crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP1C. Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
	SPF Coefficients		Overdispersion Parameter, *k*	Initial N_{brmv}		Adjusted N_{brmv}	Combined CMFs	Calibration Factor	Predicted N_{brmv}
	from Table 12-3								
Crash Severity Level	**a**	**b**	**from Table 12-3**	**from Equation 12-10**	**Proportion of Total Crashes**	$(4)_{total}$*(5)	(6) from Worksheet SP1B	C_r	(6)*(7)*(8)
Total	−12.40	1.41	0.66	3.085	1.000	3.085	1.61	1.00	4.967
Fatal and injury (FI)	−16.45	1.69	0.59	0.728	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$	0.743	1.61	1.00	1.196
					0.241				
Property damage only (PDO)	−11.95	1.33	0.59	2.298	$(5)_{total}-(5)_{FI}$	2.342	1.61	1.00	3.771
					0.759				

Worksheet SP1D—Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Roadway Segments

Worksheet SP1D presents the default proportions for collision type (from Table 12-4) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for multiple-vehicle nondriveway crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle nondriveway crashes (from Column 9, Worksheet SP1C) into components by crash severity and collision type.

Worksheet SP1D. Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{brmv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{brmv\ (PDO)}$ (crashes/year)	Predicted $N_{brmv\ (total)}$ (crashes/year)
Collision Type	from Table 12-4	$(9)_{FI}$ from Worksheet SP1C	from Table 12-4	$(9)_{PDO}$ from Worksheet SP1C	$(9)_{total}$ from Worksheet SP1C
Total	1.000	1.196 $(2)*(3)_{FI}$	1.000	3.771 $(4)*(5)_{PDO}$	4.967 (3)+(5)
Rear-end collision	0.845	1.011	0.842	3.175	4.186
Head-on collision	0.034	0.041	0.020	0.075	0.116
Angle collision	0.069	0.083	0.020	0.075	0.158
Sideswipe, same direction	0.001	0.001	0.078	0.294	0.295
Sideswipe, opposite direction	0.017	0.020	0.020	0.075	0.095
Other multiple-vehicle collision	0.034	0.041	0.020	0.075	0.116

Worksheet SP1E—Single-Vehicle Crashes by Severity Level for Urban and Suburban Roadway Segments

The SPF for single-vehicle crashes along the roadway segment in Sample Problem 1 is calculated using Equation 12-13 and entered into Column 4 of Worksheet SP1E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 6 in Worksheet SP1B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle nondriveway crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP1E. Single-Vehicle Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
	SPF Coefficients		Overdispersion Parameter, *k*	Initial N_{brsv}		Adjusted N_{brsv}	Combined CMFs	Calibration Factor	Predicted N_{brsv}
Crash Severity Level	from Table 12-5		from Table 12-5	from Equation 12-13	Proportion of Total Crashes	$(4)_{total}$*(5)	(6) from Worksheet SP1B	C_r	(6)*(7)*(8)
	a	b							
Total	−5.74	0.54	1.37	0.734	1.000	0.734	1.61	1.00	1.182
Fatal and injury (FI)	−6.37	0.47	1.06	0.204	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$ 0.286	0.210	1.61	1.00	0.338
Property damage only (PDO)	−6.29	0.56	1.93	0.510	$(5)_{total}-(5)_{FI}$ 0.714	0.524	1.61	1.00	0.844

Worksheet SP1F—Single-Vehicle Crashes by Collision Type for Urban and Suburban Roadway Segments

Worksheet SP1F presents the default proportions for collision type (from Table 12-5) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by collision type is presented in 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and Columns 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 9, Worksheet SP1E) into components by crash severity and collision type.

Worksheet SP1F. Single-Vehicle Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{brsv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{brsv\ (PDO)}$ (crashes/year)	Predicted $N_{brsv\ (total)}$ (crashes/year)
Collision Type	from Table 12-6	$(9)_{FI}$ from Worksheet SP1E	from Table 12-6	$(9)_{PDO}$ from Worksheet SP1E	$(9)_{total}$ from Worksheet SP1E
Total	1.000	0.338 $(2)*(3)_{FI}$	1.000	0.844 $(4)*(5)_{PDO}$	1.182 (3)+(5)
Collision with animal	0.001	0.000	0.001	0.001	0.001
Collision with fixed object	0.688	0.233	0.963	0.813	1.046
Collision with other object	0.001	0.000	0.001	0.001	0.001
Other single-vehicle collision	0.310	0.105	0.035	0.030	0.135

Worksheet SP1G—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Roadway Segments

Worksheet SP1G determines and presents the number of driveway-related multiple-vehicle collisions. The number of driveways along both sides of the road is entered in Column 2 by driveway type (Column 1). The associated number of crashes per driveway per year by driveway type as found in Table 12-7 is entered in Column 3. Column 4 contains the regression coefficient for AADT also found in Table 12-7. The initial average crash frequency of multiple-vehicle driveway-related crashes is calculated from Equation 12-16 and entered into Column 5. The overdispersion parameter from Table 12-7 is entered into Column 6; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized).

Worksheet SP1G. Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
		Crashes per Driveway per Year, N_j	Coefficient for Traffic Adjustment, t	Initial N_{brdwy}	Overdispersion Parameter, k
Driveway Type	Number of Driveways, n_j	from Table 12-7	from Table 12-7	Equation 12-16 $n_j*N_j*(AADT/15,000)t$	from Table 12-7
Major commercial	0	0.102	1.000	0.000	—
Minor commercial	10	0.032	1.000	0.235	
Major industrial/institutional	0	0.110	1.000	0.000	
Minor industrial/institutional	3	0.015	1.000	0.033	
Major residential	2	0.053	1.000	0.078	
Minor residential	15	0.010	1.000	0.110	
Other	0	0.016	1.000	0.000	
Total	—	—	—	0.456	1.10

Worksheet SP1H—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Roadway Segments

The initial average crash frequency of multiple-vehicle driveway-related crashes from Column 5 of Worksheet SP1G is entered in Column 2. This value is multiplied by the proportion of crashes by severity (Column 3) found in Table 12-7 and the adjusted value is entered into Column 4. Column 5 represents the combined CMF (from Column 6 in Worksheet SP1B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of multiple-vehicle driveway-related crashes using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SP1H. Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Initial N_{brdwy}	Proportion of Total Crashes (f_{dwy})	Adjusted N_{brdwy}	Combined CMFs		Predicted N_{brdwy}
Crash Severity Level	(5)$_{total}$ from Worksheet SP1G	from Table 12-7	(2)$_{total}$ *(3)	(6) from Worksheet SP1B	Calibration Factor, C_r	(4)*(5)*(6)
Total	0.456	1.000	0.456	1.61	1.00	0.734
Fatal and injury (FI)	—	0.243	0.111	1.61	1.00	0.179
Property damage only (PDO)	—	0.757	0.345	1.61	1.00	0.555

Worksheet SP1I—Vehicle-Pedestrian Collisions for Urban and Suburban Roadway Segments

The predicted average crash frequency of multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related predicted crashes from Worksheets SP1C, SP1E, and SP1H are entered into Columns 2, 3, and 4, respectively. These values are summed in Column 5. Column 6 contains the pedestrian crash adjustment factor (see Table 12-8). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP1I. Vehicle-Pedestrian Collisions for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted N_{brmv}	Predicted N_{brsv}	Predicted N_{brdwy}	Predicted N_{br}	f_{pedr}		Predicted N_{pedr}
Crash Severity Level	(9) from Worksheet SP1C	(9) from Worksheet SP1E	(7) from Worksheet SP1H	(2)+(3)+(4)	from Table 12-8	Calibration Factor, C_r	(5)*(6)*(7)
Total	4.967	1.182	0.734	6.883	0.013	1.00	0.089
Fatal and injury (FI)	—	—	—	—	—	1.00	0.089

Worksheet SP1J—Vehicle-Bicycle Collisions for Urban and Suburban Roadway Segments

The predicted average crash frequency of multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related predicted crashes from Worksheets SP1C, SP1E, and SP1H are entered into Columns 2, 3, and 4, respectively. These values are summed in Column 5. Column 6 contains the bicycle crash adjustment factor (see Table 12-9). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-bicycle collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-bicycle collisions are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP1J. Vehicle-Bicycle Collisions for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted N_{brmv}	Predicted N_{brsv}	Predicted N_{brdwy}	Predicted N_{br}	f_{biker}		Predicted N_{biker}
Crash Severity Level	(9) from Worksheet SP1C	(9) from Worksheet SP1E	(7) from Worksheet SP1H	(2)+(3)+(4)	from Table 12-9	Calibration Factor, C_r	(5)*(6)*(7)
Total	4.967	1.182	0.734	6.883	0.007	1.00	0.048
Fatal and injury	—	—	—	—	—	1.00	0.048

Worksheet SP1K—Crash Severity Distribution for Urban and Suburban Roadway Segments

Worksheet SP1K provides a summary of all collision types by severity level. Values from Worksheets SP1C, SP1E, SP1H, SP1I, and SP1J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP1K. Crash Severity Distribution for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	Property Damage Only (PDO)	Total
Collision Type	(3) from Worksheets SP1D and SP1F; (7) from Worksheet SP1H; and (8) from Worksheets SP1I and SP1J	(5) from Worksheets SP1D and SP1F; and (7) from Worksheet SP1H	(6) from Worksheets SP1D and SP1F; (7) from Worksheet SP1H; and (8) from Worksheets SP1I and SP1J
MULTIPLE-VEHICLE			
Rear-end collisions (from Worksheet SP1D)	1.011	3.175	4.186
Head-on collisions (from Worksheet SP1D)	0.041	0.075	0.116
Angle collisions (from Worksheet SP1D)	0.083	0.075	0.158
Sideswipe, same direction (from Worksheet SP1D)	0.001	0.294	0.295
Sideswipe, opposite direction (from Worksheet SP1D)	0.020	0.075	0.095
Driveway-related collisions (from Worksheet SP1H)	0.179	0.555	0.734
Other multiple-vehicle collision (from Worksheet SP1D)	0.041	0.075	0.116
Subtotal	1.376	4.324	5.700
SINGLE-VEHICLE			
Collision with animal (from Worksheet SP1F)	0.000	0.001	0.001
Collision with fixed object (from Worksheet SP1F)	0.233	0.813	1.046
Collision with other object (from Worksheet SP1F)	0.000	0.001	0.001
Other single-vehicle collision (from Worksheet SP1F)	0.105	0.030	0.135
Collision with pedestrian (from Worksheet SP1I)	0.089	0.000	0.089
Collision with bicycle (from Worksheet SP1J)	0.048	0.000	0.048
Subtotal	0.475	0.845	1.320
Total	1.851	5.169	7.020

Worksheet SP1L—Summary Results for Urban and Suburban Roadway Segments

Worksheet SP1L presents a summary of the results. Using the roadway segment length and the AADT, the worksheet presents the crash rate in miles per year (Column 4) and in million vehicle miles (Column 6).

Worksheet SP1L. Summary Results for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
	Predicted Average Crash Frequency, $N_{predicted\ rs}$ (crashes/year)		Crash Rate (crashes/mi/year)
Crash Severity Level	(Total) from Worksheet SP1K	Roadway Segment Length, L (mi)	(2)/(3)
Total	7.020	1.5	4.7
Fatal and injury (FI)	1.851	1.5	1.2
Property damage only (PDO)	5.169	1.5	3.4

12.13.2. Sample Problem 2

The Highway
A four-lane divided urban arterial roadway segment.

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

The Facts

- 0.75-mi length
- 23,000 veh/day
- On-street parking not permitted
- 8 driveways (1 major commercial, 4 minor commercial, 1 major residential, 1 minor residential, 1 minor industrial/institutional)
- 20 roadside fixed objects per mile
- 12-ft offset to roadside fixed objects
- 40-ft median
- Lighting present
- 30-mph posted speed

Assumptions
Collision type distributions used are the default values presented in Tables 12-4 and 12-6 and Equations 12-19 and 12-20.

The calibration factor is assumed to be 1.00.

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 3.4 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.

For a four-lane divided urban arterial roadway segment, SPF values for multiple-vehicle nondriveway, single-vehicle, multiple-vehicle driveway-related, vehicle-pedestrian, and vehicle-bicycle collisions are determined. The calculations for total multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related collisions are presented below. Detailed steps for calculating SPFs for fatal-and-injury (FI) and property-damage-only (PDO) crashes are presented in Sample Problem 1. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these two models.

Multiple-Vehicle Nondriveway Collisions

The SPF for multiple-vehicle nondriveway collisions for the roadway segment is calculated from Equation 12-10 and Table 12-3 as follows:

$$\begin{aligned} N_{brmv} &= exp\left(a + b \times 1\text{n}\left(AADT\right) + 1\text{n}\left(L\right)\right) \\ N_{brmv(\text{total})} &= exp\left(-12.34 + 1.36 \times 1\text{n}\left(23{,}000\right) + 1\text{n}\left(0.75\right)\right) \\ &= 2.804 \text{ crashes/year} \end{aligned}$$

Single-Vehicle Crashes

The SFP for single-vehicle crashes for the roadway segments is calculated from Equation 12-13 and Table 12-5 as follows:

$$\begin{aligned} N_{brsv} &= exp\left(a + b \times 1\text{n}\left(AADT\right) + 1\text{n}\left(L\right)\right) \\ N_{brsv(\text{total})} &= exp\left(-5.05 + 0.47 \times 1\text{n}\left(23{,}000\right) + 1\text{n}\left(0.75\right)\right) \\ &= 0.539 \text{ crashes/year} \end{aligned}$$

Multiple-Vehicle Driveway-Related Collisions

The SPF for multiple-vehicle driveway-related collisions for the roadway segment is calculated from Equation 12-16 as follows:

$$N_{brdwy(\text{total})} = \sum_{\substack{\text{all} \\ \text{driveway} \\ \text{types}}} n_j \times N_j \times \left(\frac{AADT}{15{,}000}\right)^{(t)}$$

The number of driveways within the roadway segment, n_j, for Sample Problem 1 is one major commercial, four minor commercial, one major residential, one minor residential, and one minor industrial/institutional.

The number of driveway-related collisions, N_j, and the regression coefficient for AADT, t, for a four-lane divided arterial, are provided in Table 12-7.

$$\begin{aligned} N_{brdwy(\text{total})} &= 1 \times 0.033 \times \left(\frac{23{,}000}{15{,}000}\right)^{(1.106)} + 4 \times 0.011 \times \left(\frac{23{,}000}{15{,}000}\right)^{(1.106)} + 1 \times 0.018 \times \left(\frac{23{,}000}{15{,}000}\right)^{(1.106)} \\ &\quad + 1 \times 0.003 \times \left(\frac{23{,}000}{15{,}000}\right)^{(1.106)} + 1 \times 0.005 \times \left(\frac{23{,}000}{15{,}000}\right)^{(1.106)} \\ &= 0.165 \text{ crashes/year} \end{aligned}$$

The fatal-and-injury (FI) and property-damage-only (PDO) SPF values for multiple-vehicle nondriveway collisions, single-vehicle crashes and multiple-vehicle driveway-related collisions can be determined by using the same procedure presented in Sample Problem 1.

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.
Each CMF used in the calculation of the predicted average crash frequency of the roadway segment is calculated below:

On-Street Parking (CMF_{1r})
Since on-street parking is not permitted, $CMF_{1r} = 1.00$ (i.e., the base condition for CMF_{1r} is the absence of on-street parking).

Roadside Fixed Objects (CMF_{2r})
CMF_{2r} is calculated from Equation 12-33 as follows:

$$CMF_{2r} = f_{\text{offset}} \times D_{fo} \times p_{fo} + (1.0 - p_{fo})$$

From Table 12-20, for a roadside fixed object with a 12-ft offset, the fixed-object offset factor, f_{offset}, is interpolated as 0.079.

From Table 12-21, for a four-lane divided arterial the proportion of total crashes, $p_{fo} = 0.036$.

$$\begin{aligned} CMF_{2r} &= 0.079 \times 20 \times 0.036 + (1.0 - 0.036) \\ &= 1.02 \end{aligned}$$

Median Width (CMF_{3r})
From Table 12-22, for a four-lane divided arterial with a 40-ft median, $CMF_{3r} = 0.97$.

Lighting (CMF_{4r})
CMF_{4r} can be calculated from Equation 12-34 as follows:

$$CMF_{4r} = 1.0 - \left(p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})\right)$$

For a four-lane divided arterial, $p_{inr} = 0.364$, $p_{pnr} = 0.636$, and $p_{nr} = 0.410$ (see Table 12-23).

$$\begin{aligned} CMF_{4r} &= 1.0 - \left(0.410 \times (1.0 - 0.72 \times 0.364 - 0.83 \times 0.636)\right) \\ &= 0.91 \end{aligned}$$

Automated Speed Enforcement (CMF_{5r})
Since there is no automated speed enforcement in Sample Problem 2, $CMF_{5r} = 1.00$ (i.e., the base condition for CMF_{5r} is the absent of automated speed enforcement).

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

$$\begin{aligned} CMF_{comb} &= 1.02 \times 0.97 \times 0.91 \\ &= 0.90 \end{aligned}$$

Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions) for SPF base conditions, N_{br}, is calculated first in order to determine vehicle-pedestrian and vehicle-bicycle crashes. N_{br} is determined from Equation 12-3 as follows:

$$N_{br} = N_{spf\ rs} \times (CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{nr})$$

From Equation 12-4, $N_{spf\,rs}$ can be calculated as follows:

$$\begin{aligned} N_{spf\ rs} &= N_{brmv} + N_{brsv} + N_{brdwy} \\ &= 2.804 + 0.539 + 0.165 \\ &= 3.508 \text{ crashes/year} \end{aligned}$$

The combined CMF value for Sample Problem 2 is 0.90.

$$\begin{aligned} N_{br} &= 3.508 \times (0.90) \\ &= 3.157 \text{ crashes/year} \end{aligned}$$

The SPF for vehicle-pedestrian collisions for the roadway segment is calculated from Equation 12-19 as follows:

$$N_{pedr} = N_{br} \times f_{pedr}$$

From Table 12-8, for a posted speed of 30 mph on four-lane divided arterials, the pedestrian crash adjustment factor $f_{pedr} = 0.067$.

$$\begin{aligned} N_{pedr} &= 3.157 \times 0.067 \\ &= 0.212 \text{ crashes/year} \end{aligned}$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-20 as follows:

$$N_{biker} = N_{br} \times f_{biker}$$

From Table 12-9, for a posted speed of 30 mph on four-lane divided arterials, the bicycle crash adjustment factor $f_{biker} = 0.013$.

$$\begin{aligned} N_{biker} &= 3.157 \times 0.013 \\ &= 0.041 \text{ crashes/year} \end{aligned}$$

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

It is assumed in that a calibration factor, C_r, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency

The predicted average crash frequency is calculated using Equation 12-2 based on the results obtained in Steps 9 through 11 as follows:

$$\begin{aligned} N_{\text{predicted}\ rs} &= C_r \times \left(N_{br} + N_{pedr} + N_{biker}\right) \\ &= 1.00 \times (3.157 + 0.212 + 0.041) \\ &= 3.410 \end{aligned}$$

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 12 worksheets are provided for determining the predicted average crash frequency. The 12 worksheets include:

- *Worksheet SP2A (Corresponds to Worksheet 1A)*—General Information and Input Data for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2B (Corresponds to Worksheet 1B)*—Crash Modification Factors for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2C (Corresponds to Worksheet 1C)*—Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2D (Corresponds to Worksheet 1D)*—Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2E (Corresponds to Worksheet 1E)*—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2F (Corresponds to Worksheet 1F)*—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2G (Corresponds to Worksheet 1G)*—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2H (Corresponds to Worksheet 1H)*—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2I (Corresponds to Worksheet 1I)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2J (Corresponds to Worksheet 1J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2K (Corresponds to Worksheet 1K)*—Crash Severity Distribution for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2L (Corresponds to Worksheet 1L)*—Summary Results for Urban and Suburban Arterial Roadway Segments

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheet SP2A—General Information and Input Data for Urban and Suburban Roadway Segments

Worksheet SP2A is a summary of general information about the roadway segment, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 2a

Worksheet SP2A. General Information and Input Data for Urban and Suburban Roadway Segments

General Information		**Location Information**	
Analyst		Roadway	
Agency or Company		Roadway Section	
Date Performed		Jurisdiction	
		Analysis Year	
Input Data		**Base Conditions**	**Site Conditions**
Road type (2U, 3T, 4U, 4D, 5T)		—	4D
Length of segment, L (mi)		—	0.75
AADT (veh/day)		—	23,000
Type of on-street parking (none/parallel/angle)		none	None
Proportion of curb length with on-street parking		—	N/A
Median width (ft)		15	40
Lighting (present/not present)		not present	present
Auto speed enforcement (present/not present)		not present	not present
Major commercial driveways (number)		—	1
Minor commercial driveways (number)		—	4
Major industrial/institutional driveways (number)		—	—
Minor industrial/institutional driveways (number)		—	1
Major residential driveways (number)		—	1
Minor residential driveways (number)		—	1
Other driveways (number)		—	—
Speed Category		—	Low (30mph)
Roadside fixed object density (fixed objects/mi)		not present	20
Offset to roadside fixed objects (ft)		not present	12
Calibration Factor, C_r		1.0	1.0

Worksheet SP2B—Crash Modification Factors for Urban and Suburban Roadway Segments

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 6 of Worksheet SP2B which indicates the combined CMF value.

Worksheet SP2B. Crash Modification Factors for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
CMF for On-Street Parking	**CMF for Roadside Fixed Objects**	**CMF for Median Width**	**CMF for Lighting**	**CMF for Auto Speed Enforcement**	**Combined CMF**
CMF_{1r}	CMF_{2r}	CMF_{3r}	CMF_{4r}	CMF_{5r}	CMF_{comb}
from Equation 12-32	from Equation 12-33	from Table 12-22	from Equation 12-34	from Section 12.7.1	(1)*(2)*(3)*(4)*(5)
1.00	1.02	0.97	0.91	1.00	0.90

Worksheet SP2C—Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Roadway Segments

The SPF for multiple-vehicle nondriveway collisions along the roadway segment in Sample Problem 2 is calculated using Equation 12-10 and entered into Column 4 of Worksheet SP2C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 2 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values(from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 6 in Worksheet SP2B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle nondriveway crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP2C. Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
	SPF Coefficients		**Overdispersion Parameter, *k***	**Initial N_{brmv}**		**Adjusted N_{brmv}**	**Combined CMFs**	**Calibration Factor**	**Predicted N_{brmv}**
Crash Severity Level	**from Table 12-3**			**from Equation 12-10**	**Proportion of Total Crashes**		**(6) from Worksheet SP2B**		
	a	**b**	**from Table 12-3**			**$(4)_{total}$*(5)**		C_r	**(6)*(7)*(8)**
Total	−12.34	1.36	1.32	2.804	1.000	2.804	0.90	1.00	2.524
Fatal and injury (FI)	−12.76	1.28	1.31	0.825	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$ 0.278	0.780	0.90	1.00	0.702
Property damage only (PDO)	−12.81	1.38	1.34	2.143	$(5)_{total}-(5)_{FI}$ 0.722	2.024	0.90	1.00	1.822

Worksheet SP2D—Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Roadway Segments

Worksheet SP2D presents the default proportions for collision type (from Table 12-4) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for multiple-vehicle nondriveway crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle nondriveway crashes (from Column 9, Worksheet SP2C) into components by crash severity and collision type.

Worksheet SP2D. Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{brmv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{brmv\ (PDO)}$ (crashes/year)	Predicted $N_{brmv\ (total)}$ (crashes/year)
Collision Type	from Table 12-4	$(9)_{FI}$ from Worksheet SP2C	from Table 12-4	$(9)_{PDO}$ from Worksheet SP2C	(9)total from Worksheet SP2C
Total	1.000	0.702 $(2)*(3)_{FI}$	1.000	1.822 $(4)*(5)_{PDO}$	2.524 (3)+(5)
Rear-end collision	0.832	0.584	0.662	1.206	1.790
Head-on collision	0.020	0.014	0.007	0.013	0.027
Angle collision	0.040	0.028	0.036	0.066	0.094
Sideswipe, same direction	0.050	0.035	0.223	0.406	0.441
Sideswipe, opposite direction	0.010	0.007	0.001	0.002	0.009
Other multiple-vehicle collision	0.048	0.034	0.071	0.129	0.163

Worksheet SP2E—Single-Vehicle Crashes by Severity Level for Urban and Suburban Roadway Segments

The SPF for single-vehicle crashes along the roadway segment in Sample Problem 2 is calculated using Equation 12-13 and entered into Column 4 of Worksheet SP2E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 2 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 6 in Worksheet SP2B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle nondriveway crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP2E. Single-Vehicle Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
	SPF Coefficients		Overdispersion Parameter, k	Initial N_{brsv}		Adjusted N_{brsv}	Combined CMFs	Calibration Factor	Predicted N_{brsv}
Crash Severity Level	from Table 12-5		from Table 12-5	from Equation 12-13	Proportion of Total Crashes	$(4)_{total}*(5)$	(6) from worksheet SP2B	C_r	(6)*(7)*(8)
	a	b							
Total	−5.05	0.47	0.86	0.539	1.000	0.539	0.90	1.00	0.485
Fatal and injury (FI)	−8.71	0.66	0.28	0.094	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$ 0.174	0.094	0.90	1.00	0.085
Property damage only (PDO)	−5.04	0.45	1.06	0.446	$(5)_{total}-(5)_{FI}$ 0.826	0.445	0.90	1.00	0.401

Worksheet SP2F—Single-Vehicle Crashes by Collision Type for Urban and Suburban Roadway Segments

Worksheet SP2F presents the default proportions for collision type (from Table 12-5) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by collision type is presented in 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and Columns 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 9, Worksheet SP2E) into components by crash severity and collision type.

Worksheet SP2F. Single-Vehicle Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{brsv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{brsv\ (PDO)}$ (crashes/year)	Predicted $N_{brsv\ (total)}$ (crashes/year)
Collision Type	from Table 12-6	$(9)_{FI}$ from Worksheet SP2E	from Table 12-6	$(9)_{PDO}$ from Worksheet SP2E	$(9)_{total}$ from Worksheet SP2E
Total	1.000	0.085 $(2)*(3)_{FI}$	1.000	0.401 $(4)*(5)_{PDO}$	0.485 (3)+(5)
Collision with animal	0.001	0.000	0.063	0.025	0.025
Collision with fixed object	0.500	0.043	0.813	0.326	0.369
Collision with other object	0.028	0.002	0.016	0.006	0.008
Other single-vehicle collision	0.471	0.040	0.108	0.043	0.083

Worksheet SP2G—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Roadway Segments

Worksheet SP2G determines and presents the number of multiple-vehicle driveway-related collisions. The number of driveways along both sides of the road is entered in Column 2 by driveway type (Column 1). The associated number of crashes per driveway per year by driveway type as found in Table 12-7 is entered in Column 3. Column 4 contains the regression coefficient for AADT also found in Table 12-7. The initial average crash frequency of multiple-vehicle driveway-related crashes is calculated from Equation 12-16 and entered into Column 5. The overdispersion parameter from Table 12-7 is entered into Column 6; however, the overdispersion parameter is not needed for Sample Problem 2 (as the EB Method is not utilized).

Worksheet SP2G. Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
		Crashes per Driveway per Year, N_j	**Coefficient for Traffic Adjustment, t**	**Initial N_{brdwy}**	**Overdispersion Parameter, k**
Driveway Type	**Number of Driveways, n_j**	**from Table 12-7**	**from Table 12-7**	**Equation 12-16 n_j*N_j*(AADT/15,000)$_t$**	**from Table 12-7**
Major commercial	1	0.033	1.106	0.053	—
Minor commercial	4	0.011	1.106	0.071	
Major industrial/institutional	0	0.036	1.106	0.000	
Minor industrial/institutional	1	0.005	1.106	0.008	
Major residential	1	0.018	1.106	0.029	
Minor residential	1	0.003	1.106	0.005	
Other	0	0.005	1.106	0.000	
Total	—	—	—	0.166	1.39

Worksheet SP2H—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Roadway Segments

The initial average crash frequency of multiple-vehicle driveway-related crashes from Column 5 of Worksheet SP2G is entered in Column 2. This value is multiplied by the proportion of crashes by severity (Column 3) found in Table 12-7, and the adjusted value is entered into Column 4. Column 5 represents the combined CMF (from Column 6 in Worksheet SP2B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of multiple-vehicle driveway-related crashes using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SP2H. Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Initial N_{brdwy}	Proportion of Total Crashes (f_{dwy})	Adjusted N_{brdwy}	Combined CMFs		Predicted N_{brdwy}
Crash Severity Level	$(5)_{total}$ from Worksheet SP2G	from Table 12-7	$(2)_{total}$ *(3)	(6) from Worksheet SP2B	Calibration Factor, C_r	(4)*(5)*(6)
Total	0.166	1.000	0.166	0.90	1.00	0.149
Fatal and injury (FI)	—	0.284	0.047	0.90	1.00	0.042
Property damage only (PDO)	—	0.716	0.119	0.90	1.00	0.107

Worksheet SP2I—Vehicle-Pedestrian Collisions for Urban and Suburban Roadway Segments

The predicted average crash frequency of multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related predicted crashes from Worksheets SP2C, SP2E, and SP2H are entered into Columns 2, 3, and 4, respectively. These values are summed in Column 5. Column 6 contains the pedestrian crash adjustment factor (see Table 12-8). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP2I. Vehicle-Pedestrian Collisions

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted N_{brmv}	Predicted N_{brsv}	Predicted N_{brdwy}	Predicted N_{br}	f_{pedr}		Predicted N_{pedr}
Crash Severity Level	(9) from Worksheet SP2C	(9) from Worksheet SP2E	(7) from Worksheet SP2H	(2)+(3)+(4)	from Table 12-8	Calibration Factor, C_r	(5)*(6)*(7)
Total	2.524	0.485	0.149	3.158	0.067	1.000	0.212
Fatal and injury (FI)	—	—	—	—	—	1.00	0.212

Worksheet SP2J—Vehicle-Bicycle Collisions for Urban and Suburban Roadway Segments

The predicted average crash frequency of multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related predicted crashes from Worksheets SP2C, SP2E, and SP2H are entered into Columns 2, 3, and 4, respectively. These values are summed in Column 5. Column 6 contains the bicycle crash adjustment factor (see Table 12-9). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-bicycle collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-bicycle collisions are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP2J. Vehicle-Bicycle Collisions for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted N_{brmv}	Predicted N_{brsv}	Predicted N_{brdwy}	Predicted N_{br}	f_{biker}		Predicted N_{biker}
Crash Severity Level	**(9) from Worksheet SP2C**	**(9) from Worksheet SP2E**	**(7) from Worksheet SP2H**	**(2)+(3)+(4)**	**from Table 12-9**	**Calibration Factor, C_r**	**(5)*(6)*(7)**
Total	2.524	0.485	0.149	3.158	0.013	1.00	0.041
Fatal and injury	—	—	—	—	—	1.00	0.041

Worksheet SP2K—Crash Severity Distribution for Urban and Suburban Roadway Segments

Worksheet SP2K provides a summary of all collision types by severity level. Values from Worksheets SP2C, SP2E, SP2H, SP2I, and SP2J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP2K. Crash Severity Distribution for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	Property Damage Only (PDO)	Total
Collision Type	(3) from Worksheet SP2D and SP2F; (7) from Worksheet SP2H; and (8) from Worksheet SP2I and SP2J	(5) from Worksheet SP2D and SP2F; and (7) from Worksheet SP2H	(6) from Worksheet SP2D and SP2F; (7) from Worksheet SP2H; and (8) from Worksheet SP2I and SP2J
MULTIPLE-VEHICLE			
Rear-end collisions (from Worksheet SP2D)	0.584	1.206	1.790
Head-on collisions (from Worksheet SP2D)	0.014	0.013	0.027
Angle collisions (from Worksheet SP2D)	0.028	0.066	0.094
Sideswipe, same direction (from Worksheet SP2D)	0.035	0.406	0.441
Sideswipe, opposite direction (from Worksheet SP2D)	0.007	0.002	0.009
Driveway-related collisions (from Worksheet SP2H)	0.042	0.107	0.149
Other multiple-vehicle collision (from Worksheet SP2D)	0.034	0.129	0.163
Subtotal	0.744	1.929	2.673
SINGLE-VEHICLE			
Collision with animal (from Worksheet SP2F)	0.000	0.025	0.025
Collision with fixed object (from Worksheet SP2F)	0.043	0.326	0.369
Collision with other object (from Worksheet SP2F)	0.002	0.006	0.008
Other single-vehicle collision (from Worksheet SP2F)	0.040	0.043	0.083
Collision with pedestrian (from Worksheet SP2I)	0.212	0.000	0.212
Collision with bicycle (from Worksheet SP2J)	0.041	0.000	0.041
Subtotal	0.338	0.400	0.738
Total	1.082	2.329	3.411

Worksheet SP2L—Summary Results for Urban and Suburban Roadway Segments

Worksheet SP2L presents a summary of the results. Using the roadway segment length and the AADT, the worksheet presents the crash rate in miles per year (Column 4) and in million vehicle miles (Column 6).

Worksheet SP2L. Summary Results for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
Crash Severity Level	Predicted Average Crash Frequency, $N_{predicted\ rs}$ (crashes/year) (Total) from Worksheet SP2K	Roadway Segment Length, L (mi)	Crash Rate (crashes/mi/year) (2)/(3)
Total	3.411	0.75	4.5
Fatal and injury (FI)	1.082	0.75	1.4
Property damage only (PDO)	2.329	0.75	3.1

12.13.3. Sample Problem 3

The Site/Facility
A three-leg stop-controlled intersection located on an urban arterial.

The Question
What is the predicted crash frequency of the unsignalized intersection for a particular year?

The Facts
- 1 left-turn lane on one major road approach
- No right-turn lanes on any approach
- AADT of major road is 14,000 veh/day
- AADT of minor road is 4,000 veh/day

Assumptions
Collision type distributions used are the default values from Tables 12-11 and 12-13 and Equations 12-30 and 12-31.

The calibration factor is assumed to be 1.00.

Results
Using the predictive method steps as outlined below, the predicted average crash frequency for the unsignalized intersection in Sample Problem 3 is determined to be 1.6 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 3, 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.
For a three-leg stop-controlled intersection, SPF values for multiple-vehicle, single-vehicle, vehicle-pedestrian, and vehicle-bicycle collisions are determined. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these two models.

Multiple-Vehicle Crashes
The SPF for multiple-vehicle collisions for a single three-leg stop-controlled intersection is calculated from Equation 12-21 and Table 12-10 as follows:

$$N_{bimv} = exp\left(a + b \times \ln\left(AADT_{maj}\right) + c \times \ln\left(AADT_{min}\right)\right)$$
$$N_{bimv(\text{total})} = exp\left(-13.63 + 1.11 \times \ln(14{,}000) + 0.41 \times \ln(4{,}000)\right)$$
$$= 1.892 \text{ crashes/year}$$
$$N_{bimv(FI)} = exp\left(-14.01 + 1.16 \times \ln(14{,}000) + 0.30 \times \ln(4{,}000)\right)$$
$$= 0.639 \text{ crashes/year}$$
$$N_{bimv(PDO)} = exp\left(-15.38 + 1.20 \times \ln(14{,}000) + 0.51 \times \ln(4{,}000)\right)$$
$$= 1.358 \text{ crashes/year}$$

These initial values for fatal-and-injury (FI) and property-damage-only (PDO) crashes are then adjusted using Equations 12-22 and 12-23 to assure that they sum to the value for total crashes as follows:

$$N_{bimv(FI)} = N_{bimv(\text{total})}\left(\frac{N'_{bimv(FI)}}{N'_{bimv(FI)} + N'_{bimv(PDO)}}\right)$$
$$= 1.892 \times \left(\frac{0.639}{0.639 + 1.358}\right)$$
$$= 0.605 \text{ crashes/year}$$

$$N_{bimv(PDO)} = N_{bimv(\text{total})} - N_{bimv(FI)}$$
$$= 1.892 - 0.605$$
$$= 1.287 \text{ crashes/year}$$

Single-Vehicle Crashes

The SPF for single-vehicle crashes for a single three-leg stop-controlled intersection is calculated from Equation 12-24 and Table 12-12 as follows:

$$N_{bisv} = exp\left(a + b \times \ln\left(AADT_{maj}\right) + c \times \ln\left(AADT_{min}\right)\right)$$
$$N_{bisv(\text{total})} = exp\left(-6.81 + 0.16 \times \ln(14{,}000) + 0.51 \times \ln(4{,}000)\right)$$
$$= 0.349 \text{ crashes/year}$$
$$N_{bisv(PDO)} = exp\left(-8.36 + 0.25 \times \ln(14{,}000) + 0.55 \times \ln(4{,}000)\right)$$
$$= 0.244 \text{ crashes/year}$$

Since there are no models for fatal-and-injury crashes at a three-leg stop-controlled intersections, $N_{bisv(FI)}$ is calculated using Equation 12-27 (in place of Equation 12-25), and the initial value for $N_{bisv(PDO)}$ calculated above is then adjusted using Equation 12-26 to assure that fatal-and-injury and property-damage-only crashes sum to the value for total crashes as follows:

$$N_{bisv(FI)} = N_{bisv(\text{total})} \times f_{bisv}$$

For a three-leg stop-controlled intersection, the default proportion of fatal-and-injury crashes, $f_{bisv} = 0.31$ (see Section 12.6.2, Single-Vehicle Crashes)

$$\begin{aligned} N_{bisv(FI)} &= 0.349 \times 0.31 \\ &= 0.108 \text{ crashes/year} \\ N_{bisv(PDO)} &= N_{bisv(\text{total})} - N_{bisv(FI)} \\ &= 0.349 - 0.108 \\ &= 0.241 \text{ crashes/year} \end{aligned}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.

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

Intersection Left-Turn Lanes (CMF_{1i})

From Table 12-24, for a three-leg stop-controlled intersection with one left-turn lane on the major road, $CMF_{1i} = 0.67$.

Intersection Left-Turn Signal Phasing (CMF_{2i})

For unsignalized intersections, $CMF_{2i} = 1.00$.

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

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

Right-Turn-on-Red (CMF_{4i})

For unsignalized intersections, $CMF_{4i} = 1.00$.

Lighting (CMF_{5i})

Since there is no lighting at this intersection, CMF_{5i} is 1.00 (i.e., the base condition for CMF_{5i} is the absence of intersection lighting).

Red-Light Cameras (CMF_{6i})

For unsignalized intersections, CMF_{6i} is always 1.00.

The combined CMF value for Sample Problem 3 is 0.67.

Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The predicted average crash frequency of an intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions) for SPF base conditions, N_{bi}, must be calculated in order to determine vehicle-pedestrian and vehicle-bicycle crashes. N_{bi} is determined from Equation 12-6 as follows:

$$N_{bi} = N_{spf\ int} \times \left(CMF_{1i} \times CMF_{2i} \times \ldots \times CMF_{6i}\right)$$

From Equation 12-7, $N_{spf\ int}$ can be calculated as follows:

$$\begin{aligned} N_{spf\ int} &= N_{bimv} + N_{bisv} \\ &= 1.892 + 0.349 \\ &= 2.241 \text{ crashes/year} \end{aligned}$$

The combined CMF value for Sample Problem 3 is 0.67.

$$N_{bi} = 2.241 \times (0.67)$$
$$= 1.501 \text{ crashes/year}$$

The SPF for vehicle-pedestrian collisions for a three-leg stop-controlled intersection is calculated from Equation 12-30 as follows:

$$N_{pedi} = N_{bi} \times f_{pedi}$$

From Table 12-16, for a three-leg stop-controlled intersection the pedestrian crash adjustment factor, $f_{pedi} = 0.211$.

$$N_{pedi} = 1.501 \times 0.021$$
$$= 0.032 \text{ crashes/year}$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-31 as follows:

$$N_{bikei} = N_{pedi} \times f_{bikei}$$

From Table 12-17, for a three-leg stop-controlled intersection, the bicycle crash adjustment factor $f_{bikei} = 0.016$.

$$N_{bikei} = 1.501 \times 0.016$$
$$= 0.024 \text{ crashes/year}$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed in Sample Problem 3 that a calibration factor, C_i, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 12-5 based on results obtained in Steps 9 through 11 as follows:

$$N_{\text{predicted } int} = C_i \times (N_{bi} + N_{pedi} + N_{bikei})$$
$$= 1.00 \times (1.501 + 0.032 + 0.024)$$
$$= 1.557 \text{ crashes/year}$$

Worksheets

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for an intersection. To apply the predictive method steps to multiple intersections, a series of 12 worksheets are provided for determining the predicted average crash frequency at intersections. The 12 worksheets include:

- *Worksheet SP3A (Corresponds to Worksheet 2A)*—General Information and Input Data for Urban and Suburban Arterial Intersections
- *Worksheet SP3B (Corresponds to Worksheet 2B)*—Crash Modification Factors for Urban and Suburban Arterial Intersections
- *Worksheet SP3C (Corresponds to Worksheet 2C)*—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SP3D (Corresponds to Worksheet 2D)*—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

- *Worksheet SP3E (Corresponds to Worksheet 2E)*—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SP3F (Corresponds to Worksheet 2F)*—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SP3G (Corresponds to Worksheet 2G)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Stop-Controlled Intersections
- *Worksheet SP3J (Corresponds to Worksheet 2J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections
- *Worksheet SP3K (Corresponds to Worksheet 2K)*—Crash Severity Distribution for Urban and Suburban Arterial Intersections
- *Worksheet SP3L (Corresponds to Worksheet 2L)*—Summary Results for Urban and Suburban Arterial Intersections

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheet SP3A—General Information and Input Data for Urban and Suburban Arterial Intersections

Worksheet SP3A is a summary of general information about the intersection, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 3.

Worksheet SP3A. General Information and Input Data for Urban and Suburban Arterial 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, 3ST-HS, 3STT, 3aST, 3SG, 3SG-HS, 4ST, 4ST-HS, 4aST, 4SG, 4SG-HS, 5SG)~~(3ST, 3SG, 4ST, 4SG)~~	—	3ST
$AADT_{maj}$ (veh/day)~~,~~ ~~(~~$AADT_{maj1}$ (veh/day) (for 3STT only)	—	14,000
$AADT_{maj2}$ (veh/day)~~,~~ (for 3STT only)	—	—
$AADT_{min}$ (veh/day)	—	4,000
$AADT_{fifth}$ (veh/day)	—	—
Intersection lighting (present/not present)	not present	not present
Calibration factor, C_i	1.00	1.00
Data for unsignalized intersections only:	—	—
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	1
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	0
Horizontal curve radius (ft) [for 3STT only]	84	—
Horizontal curve length (ft) [for 3STT only]	100	—
Data for signalized intersections only:	—	—
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)	0	N/A
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)	0	N/A
Number of approaches with left-turn signal phasing	—	N/A
Number of approaches with right-turn-on-red prohibited	0	N/A
Type of left-turn signal phasing	permissive	N/A
Intersection red light cameras (present/not present)	not present	N/A
Sum of all pedestrian crossing volumes (PedVol)	—	N/A
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	N/A
Number of bus stops within 300 m (1,000 ft) of the intersection	0	N/A
Schools within 300 m (1,000 ft) of the intersection (present/not present)	not present	N/A
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection	0	N/A

Worksheet SP3B—Crash Modification Factors for Urban and Suburban Arterial Intersections

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 8~~7~~ of Worksheet SP3B which indicates the combined CMF value.

Worksheet SP3B. Crash Modification Factors for Urban and Suburban Arterial Intersections

~~(1)~~	~~(2)~~	~~(3)~~	~~(4)~~	~~(5)~~	~~(6)~~	~~(7)~~
~~CMF for Left-Turn Lanes~~	~~CMF for Left-Turn Signal Phasing~~	~~CMF for Right-Turn Lanes~~	~~CMF for Right-Turn-on-Red~~	~~CMF for Lighting~~	~~CMF for Red-Light Cameras~~	~~Combined CMF~~
~~CMF_{1i}~~	~~CMF_{2i}~~	~~CMF_{3i}~~	~~CMF_{4i}~~	~~CMF_{5i}~~	~~CMF_{6i}~~	~~CMF_{comb}~~
~~from Table 12-24~~	~~from Table 12-25~~	~~from Table 12-26~~	~~from Equation 12-35~~	~~from Equation 12-36~~	~~from Equation 12-37~~	~~(1)*(2)*(3)*(4)*(5)*(6)~~
~~0.67~~	~~1.00~~	~~1.00~~	~~1.00~~	~~1.00~~	~~1.00~~	~~0.67~~

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	CMF for Left-Turn Lanes	**CMF for Left-Turn Signal Phasing**	**CMF for Right-Turn Lanes**	**CMF for Right-Turn-on-Red**	**CMF for Lighting**	**CMF for Red-Light Cameras**	**CMF for Horizontal Curves**	**Combined CMF**
	CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{5i}	CMF_{6i}	CMF_{7i}	CMF_{comb}
Crash Type and Severity	from Table 12-24	from Table 12-25	from Table 12-26	from Equation 12-35	from Equation 12-36	from Equation 12-37	from Equation 12-CMF	(1)*(2)*(3)*(4)*(5)*(6)
MV-Total	0.67	1.00	1.00	1.00	1.00	1.00	1.00	0.67
MV-FI	0.67	1.00	1.00	1.00	1.00	1.00	1.00	0.67
MV-PDO	0.67	1.00	1.00	1.00	1.00	1.00	1.00	0.67
SV-Total	0.67	1.00	1.00	1.00	1.00	1.00	1.00	0.67
SV-FI	0.67	1.00	1.00	1.00	1.00	1.00	1.00	0.67
SV-PDO	0.67	1.00	1.00	1.00	1.00	1.00	1.00	0.67

Worksheet SP3C—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

The SPF for multiple-vehicle collisions at the intersection in Sample Problem 3 is calculated using Equation 12-21~~2~~ and entered into Column 4 of Worksheet SP3C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 3 (as the EB Method is not utilized). Column 5 of the worksheet adjusts the results in Column 4 to account for the site specific horizontal curve CMF. Column 6~~5~~ of the worksheet presents the proportions for crash severity levels calculated from the results in Column 5~~4~~. These proportions are used to adjust the initial SPF values (from Column 5~~4~~) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 7~~6~~. Column 8~~7~~ represents the combined CMF (from Column 8~~7~~ in Worksheet SP3B), and Column 9~~8~~ represents the calibration factor. Column ~~9~~10 calculates the predicted average crash frequency of multiple-vehicle crashes using the values in Column 7~~6~~, the combined CMF in Column 8~~7~~, and the calibration factor in Column 9~~8~~.

Worksheet SP3C. Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections (Applicable to 3ST, 3ST-HS, 3STT, 3SG, 3SG-HS, 4ST, 4ST-HS, 4SG, 4SG-HS, 5SG)

(1)	(2)						(3)	(4)	(5)	(~~5~~6)	(~~6~~7)	(~~7~~8)	(~~8~~9)	(~~9~~10)
	SPF Coefficients						Overdispersion Parameter, k	Initial N_{bimv}	Initial N_{bimv} Adjusted for Curve CMF		Adjusted N_{bimv}	Combined CMFs		Predicted N_{bimv}
	from Table 12-10							from Equation 12-21~~22~~, 12-EMVA, or 12-EMVB	(4)*(7) from Worksheet 2B					
Crash Severity Level	a	b	c~~, e(FI)~~	d~~d~~	e	f	from Table 12-10			Proportion of Total Crashes	$(\sim\!\!\sim 4 \sim\!\!\sim 5)_{total}$*(~~5~~6)	(~~7~~8) from Worksheet SP3B	Calibration Factor, C_i	(~~6~~7)*(~~7~~8)*(~~8~~9)
Total	−13.36	1.11	0.41	--	-	-	0.80	1.892	1.892	1.000	1.892	0.67	1.00	1.268
Fatal and injury (FI)	−14.01	1.16	0.30	--	-	-	0.69	0.639	0.639	$(\sim 4 \sim 5)_{FI}$/(($(\sim 4 \sim 5)_{FI}$+$(\sim 4 \sim 5)_{PDO}$) 0.320	0.605	0.67	1.00	0.405
Property damage only (PDO)	−15.38	1.20	0.51	--	-	-	0.77	1.358	1.358	$(\sim 5 \sim 6)_{total}$−$(\sim 5 \sim 6)_{FI}$ 0.680	1.287	0.67	1.00	0.862

Worksheet SP3D—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

Worksheet SP3D presents the default proportions for collision type (from Table 12-11) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for multiple-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle crashes (from Column 10~~9~~, Worksheet SP3C) into components by crash severity and collision type.

Worksheet SP3D. Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{bimv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{bimv\ (PDO)}$ (crashes/year)	Predicted $N_{bimv\ (total)}$ (crashes/year)
Collision Type	from Table 12-11 or 12-XB	(~~9~~10)$_{FI}$ from Worksheet SP3C	from Table 12-11 or 12-XB	(~~9~~10)$_{PDO}$ from Worksheet SP3C	(~~9~~10)$_{total}$ from Worksheet SP3C
Total	1.000	0.405 (2)*(3)$_{FI}$	1.000	0.862 (4)*(5)$_{PDO}$	1.268 (3)+(5)
Rear-end collision	0.421	0.171	0.440	0.379	0.550
Head-on collision	0.045	0.018	0.023	0.020	0.038
Angle collision	0.343	0.139	0.262	0.226	0.365
Sideswipe	0.126	0.051	0.040	0.034	0.085
Other multiple-vehicle collision	0.065	0.026	0.235	0.203	0.229

Worksheet SP3E—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections

The SPF for single-vehicle crashes at the intersection in Sample Problem 3 is calculated using Equation 12-24~~25~~ for total and property-damage-only (PDO) crashes and entered into Column 4 of Worksheet SP3E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 3 (as the EB Method is not utilized). Since there are no models for fatal-and-injury crashes at a three-leg stop-controlled intersections, $N_{bisv(FI)}$ is calculated using Equation 12-27~~ (in place of Equation 12-25)~~, and the value is entered into Column 4. Column 5 of the worksheet adjusts the results in Column 4 to account for site specific horizontal curvature. ~~and 6 since no further adjustment is required.~~ Column 6~~5~~ of the worksheet presents the proportions for crash severity levels calculated from the results in Column 5~~4~~. Column 6 is not applicable since there are no models for fatal-and-injury single-vehicle crashes for three-leg stop-controlled intersections. In Column 7, PDO crashes are adjusted based on total and fatal-and-injury crashes. ~~These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6.~~ Column 8~~7~~ represents the combined CMF (from Column 8~~7~~ in Worksheet SP3B), and Column 9~~8~~ represents the calibration factor. Column 10~~9~~ calculates the predicted average crash frequency of single-vehicle crashes using the values in Column 7~~6~~, the combined CMF in Column 8~~7~~, and the calibration factor in Column 9~~8~~.

Worksheet SP3E. Single-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections (Applicable to 3ST, 3ST-HS, 3STT, 3SG, 3SG-HS, 4ST, 4ST-HS, 4SG, 4SG-HS, 5SG)

(1)	(2)					(3)	(4)	(5)	(~~5~~6)	(~~6~~7)	(~~7~~8)	(~~8~~9)	(~~9~~10)
	SPF Coefficients					Overdispersion Parameter, k	Initial N_{bisv}	Initial N_{bisv} Adjusted for Curve CMF		Adjusted N_{bisv}	Combined CMFs		Predicted N_{bisv}
	from Table 12-12												
Crash Severity Level	a	b/~~f~~	c	f	g	from Table 12-12	from Equation 12-24, ~~or 12-~~ESVA~~25; (FI) from Equation 12-25 or 12-27~~, or 12-ESVB	(4)*(7) from Worksheet 2B	Proportion of Total Crashes [not used for 3ST, 4ST, and 3STT]~~Proportion of Total Crashes~~	$(5)_{total}$*(6) [not used for 3ST, 4ST, and 3STT]~~$(4)_{total}$*(5)~~	(~~7~~8) from Worksheet SP3B	Calibration Factor, C_i	(~~6~~7)*(~~7~~8)*(~~8~~9)
Total	−6.81	0.16	0.51	-	-	1.14	0.349	0.349	1.000	0.349	0.67	1.00	0.234
Fatal and injury (FI)	-~~N/A~~	-~~N/A~~	-~~N/A~~	-	-	-~~N/A~~	Equation 12-27 [3ST and 4ST only] ~~0.108~~ 0.108	0.108	$(\sout{4}5)_{FI}/((\sout{4}5)_{FI}+(\sout{4}5)_{PDO})$ N/A	$(5)_{FI}$ [3ST, 4ST, 3STT only]~~0.108~~ 0.108	0.67	1.00	0.072
Property damage only (PDO)	−8.36	0.25	0.55	-	-	1.29	0.244	0.244	$(\sout{5}6)_{total}-(\sout{5}6)_{FI}$ ~~0.693~~N/A	$(7)_{total}-(7)_{FI}$ [3ST, 4ST, 3STT only]~~0.242~~ 0.242	0.67	1.00	0.162

Worksheet SP3F—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections

Worksheet SP3F presents the default proportions for collision type (from Table 12-13) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 10~~9~~, Worksheet SP3E) into components by crash severity and collision type.

Worksheet SP3F. Single-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type (FI)	Predicted $N_{bisv\,(FI)}$ (crashes/year)	Proportion of Collision Type (PDO)	Predicted $N_{bisv\,(PDO)}$ (crashes/year)	Predicted $N_{bisv\,(total)}$ (crashes/year)
Collision Type	Table 12-13 or 12-XB	(~~9~~10)$_{FI}$ from Worksheet SP3E	Table 12-13 or 12-XB	(~~9~~10)$_{PDO}$ from Worksheet SP3E	(~~9~~10)~~PDO~~total from Worksheet SP3E
Total	1.000	0.072 (2)*(3)$_{FI}$	1.000	0.162 (4)*(5)$_{PDO}$	0.234 (3)+(5)
Collision with parked vehicle	0.001	0.000	0.003	0.000	0.000
Collision with animal	0.003	0.000	0.018	0.003	0.003
Collision with fixed object	0.762	0.055	0.834	0.135	0.190
Collision with other object	0.090	0.006	0.092	0.015	0.021
Other single-vehicle collision	0.039	0.003	0.023	0.004	0.007
Single-vehicle noncollision	0.105	0.008	0.030	0.005	0.013

Worksheet SP3G—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Stop-Controlled Intersections

The predicted average crash frequency of multiple-vehicle predicted crashes and single-vehicle predicted crashes from Worksheets SP3C and SP3E are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the pedestrian crash adjustment factor (see Table 12-16). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP3G. Vehicle-Pedestrian Collisions for Urban and Suburban Arterial ~~Stop-Controlled~~ Intersections (Applicable to 3ST, 3ST-HS, 3aST, 3SG-HS, 4ST, 4ST-HS, 4aST, 4SG-HS, and 5SG)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv} or Predicted $N_{bimv+sv}$ for aST(1)	Predicted N_{bisv}(1)	Predicted N_{bi}(1)	f_{pedi}		Predicted N_{pedi}
Crash Severity Level	(7)*(8)~~(10)~~~~(7)*(8)~~ (9) from Worksheet SP3C	(7)*(8)~~(10)~~~~(7)*(8)~~ (9) from Worksheet SP3E [not used for 3aST and 4aST]	(2)+(3)	from Table 12-16	Calibration Factor, C_i	(4)*(5)*(6)
Total	1.268	0.234	1.502	0.021	1.00	0.032
Fatal and injury (FI)	—	—	—	—	1.00	0.032

(1) Predicted values prior to calibration

Worksheet SP3J—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

The predicted average crash frequency of multiple-vehicle predicted crashes and single-vehicle predicted crashes from Worksheets SP3C and SP3E are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the bicycle crash adjustment factor (see Table 12-17). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-bicycle collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP3J. Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv} or Predicted $N_{bimv+sv}$ for aST(1)	Predicted N_{bisv}(1)	Predicted N_{bi}(1)	f_{bikei}		Predicted N_{pedi}
Crash Severity Level	(7)*(8)~~(10)~~~~(7)*(8)~~ (9) from Worksheet SP3C	(7)*(8)~~(10)~~~~(7)*(8)~~ (9) from Worksheet SP3E [not used for 3aST and 4aST]	(2)+(3)	from Table 12-17	Calibration Factor, C_i	(4)*(5)*(6)
Total	1.268	0.234	1.502	0.016	1.000	0.024
Fatal and injury (FI)	—	—	—	—	1.000	0.024

(1) Predicted values prior to calibration

Worksheet SP3K—Crash Severity Distribution for Urban and Suburban Arterial Intersections

Worksheet SP3K provides a summary of all collision types by severity level. Values from Worksheets SP3D, SP3F, SP3G, and SP3J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP3K. Crash Severity Distribution for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	Property Damage Only (PDO)	Total
Collision Type	(3) from Worksheets SP3D and SP3F; (7) from SP3G (or SP3I) and SP3J	(5) from Worksheets SP3D and SP3F	(6) from Worksheets SP3D and SP3F; (7) from SP3G (or SP3I) and SP3J
MULTIPLE-VEHICLE COLLISIONS			
Rear-end collisions (from Worksheet SP3D)	0.171	0.379	0.550
Head-on collisions (from Worksheet SP3D)	0.018	0.020	0.038
Angle collisions (from Worksheet SP3D)	0.139	0.226	0.365
Sideswipe (from Worksheet SP3D)	0.051	0.034	0.085
Other multiple-vehicle collision (from Worksheet SP3D)	0.026	0.203	0.229
Subtotal	0.405	0.862	1.267
SINGLE-VEHICLE COLLISIONS			
Collision with parked vehicle (from Worksheet SP3F)	0.000	0.000	0.000
Collision with animal (from Worksheet SP3F)	0.000	0.003	0.003
Collision with fixed object (from Worksheet SP3F)	0.055	0.135	0.190
Collision with other object (from Worksheet SP3F)	0.006	0.015	0.021
Other single-vehicle collision (from Worksheet SP3F)	0.003	0.004	0.007
Single-vehicle noncollision (from Worksheet SP3F)	0.008	0.005	0.013
Collision with pedestrian (from Worksheet SP3G or SP3I)	0.032	0.000	0.032
Collision with bicycle (from Worksheet SP3J)	0.024	0.000	0.024
Subtotal	0.128	0.162	0.290
Total	0.533	1.024	1.557

Worksheet SP3L—Summary Results for Urban and Suburban Arterial Intersections

Worksheet SP3L presents a summary of the results.

Worksheet SP3L. Summary Results for Urban and Suburban Arterial Intersections

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	(Total) from Worksheet SP3K
Total	1.557
Fatal and injury (FI)	0.533
Property damage only (PDO)	1.024

12.13.4. Sample Problem 4

The Intersection
A four-leg signalized intersection located on an urban arterial.

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

The Facts

- 1 left-turn lane on each of the two major road approaches
- 1 right-turn lane on each of the two major road approaches
- Protected/permissive left-turn signal phasing on major road
- AADT of major road is 15,000 veh/day
- AADT of minor road is 9,000 veh/day
- Lighting is present
- No approaches with prohibited right-turn-on-red
- Four-lane divided major road
- Two-lane undivided minor road
- Pedestrian volume is 1,500 peds/day
- The number of bus stops within 1,000 ft of intersection is 2
- A school is present within 1,000 ft of intersection
- The number of alcohol establishments within 1,000 ft of intersection is 6

Assumptions
Collision type distributions used are the default values from Tables 12-11 and 12-13 and Equations 12-28 and 12-31.

The calibration factor is assumed to be 1.00.

The maximum number of lanes crossed by a pedestrian is assumed to be four (crossing two through lanes, one left-turn lane, and one right-turn lane across one side of the divided major road).

Results
Using the predictive method steps as outlined below, the predicted average crash frequency for the signalized intersection in Sample Problem 4 is determined to be 3.4 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 4, 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.
For a four-leg signalized intersection, SPF values for multiple-vehicle, single-vehicle, vehicle-pedestrian, and vehicle-bicycle collisions are determined. The calculations for total multiple- and single-vehicle collisions are presented below. Detailed steps for calculating SPFs for fatal-and-injury (FI) and property-damage-only (PDO) crashes are presented in Sample Problem 3 ~~(for fatal-and-injury base crashes at a four-leg signalized intersection,~~

~~Equation 12-25 in place of Equation 12-27 is used)~~. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these two models.

Multiple-Vehicle Collisions

The SPF for multiple-vehicle collisions for a single four-leg signalized intersection is calculated from Equation 12-21 and Table 12-10 as follows:

$$\begin{aligned} N_{bimv} &= exp\left(a + b \times \ln\left(AADT_{maj}\right) + c \times \ln\left(AADT_{min}\right)\right) \\ N_{bimv(\text{total})} &= exp\left(-10.99 + 1.07 \times \ln(15{,}000) + c \times \ln(9{,}000)\right) \\ &= 4.027 \text{ crashes/year} \end{aligned}$$

Single-Vehicle Crashes

The SPF for single-vehicle crashes for a single four-leg signalized intersection is calculated from Equation 12-24 and Table 12-12 as follows:

$$\begin{aligned} N_{bisv} &= exp\left(a + b \times \ln\left(AADT_{maj}\right) + c \times \ln\left(AADT_{min}\right)\right) \\ N_{bisv(\text{total})} &= exp\left(-10.21 + 0.68 \times \ln(15{,}000) + 0.27 \times \ln(9{,}000)\right) \\ &= 0.297 \text{ crashes/year} \end{aligned}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.

Each CMF used in the calculation of the predicted average crash frequency of the intersection is calculated below. CMF_{1i} through CMF_{2i} are applied to multiple-vehicle collisions and single-vehicle crashes, while CMF_{1p} through CMF_{3p} are applied to vehicle-pedestrian collisions.

Intersection Left-Turn Lanes (CMF_{1i})

From Table 12-24, for a four-leg signalized intersection with one left-turn lane on each of two approaches, $CMF_{1i} = 0.81$.

Intersection Left-Turn Signal Phasing (CMF_{2i})

From Table 12-25, for a four-leg signalized intersection with protected/permissive left-turn signal phasing for two approaches, $CMF_{2i} = 0.98(0.99 * 0.99)$.

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

From Table 12-26, for a four-leg signalized intersection with one right-turn lane on each of two approaches, $CMF_{3i} = 0.92$.

Right-Turn-on-Red (CMF_{4i})

Since right-turn-on-red (RTOR) is not prohibited on any of the intersection legs, $CMF_{4i} = 1.00$ (i.e., the base condition for CMF_{4i} is permitting a RTOR at all approaches to a signalized intersection).

Lighting (CMF_{5i})

CMF_{5i} is calculated from Equation 12-36.

$$CMF_{5i} = 1 - 0.38 \times p_{ni}$$

From Table 12-27, the proportion of crashes that occur at night, $p_{ni} = 0.235$.

$$\begin{aligned} CMF_{5i} &= 1 - 0.38 \times 0.235 \\ &= 0.91 \end{aligned}$$

Red-Light Cameras (CMF_{6i})
Since no red light cameras are present at this intersection, $CMF_{6i} = 1.00$ (i.e., the base condition for CMF_{6i} is the absence of red light cameras).

The combined CMF value applied to multiple- and single-vehicle crashes in Sample Problem 4 is calculated below.

$$\begin{aligned} CMF_{comb} &= 0.81 \times 0.98 \times 0.92 \times 0.91 \\ &= 0.66 \end{aligned}$$

Bus Stop (CMF_{1p})
From Table 12-28, for two bus stops within 1,000 ft of the center of the intersection, $CMF_{1p} = 2.78$.

Schools (CMF_{2p})
From Table 12-29, for one school within 1,000 ft of the center of the intersection, $CMF_{2p} = 1.35$.

Alcohol Sales Establishments (CMF_{3p})
From Table 12-30, for six alcohol establishments within 1,000 ft of the center of the intersection, $CMF_{3p} = 1.12$.

Vehicle-Pedestrian and Vehicle-Bicycle Collisions
The SPF for vehicle-pedestrian collisions for a four-leg signalized intersection is calculated from Equation 12-28 as follows:

$$N_{pedi} = N_{pedbase} \times CMF_{1p} \times CMF_{2p} \times CMF_{3p}$$

Npedbase is calculated from Equation 12-29 using the coefficients from Table 12-14.

$$\begin{aligned} N_{pedbase} &= exp\left(a + b \times 1\text{n}\left(AADT_{\text{total}}\right) + c \times 1\text{n}\left(\frac{AADT_{min}}{AADT_{maj}}\right) + d \times 1\text{n}\left(PedVol\right) + e \times n_{lanesx} \right) \\ &= exp\left(-9.53 + 0.40 \times 1\text{n}\left(24,000\right) + 0.26 \times 1\text{n}\left(\frac{9,000}{15,000}\right) + 0.45 \times 1\text{n}\left(1,500\right) + 0.04 \times 4 \right) \\ &= 0.113 \text{ crashes/year} \end{aligned}$$

The CMF vehicle-pedestrian collision values calculated above are $CMF_{1p} = 2.78$, $CMF_{2p} = 1.35$, and $CMF_{3p} = 1.12$
.

$$\begin{aligned} N_{pedi} &= 0.113 \times 2.78 \times 1.35 \times 1.12 \\ &= 0.475 \text{ crashes/year} \end{aligned}$$

The predicted average crash frequency of an intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions) for SPF base conditions, N_{bi}, must be calculated in order to determine vehicle-bicycle crashes. N_{bi} is determined from Equation 12-6 as follows:

$$N_{bi} = N_{spf\ int} \times \left(CMF_{1i} \times CMF_{2i} \times \ldots \times CMF_{6i} \right)$$

From Equation 12-7, $N_{spf\ int}$ can be calculated as follows:

$$\begin{aligned} N_{spf\ int} &= N_{bimv} + N_{bisv} \\ &= 4.027 + 0.297 \\ &= 4.324 \text{ crashes/year} \end{aligned}$$

The combined CMF value for Sample Problem 4 is 0.66.

$$\begin{aligned} N_{bi} &= 4.324 \times (0.66) \\ &= 2.854 \text{ crashes/year} \end{aligned}$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-31 as follows:

$$N_{bikei} = N_{bi} \times f_{bikei}$$

From Table 12-17, for a four-leg signalized intersection the bicycle crash adjustment factor, $f_{bikei} = 0.015$.

$$\begin{aligned} N_{bikei} &= 2.854 \times 0.015 \\ &= 0.043 \text{ crashes/year} \end{aligned}$$

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

It is assumed in Sample Problem 4 that a calibration factor, C_i, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency

The predicted average crash frequency is calculated from Equation 12-5 based on the results obtained in Steps 9 through 11 as follows:

$$\begin{aligned} N_{\text{predicted } int} &= C_i \times \left(N_{bi} + N_{pedi} + N_{bikei}\right) \\ &= 1.00 \times (2.854 + 0.475 + 0.043) \\ &= 3.372 \text{ crashes/year} \end{aligned}$$

Worksheets

The step-by-step instructions abossve are provided to illustrate 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 1~~12~~ worksheets are provided for determining the predicted average crash frequency at intersections. The 12 worksheets include:

- *Worksheet SP4A (Corresponds to Worksheet 2A)*—General Information and Input Data for Urban and Suburban Arterial Intersections
- *Worksheet SP4B (Corresponds to Worksheet 2B)*—Crash Modification Factors for Urban and Suburban Arterial Intersections
- *Worksheet SP4C (Corresponds to Worksheet 2C)*—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SP4D (Corresponds to Worksheet 2D)*—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SP4E (Corresponds to Worksheet 2E)*—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SP4F (Corresponds to Worksheet 2F)*—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SP4H (Corresponds to Worksheet 2H)*—Crash Modification Factors for Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections
- *Worksheet SP4I (Corresponds to Worksheet 2I)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections

- *Worksheet SP4J (Corresponds to Worksheet 2J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections
- *Worksheet SP4K (Corresponds to Worksheet 2K)*—Crash Severity Distribution for Urban and Suburban Arterial Intersections
- *Worksheet SP4L (Corresponds to Worksheet 2L)*—Summary Results for Urban and Suburban Arterial Intersections

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheet SP4A—General Information and Input Data for Urban and Suburban Arterial Intersections

Worksheet SP4A is a summary of general information about the intersection, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 4.

Worksheet SP4A. General Information and Input Data for Urban and Suburban Arterial 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, 3ST-HS, 3STT, 3aST, 3SG, 3SG-HS, 4ST, 4ST-HS, 4aST, 4SG, 4SG-HS, 5SG)~~(3ST, 3SG, 4ST, 4SG)~~	—	4SG
$AADT_{maj}$ (veh/day), ~~(~~$AADT_{maj1}$ (veh/day) (for 3STT only)	—	15,000
$AADT_{maj2}$ (veh/day)~~,~~ (for 3STT only)	—	—
$AADT_{min}$ (veh/day)	—	9,000
$AADT_{fifth}$ (veh/day)	—	—
Intersection lighting (present/not present)	not present	present
Calibration factor, C_i	1.00	1.00
Data for unsignalized intersections only:	—	—
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	N/A
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	N/A
Horizontal curve radius (ft) [for 3STT only]	84	—
Horizontal curve length (ft) [for 3STT only]	100	—
Data for signalized intersections only:	—	—
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)	0	2
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)	0	2
Number of approaches with left-turn signal phasing	—	2
Number of approaches with right-turn-on-red prohibited	0	0
Type of left-turn signal phasing	permissive	protected/permissive
Intersection red-light cameras (present/not present)	not present	not present
Sum of all pedestrian crossing volumes (PedVol)	—	1,500
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	4
Number of bus stops within 300 m (1,000 ft) of the intersection	0	2
Schools within 300 m (1,000 ft) of the intersection (present/not present)	not present	present
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection	0	6

Worksheet SP4B—Crash Modification Factors for Urban and Suburban Arterial Intersections

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 8~~7~~ of Worksheet SP4B which indicates the combined CMF value.

Worksheet SP4B. Crash Modification Factors for Urban and Suburban Arterial Intersections

~~(1)~~	~~(2)~~	~~(3)~~	~~(4)~~	~~(5)~~	~~(6)~~	~~(7)~~
~~CMF for Left-Turn Lanes~~	~~CMF for Left-Turn Signal Phasing~~	~~CMF for Right-Turn Lanes~~	~~CMF for Right-Turn-on-Red~~	~~CMF for Lighting~~	~~CMF for Red-Light Cameras~~	~~Combined CMF~~
~~CMF_{1i}~~	~~CMF_{2i}~~	~~CMF_{3i}~~	~~CMF_{4i}~~	~~CMF_{5i}~~	~~CMF_{6i}~~	~~CMF_{comb}~~
~~from Table 12-24~~	~~from Table 12-25~~	~~from Table 12-26~~	~~from Equation 12-35~~	~~from Equation 12-36~~	~~from Equation 12-37~~	~~(1)*(2)*(3)*(4)*(5)*(6)~~
~~0.81~~	~~0.98~~	~~0.92~~	~~1.00~~	~~0.91~~	~~1.00~~	~~0.66~~

Formatted Table

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	CMF for Left-Turn Lanes	CMF for Left-Turn Signal Phasing	CMF for Right-Turn Lanes	CMF for Right-Turn-on-Red	CMF for Lighting	CMF for Red-Light Cameras	CMF for Horizontal Curves	Combined CMF
	CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{5i}	CMF_{6i}	CMF_{7i}	CMF_{comb}
Crash Type and Severity	from Table 12-24	from Table 12-25	from Table 12-26	from Equation 12-35	from Equation 12-36	from Equation 12-37	from Equation 12-CMF	(1)*(2)*(3)*(4)*(5)*(6)
MV-Total	0.81	0.98	0.92	1.00	0.91	1.00	1.00	0.66
MV-FI	0.81	0.98	0.92	1.00	0.91	1.00	1.00	0.66
MV-PDO	0.81	0.98	0.92	1.00	0.91	1.00	1.00	0.66
SV-Total	0.81	0.98	0.92	1.00	0.91	1.00	1.00	0.66
SV-FI	0.81	0.98	0.92	1.00	0.91	1.00	1.00	0.66
SV-PDO	0.81	0.98	0.92	1.00	0.91	1.00	1.00	0.66

Worksheet SP4C—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

The SPF for multiple-vehicle collisions at the intersection in Sample Problem 4 is calculated using Equation 12-21~~2~~ and entered into Column 4 of Worksheet SP4C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 4 (as the EB Method is not utilized). Column 5 of the worksheet adjusts the results in Column 4 to account for the site specific horizontal curve CMF. Column 6~~5~~ of the worksheet presents the proportions for crash severity levels calculated from the results in Column 5~~4~~. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 7~~6~~. Column 8~~7~~ represents the combined CMF (from Column 8~~7~~ in Worksheet SP4B), and Column 9~~8~~ represents the calibration factor. Column 10~~9~~ calculates the predicted average crash frequency of multiple-vehicle crashes using the values in Column 7~~6~~, the combined CMF in Column 8~~7~~, and the calibration factor in Column 9~~8~~.

Worksheet SP4C. Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

(1)	(2)						(3)	(4)	(5)	(~~5~~6)	(~~6~~7)	(~~7~~8)	(~~8~~9)	(~~9~~10)
	SPF Coefficients						**Overdispersion Parameter, *k***	**Initial N_{bimv}**	**Initial N_{bimv} Adjusted for Curve CMF**	**Proportion of Total Crashes**	**Adjusted N_{bimv}**	**Combined CMFs**		**Predicted N_{bimv}**
	from Table 12-10							**from Equation 12-~~21~~, 12-EMVA, ~~or~~ 12-EMVB, or 12-EMVC~~22~~**	**(4)*(7) from Worksheet SP~~4~~2B**	**[For 3STT, from Equation 12-EMVPROPB and 12-EMVPROPC]**		**(~~7~~8) from Worksheet SP4B**		
Crash Severity Level	**A**	**b**	**c~~, c(FI)~~**	**d**	**e**	**f**	**from Table 12-10**				**(~~4~~5)$_{total}$*(~~5~~6)**		**Calibration Factor, C_i**	**(~~6~~7)*(~~7~~8)*(~~8~~9)**
Total	**−10.99**	**1.07**	**0.23**	**--**	**-**	**-**	**0.39**	**4.027**	4.027	**1.000**	**4.027**	**0.66**	**1.00**	**2.658**
Fatal and injury (FI)	−13.14	1.18	0.22	--	-	-	0.33	1.233	1.233	(~~4~~5)$_{FI}$/((~~4~~5)$_{FI}$+(~~4~~5)$_{PDO}$) 0.318	1.281	0.66	1.00	0.845
Property damage only (PDO)	−11.02	1.02	0.24	--	-	-	0.44	2.647	2.647	(~~5~~6)$_{total}$−(~~5~~6)$_{FI}$ 0.682	2.746	0.66	1.00	1.812

Worksheet SP4D—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

Worksheet SP4D presents the default proportions for collision type (from Table 12-11) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for multiple-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle crashes (from Column 10~~9~~, Worksheet SP4C) into components by crash severity and collision type.

Worksheet SP4D. Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	**Predicted** $N_{bimv\ (FI)}$ **(crashes/year)**	**Proportion of Collision Type** $_{(PDO)}$	**Predicted** $N_{bimv\ (PDO)}$ **(crashes/year)**	**Predicted** $N_{bimv\ (total)}$ **(crashes/year)**
Collision Type	**from Table 12-11 or 12-XB**	**(~~9~~10)$_{FI}$ from Worksheet SP4C**	**from Table 12-11 or 12-XB**	**(~~9~~10)$_{PDO}$ from Worksheet SP4C**	**(~~9~~10)~~$_{PDO}$~~$_{total}$ from Worksheet SP4C**
Total	1.000	0.845 (2)*(3)$_{FI}$	1.000	1.812 (4)*(5)$_{PDO}$	2.658 (3)+(5)
Rear-end collision	0.450	0.380	0.483	0.875	1.255
Head-on collision	0.049	0.041	0.030	0.054	0.095
Angle collision	0.347	0.293	0.244	0.442	0.735
Sideswipe	0.099	0.084	0.032	0.058	0.142
Other multiple-vehicle collision	0.055	0.046	0.211	0.382	0.428

Worksheet SP4E—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections

The SPF for single-vehicle crashes at the intersection in Sample Problem 4 is calculated using Equation 12-24~~25~~ for total, fatal-and-injury, and property-damage-only (PDO) crashes and entered into Column 4 of Worksheet SP4E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2, and 3; however, the overdispersion parameter is not needed for Sample Problem 4 (as the EB Method is not utilized). Column 5 of the worksheet adjusts the results in Column 4 to account for site specific horizontal curvature. Column 6~~5~~ of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 5~~4~~) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 7~~6~~. Column 8~~7~~ represents the combined CMF (from Column 8~~7~~ in Worksheet SP4B), and Column 9~~8~~ represents the calibration factor. Column 10~~9~~ calculates the predicted average crash frequency of single-vehicle crashes using the values in Column 7~~6~~, the combined CMF in Column 8~~7~~, and the calibration factor in Column 9~~8~~.

Worksheet SP4E. Single-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

(1)	(2)					(3)	(4)	(5)	(~~5~~6)	(~~6~~7)	(~~7~~8)	(~~8~~9)	(~~9~~10)
	SPF Coefficients					Overdispersion Parameter, *k*	Initial N_{bisv}	Initial N_{bisv} Adjusted for Curve CMF		Adjusted N_{bisv}	Combined CMFs		Predicted N_{bisv}
	from Table 12-12												
Crash Severity Level	A	b/~~f~~	c	f	g	from Table 12-12	from Equation 12-24, ~~or~~ 12-ESVA~~25; (FI) from Equation 12-25 or 12-27~~, or 12-ESVB	(4)*(7) from Worksheet SP~~4~~2B	Proportion of Total Crashes [not used for 3ST, 4ST, and 3STT]~~Proportion of Total Crashes~~	$(5)_{total}$*(6) ~~[not used for 3ST, 4ST, and 3STT]$(4)_{total}$*(5)~~	(~~7~~8) from Worksheet SP4B	Calibration Factor, C_i	(~~6~~7)*(~~7~~8)*(~~8~~9)
Total	−10.21	0.68	0.27	-	-	0.36	0.297	0.297	1.000	0.297	0.66	1.000	0.196
Fatal and injury (FI)	−9.25	0.43	0.29	-	-	0.09	Equation 12-27 [3ST and 4ST only] ~~0.084~~ 0.084	0.084	(~~4~~5)$_{FI}$/((~~4~~5)$_{FI}$+(~~4~~5)$_{PDO}$) 0.287	$(5)_{FI}$ [for 3ST, 4ST, 3STT]~~[3ST, 4ST, 3STT only]0.085~~ 0.085	0.66	1.000	0.056
Property damage only (PDO)	−11.34	0.78	0.25	-	-	0.44	0.209	0.209	(~~5~~6)$_{total}$−(~~5~~6)$_{FI}$ 0.713	$(7)_{total}$-$(7)_{FI}$ [for 3ST, 4ST, 3STT]~~[3ST, 4ST, 3STT only]0.212~~ 0.212	0.66	1.000	0.140

Worksheet SP4F—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections

Worksheet SP4F presents the default proportions for collision type (from Table 12-13) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 10~~9~~, Worksheet SP4E) into components by crash severity and collision type.

Worksheet SP4F. Single-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	**Predicted** $N_{bisv\ (FI)}$ **(crashes/year)**	**Proportion of Collision Type** $_{(PDO)}$	**Predicted** $N_{bisv\ (PDO)}$ **(crashes/year)**	**Predicted** $N_{bisv\ (total)}$ **(crashes/year)**
Collision Type	**Table 12-13 or 12-XB**	**(~~9~~10)** $_{FI}$ **from Worksheet SP4E**	**Table 12-13 or 12-XB**	**(~~9~~10)** $_{PDO}$ **from Worksheet SP4E**	**(~~9~~10)** ~~PDO~~total **from Worksheet SP4E**
Total	1.000	0.056 (2)*(3)$_{FI}$	1.000	0.140 (4)*(5)$_{PDO}$	0.196 (3)+(5)
Collision with parked vehicle	0.001	0.000	0.001	0.000	0.000
Collision with animal	0.002	0.000	0.002	0.000	0.000
Collision with fixed object	0.744	0.042	0.870	0.122	0.164
Collision with other object	0.072	0.004	0.070	0.010	0.014
Other single-vehicle collision	0.040	0.002	0.023	0.003	0.005
Single-vehicle noncollision	0.141	0.008	0.034	0.005	0.013

Worksheet SP4H—Crash Modification Factors for Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values for vehicle-pedestrian collision. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 4 of Worksheet SP4H which indicates the combined CMF value for vehicle-pedestrian collisions.

Worksheet SP4H. Crash Modification Factors for Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections (Applicable to 3SG and 4SG)

(1)	(2)	(3)	(4)
CMF for Bus Stops	**CMF for Schools**	**CMF for Alcohol Sales Establishments**	**Combined CMF**
CMF_{1p}	CMF_{2p}	CMF_{3p}	(1)*(2)*(3)
from Table 12-28	from Table 12-29	from Table 12-30	
2.78	1.35	1.12	4.20

Worksheet SP4I—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections

The predicted number of vehicle-pedestrian collisions per year for base conditions at a signalized intersection, Npedbase, is calculated using Equation 12-30 and entered into Column 4 of Worksheet SP4I. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 4 (as the EB Method is not utilized). Column 5 represents the combined CMF for vehicle-pedestrian collisions (from Column 4 in Worksheet SP4H), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of vehicle-pedestrian collisions using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP4I. Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections (Applicable to 3SG and 4SG)

(1)	(2)					(3)	(4)	(5)	(6)	(7)
	SPF Coefficients						$N_{pedbase}$	Combined CMF		Predicted N_{pedi}
	from Table 12-14						from Equation 12-30	(4) from Worksheet SP4H		
Crash Severity Level	a	b	c	d	e	Overdispersion Parameter, k			Calibration Factor, C_i	(8)*(9)*(10)
Total	−9.53	0.40	0.26	0.45	0.04	0.24	0.113	4.20	1.00	0.475
Fatal and injury (FI)	—	—	—	—	—	—	—	—	1.00	0.475

Worksheet SP4J—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

The predicted average crash frequency of multiple-vehicle predicted crashes and single-vehicle predicted crashes from Worksheets SP4C and SP4E are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the bicycle crash adjustment factor (see Table 12-17). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-bicycle collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP4J. Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv} or Predicted $N_{bimv+sv}$ for aST(1)	Predicted N_{bisv}(1)	Predicted N_{bi}(1)	f_{bikei}		Predicted N_{pedi}
Crash Severity Level	(7)*(8)~~(7)*(8)(9)~~ from Worksheet SP4C	(7)*(8) ~~(7)*(8)(9)~~ from Worksheet SP4E [not used for 3aST and 4aST]	(2)+(3)	from Table 12-17	Calibration Factor, C_i	(4)*(5)*(6)
Total	2.658	0.196	2.854	0.015	1.00	0.043
Fatal and injury (FI)	—	—	—	—	1.00	0.043

(1) Predicted values prior to calibration

Worksheet SP4K—Crash Severity Distribution for Urban and Suburban Arterial Intersections

Worksheet SP4K provides a summary of all collision types by severity level. Values from Worksheets SP4D, SP4F, SP4I, and SP4J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP4K. Crash Severity Distribution for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	Property Damage Only (PDO)	Total
Collision Type	(3) from Worksheets SP4D and SP4F; (7) from SP4G (or SP4I) and SP4J	(5) from Worksheets SP4D and SP4F	(6) from Worksheets SP4D and SP4F; (7) from SP4G (or SP4I) and SP4J
MULTIPLE-VEHICLE COLLISIONS			
Rear-end collisions (from Worksheet SP4D)	0.380	0.875	1.255
Head-on collisions (from Worksheet SP4D)	0.041	0.054	0.095
Angle collisions (from Worksheet SP4D)	0.293	0.442	0.735
Sideswipe (from Worksheet SP4D)	0.084	0.058	0.142
Other multiple-vehicle collision (from Worksheet SP4D)	0.046	0.382	0.428
Subtotal	0.844	1.811	2.655
SINGLE-VEHICLE COLLISIONS			
Collision with parked vehicle (from Worksheet SP4F)	0.000	0.000	0.000
Collision with animal (from Worksheet SP4F)	0.000	0.000	0.000
Collision with fixed object (from Worksheet SP4F)	0.042	0.122	0.164
Collision with other object (from Worksheet SP4F)	0.004	0.010	0.014
Other single-vehicle collision (from Worksheet SP4F)	0.002	0.003	0.005
Single-vehicle noncollision (from Worksheet SP4F)	0.008	0.005	0.013
Collision with pedestrian (from Worksheet SP4G or SP4I)	0.475	0.000	0.475
Collision with bicycle (from Worksheet SP4J)	0.043	0.000	0.043

Subtotal	0.574	0.140	0.714
Total	1.418	1.951	3.369

Worksheet SP4L—Summary Results for Urban and Suburban Arterial Intersections

Worksheet SP4L presents a summary of the results.

Worksheet SP4L. Summary Results for Urban and Suburban Arterial Intersections

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	(Total) from Worksheet SP4K
Total	3.369
Fatal and injury (FI)	1.418
Property damage only (PDO)	1.951

12.13.5. Sample Problem XA

The Site/Facility

A three-leg all-way stop-controlled intersection located on an urban arterial.

The Question

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

The Facts

- AADT of major road is 8,000 veh/day
- AADT of minor road is 6,000 veh/day
- No lighting at intersection

Assumptions

Collision type distributions used are the default values from Tables 12-XB and Equations 12-30 and 12-31.

The calibration factor is assumed to be 1.20.

Results

Using the predictive method steps as outlined below, the predicted average crash frequency for the unsignalized intersection in Sample Problem XA is determined to be 2.0 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 XA, 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.

For a three-leg all-way stop-controlled intersection, SPF values for multiple-vehicle, single-vehicle, vehicle-pedestrian, and vehicle-bicycle collisions are determined. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these two models.

Multiple- and Single-Vehicle Crashes

The SPF for multiple- and single-vehicle collisions for a single three-leg all-way stop-controlled intersection is calculated from Equation 12-MV+SVB and Table 12-XA as follows:

$$N_{bimv+sv} = exp[a + f \times \ln(AADT_{total})]$$
$$N_{bimv+sv\ (FI)} = exp[-8.19 + 0.77 \times \ln(14{,}000)] = 0.432 \text{ crashes/year}$$
$$N_{bimv+sv\ (PDO)} = exp[-7.94 + 0.85 \times \ln(14{,}000)] = 1.191 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.

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

Intersection Left-Turn Lanes (CMF_{1i})

For all-way stop-controlled intersections, $CMF_{1i} = 1.00$.

Intersection Left-Turn Signal Phasing (CMF_{2i})

For all-way stop-controlled intersections, $CMF_{2i} = 1.00$.

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

For all-way stop-controlled intersections, $CMF_{3i} = 1.00$.

Right-Turn-on-Red (CMF_{4i})

For all-way stop-controlled intersections, $CMF_{4i} = 1.00$.

Lighting (CMF_{5i})

Since there is no lighting at this intersection, CMF_{5i} is 1.00 (i.e., the base condition for CMF_{5i} is the absence of intersection lighting).

Red-Light Cameras (CMF_{6i})

For all-way stop-controlled intersections, $CMF_{6i} = 1.00$.

The combined CMF value for Sample Problem XA is 1.00.

Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The predicted average crash frequency of an intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions) for SPF base conditions, N_{bi}, must be calculated in order to determine vehicle-pedestrian and vehicle-bicycle crashes. N_{bi} is determined from Equation 12-6 as follows:

$$N_{bi} = N_{spf\ int} \times (CMF_{1i} \times CMF_{2i} \times \ldots \times CMF_{6i})$$

From Equation 12-EA, $N_{spf\ int}$ can be calculated as follows:

$$N_{spf\ int} = N_{bimv+sv\ (FI)} + N_{bimv+sv\ (PDO)} = 0.432 + 1.191 = 1.623 \text{ crashes/year}$$

The combined CMF value for Sample Problem XA is 1.00.

$$N_{bimv+sv} = 1.623 \times (1.00) = 1.623 \text{ crashes/year}$$

The SPF for vehicle-pedestrian collisions for a three-leg all-way stop-controlled intersection is calculated from Equation 12-30 as follows:

$$N_{pedi} = N_{bi} \times f_{pedi}$$

From Table 12-16, for a three-leg all-way stop-controlled intersection the pedestrian crash adjustment factor, f_{pedi} = 0.017.

N_{pedi} = 1.623 × 0.017 = 0.028 crashes/year

The SPF for vehicle-bicycle collisions is calculated from Equation 12-31 as follows:

$N_{bikei} = N_{bi} \times f_{bikei}$

From Table 12-17, for a three-leg all-way stop-controlled intersection, the bicycle crash adjustment factor, f_{bikei} = 0.011.

N_{bikei} = 1.623 × 0.011 = 0.018 crashes/year

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed in Sample Problem XA that a calibration factor, C_i, of 1.20 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 12-5 based on results obtained in Steps 9 through 11 as follows:

$N_{predicted\ int} = C_i \times (N_{bi} + N_{pedi} + N_{bikei})$ = 1.20 (1.623 + 0.028 + 0.018) = 2.002 crashes/year

Worksheets

The step-by-step instructions above are provided to illustrate 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 8 worksheets are provided for determining the predicted average crash frequency at intersections. For this sample problem, the applicable worksheets include:

- *Worksheet SPXAA (Corresponds to Worksheet 2A)*—General Information and Input Data for Urban and Suburban Arterial Intersections
- *Worksheet SPXAB (Corresponds to Worksheet 2B)*—Crash Modification Factors for Urban and Suburban Arterial Intersections
- *Worksheet SPXAC (Corresponds to Worksheet 2C)*—Multiple- and Single-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SPXAD and SPXAF (Corresponds to Worksheet 2D)*—Multiple- and Single-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SPXAG (Corresponds to Worksheet 2G)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Stop-Controlled Intersections
- *Worksheet SPXAJ (Corresponds to Worksheet 2J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections
- *Worksheet SPXAK (Corresponds to Worksheet 2K)*—Crash Severity Distribution for Urban and Suburban Arterial Intersections
- *Worksheet SPXAL (Corresponds to Worksheet 2L)*—Summary Results for Urban and Suburban Arterial Intersections

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheet SPXAA—General Information and Input Data for Urban and Suburban Arterial Intersections

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

Worksheet SPXAA. General Information and Input Data for Urban and Suburban Arterial 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, 3ST-HS, 3STT, 3aST, 3SG, 3SG-HS, 4ST, 4ST-HS, 4aST, 4SG, 4SG-HS, 5SG)	—	3aST
$AADT_{maj}$ (veh/day), ~~(~~$AADT_{maj1}$ (veh/day) (for 3STT only)	—	8,000
$AADT_{maj2}$ (veh/day)~~,~~ (for 3STT only)	—	—
$AADT_{min}$ (veh/day)	—	6,000
$AADT_{fifth}$ (veh/day)	—	—
Intersection lighting (present/not present)	not present	not present
Calibration factor, C_i	1.00	1.20
Data for unsignalized intersections only:	—	—
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	0
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	0
Horizontal curve radius (ft) [for 3STT only]	84	—
Horizontal curve length (ft) [for 3STT only]	100	—
Data for signalized intersections only:	—	—
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)	0	N/A
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)	0	N/A
Number of approaches with left-turn signal phasing	—	N/A
Number of approaches with right-turn-on-red prohibited	0	N/A
Type of left-turn signal phasing	permissive	N/A
Intersection red light cameras (present/not present)	not present	N/A
Sum of all pedestrian crossing volumes (PedVol)	—	N/A
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	N/A
Number of bus stops within 300 m (1,000 ft) of the intersection	0	N/A
Schools within 300 m (1,000 ft) of the intersection (present/not present)	not present	N/A
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection	0	N/A

Worksheet SPXAB—Crash Modification Factors for Urban and Suburban Arterial Intersections

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 8 of Worksheet SPXAB which indicates the combined CMF value.

Worksheet SPXAB. Crash Modification Factors for Urban and Suburban Arterial Intersections

~~(1)~~	~~(2)~~	~~(3)~~	~~(4)~~	~~(5)~~	~~(6)~~	~~(7)~~
~~**CMF for Left-Turn Lanes**~~	~~**CMF for Left-Turn Signal Phasing**~~	~~**CMF for Right-Turn Lanes**~~	~~**CMF for Right-Turn-on-Red**~~	~~**CMF for Lighting**~~	~~**CMF for Red-Light Cameras**~~	~~**Combined CMF**~~
~~CMF_{1i}~~	~~CMF_{2i}~~	~~CMF_{3i}~~	~~CMF_{4i}~~	~~CMF_{5i}~~	~~CMF_{6i}~~	~~CMF_{comb}~~
~~from Table 12-24~~	~~from Table 12-25~~	~~from Table 12-26~~	~~from Equation 12-35~~	~~from Equation 12-36~~	~~from Equation 12-37~~	~~(1)*(2)*(3)*(4)*(5)*(6)~~
~~1.00~~	~~1.00~~	~~1.00~~	~~1.00~~	~~1.00~~	~~1.00~~	~~1.00~~

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	CMF for Left-Turn Lanes	**CMF for Left-Turn Signal Phasing**	**CMF for Right-Turn Lanes**	**CMF for Right-Turn-on-Red**	**CMF for Lighting**	**CMF for Red-Light Cameras**	**CMF for Horizontal Curves**	**Combined CMF**
	CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{5i}	CMF_{6i}	CMF_{7i}	CMF_{comb}
Crash Type and Severity	from Table 12-24	from Table 12-25	from Table 12-26	from Equation 12-35	from Equation 12-36	from Equation 12-37	from Equation 12-CMF	(1)*(2)*(3)*(4)*(5)*(6)
MV-Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
MV-FI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
MV-PDO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SV-Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SV-FI	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SV-PDO	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Worksheet SPXAC—Multiple- and Single-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

The SPFs for multiple- and single-vehicle collisions at the intersection in Sample Problem XA are calculated using Equation 12-MV+SVA for fatal-and-injury (FI) and property-damage-only (PDO) crashes and entered into Column 4 of Worksheet SPXAC. The coefficients for the SPFs and the overdispersion parameters associated with the SPFs are entered into Columns 2 and 3; however, the overdispersion parameters are not needed for Sample Problem XA (as the EB Method is not utilized). Column 5 of the worksheet adjusts the results in Column 4 to account for the site specific horizontal curve CMF. Column 6 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 5. Column 7 again presents the SPF values (from Column 5) for fatal-and-injury (FI) and property-damage-only (PDO) crashes as these initial values do not need to be adjusted because total crashes are not estimated from an SPF for all-way stop-controlled intersections. Column 8 represents the combined CMF (from Column 8 in Worksheet SPXAB), and Column 9 represents the calibration factor. Column 10 calculates the predicted average crash frequency of multiple- and single-vehicle crashes using the values in Column 7, the combined CMF in Column 8, and the calibration factor in Column 9.

Worksheet SPXAC. Multiple- and Single-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections (Applicable to 3aST and 4aST)

(1)	(2)				(3)	(4)	(5)	(~~5~~6)	(~~6~~7)	(~~7~~8)	(~~8~~9)	(~~9~~10)
	SPF Coefficients				Overdispersion Parameter, *k*	Initial $N_{bimv+sv}$	Initial N_{bimv} Adjusted for Curve CMF		Adjusted $N_{bimv+sv}$	Combined CMFs		Predicted $N_{bimv+sv}$
	from Table 12-XA					from Equation 12-MV+SVA or 12-MV+SVB	(4)*(7) from Worksheet SPXA~~2~~B					
Crash Severity Level	a	b ~~B~~	c	f	from Table 12-XA			Proportion of Total Crashes	(~~4~~5)~~total~~*~~(56)~~	(~~7~~8) from Worksheet SPXAB	Calibration Factor, C_i	(~~6~~7)*(~~7~~8)*(~~8~~9)
Total	--	-	--	--	--	--	--	1.000	--	--	--	1.948
Fatal and injury (FI)	-8.19	-	--	0.77	0.07	0.432	0.432	(~~4~~5)$_{FI}$ / ((~~4~~5)$_{FI}$ + (5~~4~~)$_{PDO}$) 0.266	0.432	1.00	1.20	0.519
Property damage only (PDO)	-7.94	-	--	0.85	0.37	1.191	1.191	(~~5~~6)$_{Total}$ – (~~5~~6)$_{FI}$ 0.734	1.191	1.00	1.20	1.429

Worksheets SPXAD and SPXAF—Multiple- and Single-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

Worksheet SPXAD presents the default proportions for collision type (from Table 12-XB) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for multiple- and single-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle crashes (from Column 10, Worksheet SPXAC) into components by crash severity and collision type.

Worksheet SPXAD. Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	**Predicted** $N_{bimv+sv\ (FI)}$ **(crashes/year)**	**Proportion of Collision Type** $_{(PDO)}$	**Predicted** $N_{bimv+sv\ (PDO)}$ **(crashes/year)**	**Predicted** $N_{bimv+sv\ (total)}$ **(crashes/year)**
Collision Type	**from Table 12-11 or 12-XB~~from Table 12-XB~~**	**(~~9~~10)$_{FI}$ from Worksheet SPXAC**	**from Table 12-11 or 12-XB~~from Table 12-XB~~**	**(~~9~~10)$_{PDO}$ from Worksheet SPXAC**	**(~~9~~10)$_{Total}$ from Worksheet SPXAC**
Total	1.000	0.519 (2)*(3)$_{FI}$	1.000	1.429 (4)*(5)$_{PDO}$	1.948 (3)+(5)
Rear-end collision	0.429	0.222	0.383	0.547	0.770
Head-on collision	0.024	0.012	0.000	0.000	0.012
Angle collision	0.167	0.087	0.241	0.344	0.431
Sideswipe	0.024	0.012	0.060	0.086	0.098
Other multiple-vehicle collision	0.048	0.025	0.113	0.161	0.186

Worksheet SPXAF. Single-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type (FI)	**Predicted** $N_{bisv\ (FI)}$ **(crashes/year)**	**Proportion of Collision Type (PDO)**	**Predicted** $N_{bisv\ (PDO)}$ **(crashes/year)**	**Predicted** $N_{bisv\ (total)}$ **(crashes/year)**
Collision Type	**Table 12-13 or 12-XB**	**(10)$_{FI}$ from Worksheet SPXAC**	**Table 12-13 or 12-XB**	**(10)$_{PDO}$ from Worksheet SPXAC**	**(10)$_{Total}$ from Worksheet SPXAC**
Total	1.000	0.519 (2)*(3)$_{FI}$	1.000	1.429 (4)*(5)$_{PDO}$	1.948 (3)+(5)
Collision with parked vehicle	0.000	0.000	0.000	0.000	0.000
Collision with animal	0.000	0.000	0.000	0.000	0.000
Collision with fixed object	0.000	0.000	0.000	0.000	0.000
Collision with other object	0.000	0.000	0.000	0.000	0.000
Other single-vehicle collision	0.262	0.136	0.203	0.290	0.426
Single-vehicle noncollision	0.048	0.025	0.000	0.000	0.025

Worksheet SPXAE does not apply for all-way stop-controlled intersections since single-vehicle crashes are combined with multiple-vehicle crashes in Worksheet SPXAC.

Worksheet SPXAG—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Stop-Controlled Intersections

The predicted average crash frequency of multiple- and single-vehicle predicted crashes from Worksheet SPXAC is entered into Column 2. Column 3 is not applicable to all-way stop-controlled intersections. Column 5 contains the pedestrian crash adjustment factor (see Table 12-16). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SPXAG. Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Intersections (Applicable to 3ST, 3ST-HS, 3aST, 3SG-HS, 4ST, 4ST-HS, 4aST, 4SG-HS, and 5SG)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv} or Predicted $N_{bimv+sv}$ for aST(1)	Predicted N_{bisv}(1)	Predicted N_{bi}(1)	f_{pedi}		Predicted N_{pedi}
Crash Severity Level	(7)*(8)~~(107)*(8)~~ from Worksheet SPXAC	(7)*(8)~~(107)*(8)~~ from Worksheet SPXAE [not used for 3aST and 4aST]	(2)+(3)	from Table 12-16	Calibration Factor, C_i	(4)*(5)*(6)
Total	1.623	—	1.623	0.017	1.20	0.033
Fatal and injury (FI)	—	—	—	—	1.20	0.033

(1) Predicted values prior to calibration

Worksheet SPXAJ—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

The predicted average crash frequency of multiple- and single-vehicle predicted crashes from Worksheet SPXAC is entered into Column 2. Column 3 is not applicable to all-way stop-controlled intersections. Column 5 contains the bicycle crash adjustment factor (see Table 12-17). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-bicycle collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SPXAJ. Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv} or Predicted $N_{bimv+sv}$ for aST(1)	Predicted N_{bisv}(1)	Predicted N_{bi}(1)	f_{bikei}		Predicted N_{pedi}
Crash Severity Level	(7)*(8)~~(107)*(8)~~ from Worksheet SPXAC	(7)*(8)~~(107)*(8)~~ from Worksheet SPXAE [not used for 3aST and 4aST]	(2)+(3)	from Table 12-17	Calibration Factor, C_i	(4)*(5)*(6)
Total	1.623	—	1.623	0.011	1.20	0.021
Fatal and injury (FI)	—	—	—	—	1.20	0.021

(1) Predicted values prior to calibration

Worksheet SPXAK—Crash Severity Distribution for Urban and Suburban Arterial Intersections

Worksheet SPXAK provides a summary of all collision types by severity level. Values from Worksheets SPXAD, SPXAF, SPXAG, and SPXAJ are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)

- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SPXAK. Crash Severity Distribution for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	Property Damage Only (PDO)	Total
Collision Type	(3) from Worksheets SPXAD and SPXAF; (7) from SPXAG (or SPXAI) and SPXAJ	(5) from Worksheets SPXAD and SPXAF	(6) from Worksheets SPXAD and SPXAF; (7) from SPXAG (or SPXAI) and SPXAJ
MULTIPLE-VEHICLE COLLISIONS			
Rear-end collisions (from Worksheet SPXAD)	0.222	0.547	0.770
Head-on collisions (from Worksheet SPXAD)	0.012	0.000	0.012
Angle collisions (from Worksheet SPXAD)	0.087	0.344	0.431
Sideswipe (from Worksheet SPXAD)	0.012	0.086	0.098
Other multiple-vehicle collision (from Worksheet SPXAD)	0.025	0.161	0.186
Subtotal	0.359	1.139	1.498
SINGLE-VEHICLE COLLISIONS			
Collision with parked vehicle (from Worksheet SPXAF)	0.000	0.000	0.000
Collision with animal (from Worksheet SPXAF)	0.000	0.000	0.000
Collision with fixed object (from Worksheet SPXAF)	0.000	0.000	0.000
Collision with other object (from Worksheet SPXAF)	0.000	0.000	0.000
Other single-vehicle collision (from Worksheet SPXAF)	0.136	0.290	0.426
Single-vehicle noncollision (from Worksheet SPXAF)	0.025	0.000	0.025
Collision with pedestrian (from Worksheet SPXAG or SPXAI)	0.033	0.000	0.033
Collision with bicycle (from Worksheet SPXAJ)	0.021	0.000	0.021
Subtotal	0.215	0.290	0.505
Total	0.574	1.429	2.003

Worksheet SPXAL—Summary Results for Urban and Suburban Arterial Intersections

Worksheet SPXAL presents a summary of the results.

Worksheet SPXAL. Summary Results for Urban and Suburban Arterial Intersections

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	(Total) from Worksheet SPXAK
Total	2.0

Fatal and injury (FI)	0.6
Property damage only (PDO)	1.4

12.13.6. Sample Problem XD

The Site/Facility
A three-leg turning intersection located on an urban arterial.

The Question
What is the predicted crash frequency of the unsignalized intersection for a particular year?

The Facts

- AADT of major road approach 1 is 12,000 veh/day
- AADT of major road approach 2 is 12,000 veh/day
- AADT of minor road is 2,000 veh/day
- Horizontal curve radius of through movement is 100 ft
- Horizontal curve length of through movement is 150 ft

Assumptions
Collision type distributions used are the default values from Tables 12-11 and 12-13 and Equations 12-30 and 12-31.

The calibration factor is assumed to be 1.00.

Results
Using the predictive method steps as outlined below, the predicted average crash frequency for the unsignalized intersection in Sample Problem XD is determined to be 2.0 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 XD, 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.

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.

For a three-leg turning intersection, Steps 9 and 10 are combined because the CMFs for three-leg turning intersections are calculated by severity level. SPF values for multiple-vehicle, single-vehicle, vehicle-pedestrian, and vehicle-bicycle collisions are determined as follows.

Multiple-Vehicle Crashes
The SPF for multiple-vehicle collisions for a single three-leg stop-controlled turning intersection is calculated from Equation 12-EMVC and Table 12-10 as follows:

$$N_{bimv} = exp\left(a + f \times ln(TEV_3)\right)$$

$$\mathrm{TEV_3} = 0.5 \times \left(\mathrm{AADT_{maj,1}} + \mathrm{AADT_{maj,2}} + \mathrm{AADT_{min}}\right)$$

$= 0.5 \times (12{,}000 + 12{,}000 + 2{,}000) = 13{,}000\ veh/day$

$N_{bimv(total)} = exp\left(-8.49 + 0.87 \times ln(13{,}000)\right)$

$= 0.780\ crashes/year$

$N_{bimv(FI)} = exp\left(-9.53 + 0.81 \times ln(13{,}000)\right)$

$= 0.156\ crashes/year$

$N_{bimv(PDO)} = exp\left(-8.12 + 0.79 \times ln(13{,}000)\right)$

$= 0.529\ crashes/year$

These initial values for fatal-and-injury (FI) and property-damage-only (PDO) crashes are then adjusted using Equations 12-EMVPROPA, 12-EMVPROPB, and 12-EMVPROPC to assure that they sum to the value for total crashes. For three-leg turning intersections, it is necessary to compute the CMFs for horizontal curvature using Equation 12-CMF prior to adjusting the values for FI and PDO crashes.

$CMF_i = e^{a(R-84)+b(L_c-100)}$

$CMF_{7i,mv,tot} = e^{-0.014(100-84)+0.017(150-100)} = 1.870$

$CMF_{7i,mv,fi} = e^{-0.014(100-84)+0.019(150-100)} = 2.067$

$CMF_{7i,mv,pdo} = e^{-0.017(100-84)+0.020(150-100)} = 2.071$

$N_{bimv(total),adj} = N_{bimv(total)} CMF_{7i,mv,tot} = 0.780 \times 1.870 = 1.458$

$$N_{bimv(FI),adj} = N_{bimv(total),adj} \times \left(\frac{N'_{bimv(FI)} CMF_{7i,mv,fi}}{N'_{bimv(FI)} CMF_{7i,mv,fi} + N'_{bimv(PDO)} CMF_{7i,mv,pdo}}\right)$$

$$N_{bimv(FI),adj} = 1.458 \times \left(\frac{0.156 \times 2.067}{0.156 \times 2.067 + 0.529 \times 2.071}\right)$$

$N_{bimv(FI),adj} = 0.332\ crashes/year$

$N_{bimv(PDO),adj} = N_{bimv(total),adj} - N_{bimv(FI),adj}$

$N_{bimv(PDO),adj} = 1.458 - 0.332$

$N_{bimv(PDO),adj} = 1.126\ crashes/year$

Single-Vehicle Crashes

The SPF for total single-vehicle crashes for a single three-leg stop-controlled turning intersection is calculated from Equation 12-ESVB and Table 12-12 as follows:

$N_{bisv} = exp\left(a + f \times ln(TEV_3)\right)$

$N_{bisv(total)} = exp\left(-5.40 + 0.46 \times ln(13{,}000)\right)$

$= 0.353\ crashes/year$

Since there are no models for fatal-and-injury single-vehicle crashes, $N_{bisv(total)}$ is multiplied by the CMF value for horizontal curves for total single-vehicle crashes ($CMF_{7i,sv,total}$) to adjust for actual conditions using Equations 12-CMF and 12-ESVTOTADJ.

$$CMF_{7i,sv,tot} = e^{-0.000(100-84)+0.009(150-100)} = 1.568$$

$$N_{bisv(total),adj} = N_{bisv(total)} \times CMF_{7i,sv,tot} = 0.353 \times 1.568 = 0.553\ crashes/year$$

Using Equations 12-ESVTOTADJ, 12-ESVFIADJ, and 12-ESVPDOADJ, adjustments are made so that $N_{bisv(FI),adj}$ and $N_{bisv(PDO),adj}$ sum to $N_{bisv(total),adj}$:

$$N_{bisv(FI),adj} = N_{bisv(total),adj} \times f_{bisv}$$

The default value of f_{bisv} in Equation 12-ESVFIADJ is 0.33.

$$N_{bisv(FI),adj} = N_{bisv(total),adj} \times f_{bisv} = 0.553 \times 0.33 = 0.182\ crashes/year$$

$$N_{bisv(PDO),adj} = N_{bisv(total),adj} - N_{bisv(FI),adj} = 0.553 - 0.182 = 0.371\ crashes/year$$

Multiple-Vehicle and Single-Vehicle Crashes Combined

Thus, from Equation 12-7, $N_{spf\ int}$ can be calculated as follows:

$$N_{b\cancel{int}} = N_{bimv} + N_{bisv}$$

= 1.458 + 0.553 = 2.011 crashes/year

Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The SPF for vehicle-pedestrian collisions for a three-leg stop-controlled turning intersection is calculated from Equation 12-30 as follows:

$$N_{pedi} = N_{bi} \times f_{pedi}$$

Field Code Changed

From Table 12-16, for a three-leg stop-controlled turning intersection the pedestrian crash adjustment factor, $f_{pedi} =$ 0.011.

$$N_{pedi} = 2.011 \times 0.011$$

$$= 0.022\ crashes/year$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-31 as follows:

$$N_{bikei} = N_{pedi} \times f_{bikei}$$

Field Code Changed

From Table 12-17, for a three-leg stop-controlled turning intersection, the bicycle crash adjustment factor, $f_{bikei} =$ 0.000.

$$N_{bikei} = 2.011 \times 0.000$$

$= 0.000\ crashes/year$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.

The CMF for horizontal curves (CMF_{7i}) has already been used in the calculation of the predicted average crash frequency of the intersection and is the only applicable CMF for use with 3STT intersections. Values for CMF_{1i}, CMF_{2i}, CMF_{3i}, CMF_{4i}, CMF_{5i}, and CMF_{6i} equal 1.00 for three-leg stop-controlled turning intersections. Therefore, no further calculations with CMFs are needed to adjust the base conditions to site specific geometric design and traffic control features.

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

It is assumed in Sample Problem XD that a calibration factor, C_i, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency

The predicted average crash frequency is calculated using Equation 12-5 based on results obtained in Steps 9 through 11 as follows:

$$N_{predicted\ int} = C_i \times (N_{bi} + N_{pedi} + N_{bikei})$$

$$= 1.00 \times (2.011 + 0.022 + 0.000)$$

$$= 2.033\ crashes/year$$

Worksheets

The step-by-step instructions above are provided to illustrate 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 10 worksheets are provided for determining the predicted average crash frequency at intersections. The 10 worksheets include:

- *Worksheet SPXDA (Corresponds to Worksheet 2A)*—General Information and Input Data for Urban and Suburban Arterial Intersections
- *Worksheet SPXDB (Corresponds to Worksheet 2B)*—Crash Modification Factors for Urban and Suburban Arterial Intersections
- *Worksheet SPXDC (Corresponds to Worksheet 2C)*—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SPXDD (Corresponds to Worksheet 2D)*—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SPXDE (Corresponds to Worksheet 2E)*—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SPXDF (Corresponds to Worksheet 2F)*—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SPXDG (Corresponds to Worksheet 2G)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Stop-Controlled Intersections
- *Worksheet SPXDJ (Corresponds to Worksheet 2J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections
- *Worksheet SPXDK (Corresponds to Worksheet 2K)*—Crash Severity Distribution for Urban and Suburban Arterial Intersections

- *Worksheet SPXDL (Corresponds to Worksheet 2L)*—Summary Results for Urban and Suburban Arterial Intersections

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheet SPXDA—General Information and Input Data for Urban and Suburban Arterial Intersections

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

Worksheet SPXDA. General Information and Input Data for Urban and Suburban Arterial 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, 3ST-HS, 3STT, 3aST, 3SG, 3SG-HS, 4ST, 4ST-HS, 4aST, 4SG, 4SG-HS, 5SG)	—	3STT
$AADT_{maj}$ (veh/day), $AADT_{maj1}$ (veh/day) (for 3STT only)	—	12,000
$AADT_{maj2}$ (veh/day) (for 3STT only)	—	12,000
$AADT_{min}$ (veh/day)	—	2,000
$AADT_{fifth}$ (veh/day)	—	N/A
Intersection lighting (present/not present)	not present	N/A
Calibration factor, C_i	1.00	1.00
Data for unsignalized intersections only:	—	—
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	N/A
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	N/A
Horizontal curve radius (ft) [for 3STT only]	84	100
Horizontal curve length (ft) [for 3STT only]	100	150
Data for signalized intersections only:	—	—
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)	0	N/A
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)	0	N/A
Number of approaches with left-turn signal phasing	—	N/A
Number of approaches with right-turn-on-red prohibited	0	N/A
Type of left-turn signal phasing	permissive	N/A
Intersection red light cameras (present/not present)	not present	N/A
Sum of all pedestrian crossing volumes (PedVol)	—	N/A
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	N/A
Number of bus stops within 300 m (1,000 ft) of the intersection	0	N/A
Schools within 300 m (1,000 ft) of the intersection (present/not present)	not present	N/A
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection	0	N/A

Worksheet SPXDB—Crash Modification Factors for Urban and Suburban Arterial Intersections

For three-leg turning intersections, Steps 9 and 10 of the predictive method are combined. Crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. For three-leg turning intersections, it is necessary to compute the CMFs for horizontal curvature using Equation 12-CMF. Column 7 of Worksheet SPXDB indicates the CMFs for horizontal curvature for three-leg turning intersections.

Worksheet SPXDB. Crash Modification Factors for Urban and Suburban Arterial Intersections

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	CMF for Left-Turn Lanes	**CMF for Left-Turn Signal Phasing**	**CMF for Right-Turn Lanes**	**CMF for Right-Turn-on-Red**	**CMF for Lighting**	**CMF for Red-Light Cameras**	**CMF for Horizontal Curves**	**Combined CMF**
	CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{5i}	CMF_{6i}	CMF_{7i}	CMF_{comb}
Crash Type and Severity	from Table 12-24	from Table 12-25	from Table 12-26	from Equation 12-35	from Equation 12-36	from Equation 12-37	from Equation 12-CMF	(1)*(2)*(3)*(4)*(5)*(6)
MV-Total	1.00	1.00	1.00	1.00	1.00	1.00	1.870	1.00
MV-FI	1.00	1.00	1.00	1.00	1.00	1.00	2.067	1.00
MV-PDO	1.00	1.00	1.00	1.00	1.00	1.00	2.071	1.00
SV-Total	1.00	1.00	1.00	1.00	1.00	1.00	1.568	1.00
SV-FI	1.00	1.00	1.00	1.00	1.00	1.00	1.000	1.00
SV-PDO	1.00	1.00	1.00	1.00	1.00	1.00	1.492	1.00

Worksheet SPXDC—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

The SPF for multiple-vehicle collisions at the intersection in Sample Problem XD is calculated using Equation 12-EMVC and entered into Column 4 of Worksheet SPXDC. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem XD (as the EB Method is not utilized). Column 5 of the worksheet adjusts the results in Column 4 to account for the site specific horizontal curve CMF. Column 6 presents proportions used to adjust the initial SPF values (from Column 5) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 7. Column 8 represents the combined CMF for CMF_{1i}, CMF_{2i}, CMF_{3i}, CMF_{4i}, CMF_{5i}, and CMF_{6i} which all equal 1.00 for three-leg stop-controlled turning intersections (from Column 8 in Worksheet SPXDB), and Column 9 represents the calibration factor. Column 10 calculates the predicted average crash frequency of multiple-vehicle crashes using the values in Column 7, the combined CMF in Column 8, and the calibration factor in Column 9.

Worksheet SPXDC. Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections (Applicable to 3ST, 3ST-HS, 3STT, 3SG, 3SG-HS, 4ST, 4ST-HS, 4SG, 4SG-HS, 5SG)

(1)	(2)						(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	SPF Coefficients						Overdispersion Parameter, *k*	Initial N_{bimv}	Initial N_{bimv} Adjusted for Curve CMF	Proportion of Total Crashes	Adjusted N_{bimv}	Combined CMFs		Predicted N_{bimv}
	from Table 12-10													
Crash Severity Level	a	b	c	d	e	f	from Table 12-10	from Equation 12-21, 12-EMVA, 12-EMVB, or 12-EMVC	(4)*(7) from Worksheet SPXDB	[For 3STT, from Equation 12-EMVPROPB and 12-EMVPROPC]	$(5)_{total}$*(6)	(8) from Worksheet SPXDB	Calibration Factor, C_i	(7)*(8)*(9)
Total	-8.49	-	-	-	-	0.87	0.32	0.780	1.458	1.000	1.458	1.00	1.00	1.458
Fatal and injury (FI)	-9.53	-	-	-	-	0.81	0.00	0.156	0.323	$(5)_{FI}/((5)_{FI}+(5)_{PDO})$ 0.227	0.332	1.00	1.00	0.332
Property damage only (PDO)	-8.12	-	-	-	-	0.79	0.14	0.529	1.096	$(6)_{total}-(6)_{FI}$ 0.773	1.127	1.00	1.00	1.127

Worksheet SPXDD—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

Worksheet SPXDD presents the default proportions for collision type (from Table 12-11) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for multiple-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle crashes (from Column 10, Worksheet SPXDC) into components by crash severity and collision type.

Worksheet SPXDD. Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{bimv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{bimv\ (PDO)}$ (crashes/year)	Predicted $N_{bimv\ (total)}$ (crashes/year)
Collision Type	from Table 12-11 or 12-XB	$(10)_{FI}$ from Worksheet SPXDC	from Table 12-11 or 12-XB	$(10)_{PDO}$ from Worksheet SPXDC	$(10)_{total}$ from Worksheet SPXDC
Total	1.000	0.332 $(2)*(3)_{FI}$	1.000	1.127 $(4)*(5)_{PDO}$	1.458 (3)+(5)
Rear-end collision	0.115	0.038	0.178	0.201	0.239
Head-on collision	0.115	0.038	0.068	0.077	0.115
Angle collision	0.577	0.191	0.411	0.463	0.654
Sideswipe	0.115	0.038	0.288	0.324	0.363
Other multiple-vehicle collision	0.077	0.026	0.055	0.062	0.088

Worksheet SPXDE—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections

The SPF for single-vehicle crashes at the intersection in Sample Problem XD is calculated using Equation 12-ESVB for total and property-damage-only (PDO) crashes and entered into Column 4 of Worksheet SPXDE. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem XD (as the EB Method is not utilized). Since there are no models for fatal-and-injury crashes at a three-leg turning intersections, $N_{bisv(FI)}$ is not initially calculated. Therefore, no value is entered into Column 4 for $N_{bisv(FI)}$. Column 5 of the worksheet adjusts the results in Column 4 to account for site specific horizontal curvature. Since there are no models for fatal-and-injury single-vehicle crashes for three-leg turning intersections, $N_{bisv(FI)}$ is calculated using Equation 12-ESVFIADJ. Column 6 is not applicable since there are no models for fatal-and-injury single-vehicle crashes for three-leg turning intersections. For Column 7 Equations 12-ESVTOTADJ, 12-ESVFIADJ, and 12-ESVPDOADJ are used for adjustments so that $N_{bisv(FI),adj}$ and $N_{bisv(PDO),adj}$ sum to $N_{bisv(total),adj}$. Column 8 represents the combined CMF (from Column 7 in Worksheet SPXDB), and Column 9 represents the calibration factor. Column 10 calculates the predicted average crash frequency of single-vehicle crashes using the values in Column 7, the combined CMF in Column 8, and the calibration factor in Column 9.

Worksheet SPXDE. Single-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections (Applicable to 3ST, 3STT, 3ST-HS, 3SG, 3SG-HS, 4ST, 4ST-HS, 4SG, 4SG-HS, 5SG)

(1)	(2)					(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	SPF Coefficients					Overdispersion Parameter, k	Initial N_{bisv}	Initial N_{bisv} Adjusted for Curve CMF		Adjusted N_{bisv}	Combined CMFs		Predicted N_{bisv}
	from Table 12-12						from Equation 12-24, 12-ESVA, or 12-ESVB	(4)*(7) from Worksheet SPXDB					
Crash Severity Level	a	b	c	f	g	from Table 12-12			Proportion of Total Crashes [not used for 3ST, 4ST, and 3STT]	$(5)_{total}$*(6)	(8) from Worksheet SPXDB	Calibration Factor, C_i	(7)*(8)*(9)
Total	-5.40	-	-	-	0.46	0.50	0.353	0.553	1.000	0.553	1.00	1.00	0.553
Fatal and injury (FI)	-	-	-	-	-	-	Equation 12-27 [3ST and 4ST only]	0.182	$(5)_{FI}/((5)_{FI}+(5)_{PDO})$	$(5)_{FI}$ [for 3ST, 4ST, 3STT]	1.00	1.00	0.182
							-		-	0.182			
Property damage only (PDO)	-6.68	-	-	-	0.57	0.61	0.278	0.415	$(6)_{total}-(6)_{FI}$	$(7)_{total}-(7)_{FI}$ [for 3ST, 4ST, 3STT]	1.00	1.00	0.371
									-	0.371			

Worksheet SPXDF—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections

Worksheet SPXDF presents the default proportions for collision type (from Table 12-13) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 9, Worksheet SPXDE) into components by crash severity and collision type.

Worksheet SPXDF. Single-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type (FI)	**Predicted $N_{bisv\ (FI)}$ (crashes/year)**	**Proportion of Collision Type (PDO)**	**Predicted $N_{bisv\ (PDO)}$ (crashes/year)**	**Predicted $N_{bisv\ (total)}$ (crashes/year)**
Collision Type	**Table 12-13 or 12-XB**	**$(10)_{FI}$ from Worksheet SPXDE**	**Table 12-13 or 12-XB**	**$(10)_{PDO}$ from Worksheet SPXDE**	**$(10)_{total}$ from Worksheet SPXDE**
Total	1.000	0.182 $(2)*(3)_{FI}$	1.000	0.371 $(4)*(5)_{PDO}$	0.553 (3)+(5)
Collision with parked vehicle	0.000	0.000	0.000	0.000	0.000
Collision with animal	0.000	0.000	0.038	0.014	0.014
Collision with fixed object	0.750	0.137	0.846	0.313	0.450
Collision with other object	0.000	0.000	0.058	0.021	0.021
Other single-vehicle collision	0.167	0.030	0.058	0.021	0.052
Single-vehicle noncollision	0.083	0.015	0.000	0.000	0.015

Worksheet SPXDG—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Stop-Controlled Intersections

The predicted average crash frequency of multiple-vehicle predicted crashes and single-vehicle predicted crashes from Worksheets SPXDC and SPXDE are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the pedestrian crash adjustment factor (see Table 12-16). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SPXDG. Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Intersections (Applicable to 3ST, 3STT, 3ST-HS, 3aST, 3SG-HS, 4ST, 4ST-HS, 4aST, 4SG-HS, and 5SG)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv} or Predicted $N_{bimv+sv}$ for aST(1)	Predicted N_{bisv}(1)	Predicted N_{bi}(1)	f_{pedi}		*Predicted* N_{pedi}
Crash Severity Level	(7)*(8) from Worksheet SPXDC	(7)*(8) from Worksheet SPXDE [not used for 3aST and 4aST]	(2)+(3)	from Table 12-16	Calibration Factor, C_i	(4)*(5)*(6)
Total	1.458	0.553	2.011	0.011	1.00	0.022
Fatal and injury (FI)	—	—	—	—	1.00	0.022

(1) Predicted values prior to calibration

Worksheet SPXDJ—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

The predicted average crash frequency of multiple-vehicle predicted crashes and single-vehicle predicted crashes from Worksheets SPXDC and SPXDE are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the bicycle crash adjustment factor (see Table 12-17). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-bicycle collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SPXDJ. Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv} or Predicted $N_{bimv+sv}$ for aST(1)	Predicted N_{bisv}(1)	Predicted N_{bi}(1)	f_{bikei}		Predicted N_{pedi}
Crash Severity Level	(7)*(8) from Worksheet SPXDC	(7)*(8) from Worksheet SPXDE [not used for 3aST and 4aST]	(2)+(3)	from Table 12-17	Calibration Factor, C_i	(4)*(5)*(6)
Total	1.458	0.553	2.011	0.000	1.000	0.000
Fatal and injury (FI)	—	—	—	—	1.000	0.000

(1) Predicted values prior to calibration

Worksheet SPXDK—Crash Severity Distribution for Urban and Suburban Arterial Intersections

Worksheet SPXDK provides a summary of all collision types by severity level. Values from Worksheets SPXDD, SPXDF, SPXDG, and SPXDJ are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SPXDK. Crash Severity Distribution for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	Property Damage Only (PDO)	Total
Collision Type	(3) from Worksheets SPXDD and SPXDF; (7) from SPXDG (or SPXDI) and SPXDJ	(5) from Worksheets SPXDD and SPXDF	(6) from Worksheets SPXDD and SPXDF; (7) from SPXDG (or SPXDI) and SPXDJ
MULTIPLE-VEHICLE COLLISIONS			
Rear-end collisions (from Worksheet SPXDD)	0.038	0.201	0.239
Head-on collisions (from Worksheet SPXDD)	0.038	0.077	0.115
Angle collisions (from Worksheet SPXDD)	0.191	0.463	0.654
Sideswipe (from Worksheet SPXDD)	0.038	0.324	0.363
Other multiple-vehicle collision (from Worksheet SPXDD)	0.026	0.062	0.088
Subtotal	0.331	1.127	1.458
SINGLE-VEHICLE COLLISIONS			
Collision with parked vehicle (from Worksheet SPXDF)	0.000	0.000	0.000
Collision with animal (from Worksheet SPXDF)	0.000	0.014	0.014
Collision with fixed object (from Worksheet SPXDF)	0.137	0.313	0.450
Collision with other object (from Worksheet SPXDF)	0.000	0.021	0.021
Other single-vehicle collision (from Worksheet SPXDF)	0.030	0.021	0.052
Single-vehicle noncollision (from Worksheet SPXDF)	0.015	0.000	0.015
Collision with pedestrian (from Worksheet SPXDG or SPXDI)	0.022	0.000	0.022
Collision with bicycle (from Worksheet SPXDF)	0.000	0.000	0.000
Subtotal	0.205	0.371	0.575
Total	0.536	1.497	2.033

Worksheet SPXDL—Summary Results for Urban and Suburban Arterial Intersections

Worksheet SPXDL presents a summary of the results.

Worksheet SPXDL. Summary Results for Urban and Suburban Arterial Intersections

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	(Total) from Worksheet SPXDK
Total	2.033
Fatal and injury (FI)	0.536
Property damage only (PDO)	1.497

12.13.7. Sample Problem XB

The Intersection

A four-leg signalized intersection located on a high-speed urban arterial.

The Question

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

The Facts

- Left-turn lanes on each of the four approaches
- One right-turn lane on each of the two major road approaches
- AADT of major road is 35,000 veh/day
- AADT of minor road is 10,000 veh/day
- Lighting is present

Assumptions

Collision type distributions used are the default values from Tables 12-11 and 12-13 and Equations 12-30 and 12-31.

The calibration factor is assumed to be 1.00.

Results

Using the predictive method steps as outlined below, the predicted average crash frequency for the signalized intersection in Sample Problem XB is determined to be 14.1 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 XB, 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.

For a four-leg signalized intersection, SPF values for multiple-vehicle, single-vehicle, vehicle-pedestrian, and vehicle-bicycle collisions are determined. The calculations for total multiple- and single-vehicle collisions are presented below. Detailed steps for calculating SPFs for fatal-and-injury (FI) and property-damage-only (PDO) crashes are presented in Sample Problem 3. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these two models.

Multiple-Vehicle Collisions

The SPF for multiple-vehicle collisions for a single four-leg signalized intersection is calculated from Equation 12-21 and Table 12-10 as follows:

$N_{bimv} = exp[a + b \times ln(AADT_{maj}) + c \times ln(AADT_{min})]$

$N_{bimv\ (total)} = exp[-9.65 + 0.98 \times ln(35{,}000) + 0.28 \times ln(10{,}000)] = 24.113$ crashes/year

Single-Vehicle Crashes

The SPF for single-vehicle crashes for a single four-leg signalized intersection is calculated from Equation 12-24 and Table 12-12 as follows:

$N_{bisv} = exp[a + b \times ln(AADT_{maj}) + c \times ln(AADT_{min})]$

$N_{bisv\,(total)} = exp[-6.04 + 0.52 \times ln(35{,}000) + 0.10 \times ln(10{,}000)] = 1.380$ crashes/year

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.

Each CMF used in the calculation of the predicted average crash frequency of the intersection is calculated below. CMF_{1i} through CMF_{6i} are applied to multiple-vehicle collisions and single-vehicle crashes.

Intersection Left-Turn Lanes (CMF_{1i})

From Table 12-24, for a four-leg signalized intersection with a left-turn lane on four approaches, $CMF_{1i} = 0.66$.

Intersection Left-Turn Signal Phasing (CMF_{2i})

This CMF does not apply to intersections on high-speed arterials. Thus, $CMF_{2i} = 1.00$.

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

From Table 12-26, for a four-leg signalized intersection with one right-turn lane on each of two major-road approaches, $CMF_{3i} = 0.92$.

Right-Turn-on-Red (CMF_{4i})

This CMF does not apply to intersections on high-speed arterials. Thus, $CMF_{4i} = 1.00$.

Lighting (CMF_{5i})

CMF_{5i} is calculated from Equation 12-36.

$$CMF_{5i} = 1 - 0.38 \times pni$$

From Table 12-27, the proportion of crashes that occur at night, $p_{ni} = 0.245$.

$$CMF_{5i} = 1 - 0.38 \times 0.245 = 0.91$$

Red-Light Cameras (CMF_{6i})

This CMF does not apply to intersections on high-speed arterials. Thus, $CMF_{6i} = 1.00$.

The combined CMF value applied to multiple- and single-vehicle crashes in Sample Problem XB is calculated below.

$$CMF_{comb} = 0.66 \times 0.91 = 0.55$$

Bus Stop (CMF_{1p})

This CMF does not apply to intersections on high-speed arterials. Thus, $CMF_{1p} = 1.00$.

Schools (CMF_{2p})

This CMF does not apply to intersections on high-speed arterials. Thus, $CMF_{2p} = 1.00$.

Alcohol Sales Establishments (CMF_{3p})

This CMF does not apply to intersections on high-speed arterials. Thus, $CMF_{3p} = 1.00$.

Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The predicted average crash frequency of an intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions) for SPF base conditions, N_{bi}, must be calculated in order to determine vehicle-pedestrian and vehicle-bicycle crashes. N_{bi} is determined from Equation 12-6 as follows:

$$N_{bi} = N_{spf\,int} \times (CMF_{1i} \times CMF_{2i} \times \ldots \times CMF_{6i})$$

From Equation 12-7, $N_{spf\,int}$ can be calculated as follows:

$$N_{spf\,int} = N_{bimv} + N_{bisv} = 24.113 + 1.380 = 25.492 \text{ crashes/year}$$

The combined CMF value for Sample Problem XB is 0.55.

N_{bi} = 25.492 × (0.55) = 14.062 crashes/year

The SPF for vehicle-pedestrian collisions for a four-leg signalized intersection is calculated from Equation 12-30 as follows:

$N_{pedi} = N_{bi} \times f_{pedi}$

From Table 12-16, for a four-leg signalized intersection the pedestrian crash adjustment factor, f_{pedi} = 0.003.

N_{pedi} = 14.062 × 0.003 = 0.042 crashes/year

The SPF for vehicle-bicycle collisions is calculated from Equation 12-31 as follows:

$N_{bikei} = N_{bi} \times f_{bikei}$

From Table 12-17, for a four-leg signalized intersection the bicycle crash adjustment factor, f_{bikei} = 0.001.

N_{bikei} = 14.062 × 0.001 = 0.014 crashes/year

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed in Sample Problem XB that a calibration factor, C_i, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated from Equation 12-5 based on the results obtained in Steps 9 through 11 as follows:

$N_{predicted\ int} = C_i \times (N_{bi} + N_{pedi} + N_{bikei})$ = 1.00 × (14.062 + 0.042 + 0.014) = 14.118 crashes/year

Worksheets

The step-by-step instructions above are provided to illustrate 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 10~~2~~ worksheets are provided for determining the predicted average crash frequency at intersections. For this sample problem, the applicable worksheets include:

- *Worksheet SPXBA (Corresponds to Worksheet 2A)*—General Information and Input Data for Urban and Suburban Arterial Intersections
- *Worksheet SPXBB (Corresponds to Worksheet 2B)*—Crash Modification Factors for Urban and Suburban Arterial Intersections
- *Worksheet SPXBC (Corresponds to Worksheet 2C)*—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SPXBD (Corresponds to Worksheet 2D)*—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SPXBE (Corresponds to Worksheet 2E)*—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SPXBF (Corresponds to Worksheet 2F)*—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SPXBG (Corresponds to Worksheet 2G)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections (not including 3SG and 4SG)

- *Worksheet SPXBJ (Corresponds to Worksheet 2J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections
- *Worksheet SPXBK (Corresponds to Worksheet 2K)*—Crash Severity Distribution for Urban and Suburban Arterial Intersections
- *Worksheet SPXBL (Corresponds to Worksheet 2L)*—Summary Results for Urban and Suburban Arterial Intersections

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheet SPXBA—General Information and Input Data for Urban and Suburban Arterial Intersections

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

Worksheet SPXBA. General Information and Input Data for Urban and Suburban Arterial 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, 3ST-HS, 3STT, 3aST, 3SG, 3SG-HS, 4ST, 4ST-HS, 4aST, 4SG, 4SG-HS, 5SG)	—	4SG-HS
$AADT_{maj}$ (veh/day), $AADT_{maj1}$ (veh/day) (for 3STT only)	—	35,000
$AADT_{maj2}$ (veh/day) (for 3STT only)	—	—
$AADT_{min}$ (veh/day)	—	10,000
$AADT_{fifth}$ (veh/day)	—	—
Intersection lighting (present/not present)	not present	present
Calibration factor, C_i	1.00	1.00
Data for unsignalized intersections only:	—	—
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	N/A
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	N/A
Horizontal curve radius (ft) [for 3STT only]	84	—
Horizontal curve length (ft) [for 3STT only]	100	—
Data for signalized intersections only:	—	—
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)	0	4
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)	0	2
Number of approaches with left-turn signal phasing	—	N/A
Number of approaches with right-turn-on-red prohibited	0	N/A
Type of left-turn signal phasing	permissive	N/A
Intersection red-light cameras (present/not present)	not present	N/A
Sum of all pedestrian crossing volumes (PedVol)	—	N/A
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	N/A
Number of bus stops within 300 m (1,000 ft) of the intersection	0	N/A
Schools within 300 m (1,000 ft) of the intersection (present/not present)	not present	N/A
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection	0	N/A

Worksheet SPXBB—Crash Modification Factors for Urban and Suburban Arterial Intersections

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 8~~7~~ of Worksheet SPXBB which indicates the combined CMF value.

Worksheet SPXBB. Crash Modification Factors for Urban and Suburban Arterial Intersections

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	CMF for Left-Turn Lanes	**CMF for Left-Turn Signal Phasing**	**CMF for Right-Turn Lanes**	**CMF for Right-Turn-on-Red**	**CMF for Lighting**	**CMF for Red-Light Cameras**	**CMF for Horizontal Curves**	**Combined CMF**
	CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{5i}	CMF_{6i}	CMF_{7i}	CMF_{comb}
Crash Type and Severity	from Table 12-24	from Table 12-25	from Table 12-26	from Equation 12-35	from Equation 12-36	from Equation 12-37	from Equation 12-CMF	(1)*(2)*(3)*(4)*(5)*(6)
MV-Total	0.66	1.00	0.92	1.00	0.91	1.00	1.00	0.55
MV-FI	0.66	1.00	0.92	1.00	0.91	1.00	1.00	0.55
MV-PDO	0.66	1.00	0.92	1.00	0.91	1.00	1.00	0.55
SV-Total	0.66	1.00	0.92	1.00	0.91	1.00	1.00	0.55
SV-FI	0.66	1.00	0.92	1.00	0.91	1.00	1.00	0.55
SV-PDO	0.66	1.00	0.92	1.00	0.91	1.00	1.00	0.55

Worksheet SPXBC—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

The SPF for multiple-vehicle collisions at the intersection in Sample Problem XB is calculated using Equation 12-21~~2~~ and entered into Column 4 of Worksheet SPXBC. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem XB (as the EB Method is not utilized). Column 5 of the worksheet adjusts the results in Column 4 to account for the site specific horizontal curve CMF. Column 6~~5~~ of the worksheet presents the proportions for crash severity levels calculated from the results in Column 5~~4~~. These proportions are used to adjust the initial SPF values (from Column 5~~4~~) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 7~~6~~. Column 8~~7~~ represents the combined CMF (from Column 8~~7~~ in Worksheet SPXBB), and Column 9~~8~~ represents the calibration factor. Column ~~9~~10 calculates the predicted average crash frequency of multiple-vehicle crashes using the values in Column 7~~6~~, the combined CMF in Column 8~~7~~, and the calibration factor in Column 9~~8~~.

Worksheet SPXBC. Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections (Applicable to 3ST, 3ST-HS, 3STT, 3SG, 3SG-HS, 4ST, 4ST-HS, 4SG, 4SG-HS, 5SG)

(1)	(2)						(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	SPF Coefficients						Overdispersion Parameter, *k*	Initial N_{bimv}	Initial N_{bimv} Adjusted for Curve CMF		Adjusted N_{bimv}	Combined CMFs		Predicted N_{bimv}
	from Table 12-10							from Equation 12-21, 12-EMVA, 12-EMVB, or 12-EMVC ~~from Equation 12-22~~		Proportion of Total Crashes [For 3STT, from Equation 12-EMVPROPB and 12-EMVPROPC]				
Crash Severity Level	a	b	c	d	e	f	from Table 12-10		(4)*(7) from Worksheet SPXBB~~2B~~		$(5)_{total}$*(6)	(8~~7~~) from Worksheet SPXBB	Calibration Factor, C_i	(7)*(8)*(9)
Total	−9.65	0.98	0.28	-	-	-	0.46	24.113	24.113	1.000	24.113	0.55	1.00	13.301
Fatal and injury (FI)	-9.61	0.86	0.29	-	-	-	0.31	7.840	7.840	$(5)_{FI}/((5)_{FI}+(5)_{PDO})$ 0.311	7.510	0.55	1.00	4.143
Property damage only (PDO)	-10.70	1.04	0.29	-	-	-	0.38	17.333	17.333	$(6)_{total}-(6)_{FI}$ 0.689	16.603	0.55	1.00	9.159

Worksheet SPXBD—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

Worksheet SPXBD presents the default proportions for collision type (from Table 12-11) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for multiple-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle crashes (from Column 10~~9~~, Worksheet SPXBC) into components by crash severity and collision type.

Worksheet SPXBD. Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{bimv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{bimv\ (PDO)}$ (crashes/year)	Predicted $N_{bimv\ (total)}$ (crashes/year)
Collision Type	from Table 12-11 or 12-XB~~from Table 12-11~~	$(10)_{FI}$ from Worksheet SPXBC	from Table 12-11 or 12-XB~~from Table 12-11~~	$(10)_{PDO}$ from Worksheet SPXBC	$(10)_{PDO}$ from Worksheet SPXBC
Total	1.000	4.143 $(2)*(3)_{FI}$	1.000	9.159 $(4)*(5)_{PDO}$	13.301 (3)+(5)
Rear-end collision	0.560	2.320	0.661	6.054	8.374
Head-on collision	0.028	0.116	0.009	0.082	0.198
Angle collision	0.303	1.255	0.207	1.896	3.151
Sideswipe	0.026	0.108	0.094	0.861	0.969
Other multiple-vehicle collision	0.083	0.344	0.029	0.266	0.609

Worksheet SPXBE—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections

The SPF for single-vehicle crashes at the intersection in Sample Problem XB is calculated using Equation 12-24~~5~~ for total, FI, and PDO crashes and entered into Column 4 of Worksheet SPXBE. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2, and 3; however, the overdispersion parameter is not needed for Sample Problem XB (as the EB Method is not utilized). Column 5 of the worksheet adjusts the results in Column 4 to account for the site specific horizontal curve CMF. Column ~~5~~6 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 5~~4~~. These proportions are used to adjust the initial SPF values (from Column 5~~4~~) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 7~~6~~. Column 8~~7~~ represents the combined CMF (from Column 8~~7~~ in Worksheet SPXBB), and Column ~~8~~9 represents the calibration factor. Column ~~9~~10 calculates the predicted average crash frequency of single-vehicle crashes using the values in Column ~~6~~7, the combined CMF in Column 8~~7~~, and the calibration factor in Column ~~8~~9.

Worksheet SPXBE. Single-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections (Applicable to 3ST, 3ST-HS, 3STT, 3SG, 3SG-HS, 4ST, 4ST-HS, 4SG, 4SG-HS, 5SG)

(1)	(2)					(3)	(4)	(5)	(6~~5~~)	(7~~6~~)	(8~~7~~)	(9~~8~~)	(~~9~~10)
	SPF Coefficients					Overdispersion Parameter, k	Initial N_{bisv}	Initial N_{bisv} Adjusted for Curve CMF		Adjusted N_{bisv}	Combined CMFs		Predicted N_{bisv}
	from Table 12-12						from Equation 12-24, 12-ESVA, or 12-ESVB~~from Equation 12-25; (FI) from Equation 12-25 or 12-27~~	(4)*(7) from Worksheet SPXBB~~2B~~					
Crash Severity Level	a	b	c	f	g	from Table 12-12			Proportion of Total Crashes [not used for 3ST, 4ST, and 3STT]	$(5)_{total}$*(6) ~~[not used for 3ST, 4ST, and 3STT]~~	(8) from Worksheet SPXBB	Calibration Factor, C_i	(7)*(8)*(9)
Total	-6.04	0.52	0.10	-	-	0.55	1.380	1.380	1.000	1.380	0.55	1.00	0.761
Fatal and injury (FI)	-9.89	0.83	0.04	-	-	0.98	Equation 12-27 [3ST and 4ST only] ~~0.433~~	0.433	$(5)_{FI}/((5)_{FI}+(5)_{PDO})$	$(5)_{FI}$ [3ST, 4ST, 3STT only]	0.55	1.00	0.266
							0.433		0.349	0.482			
Property damage only (PDO)	-5.10	0.37	0.11	-	-	0.84	0.806	0.806	$(6)_{total}-(6)_{FI}$	$(7)_{total}-(7)_{FI}$ [3ST, 4ST, 3STT only]	0.55	1.00	0.495
									0.651	0.898			

Worksheet SPXBF—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections

Worksheet SPXBF presents the default proportions for collision type (from Table 12-13) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 10~~9~~, Worksheet SPXBE) into components by crash severity and collision type.

Worksheet SPXBF. Single-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{bisv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{bisv\ (PDO)}$ (crashes/year)	Predicted $N_{bisv\ (total)}$ (crashes/year)
Collision Type	Table 12-13 or 12-XB~~Table 12-13~~	$(10)_{FI}$ from Worksheet SPXBE	Table 12-13 or 12-XB~~Table 12-13~~	$(10)_{PDO}$ from Worksheet SPXBE	$(10)_{PDO}$ from Worksheet SPXBE
Total	1.000	0.266 $(2)*(3)_{FI}$	1.000	0.495 $(4)*(5)_{PDO}$	0.761 (3)+(5)
Collision with parked vehicle	0.000	0.000	0.000	0.000	0.000
Collision with animal	0.000	0.000	0.003	0.001	0.001
Collision with fixed object	0.240	0.064	0.422	0.209	0.273
Collision with other object	0.000	0.000	0.006	0.003	0.003
Other single-vehicle collision	0.620	0.165	0.520	0.257	0.422
Single-vehicle noncollision	0.140	0.037	0.049	0.024	0.061

Worksheet SPXBG—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Stop-Controlled Intersections

The predicted average crash frequency of multiple-vehicle predicted crashes and single-vehicle predicted crashes from Worksheets SPXBC and SPXBE are entered into Columns 2 and 3 respectively. These values are summed in Column 4~~The predicted average crash frequency of multiple- and single-vehicle predicted crashes from Worksheet SPXAC is entered into Column 2. .~~ Column 5 contains the pedestrian crash adjustment factor (see Table 12-16). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SPXBG. Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Intersections (Applicable to 3ST, 3ST-HS, 3aST, 3SG-HS, 4ST, 4ST-HS, 4aST, 4SG-HS, and 5SG)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv} or Predicted $N_{bimv+sv}$ for aST(1)	**Predicted N_{bisv}(1)**	**Predicted N_{bi}(1)**	f_{pedi}		*Predicted N_{pedi}*
Crash Severity Level	**(7)*(8)~~(107)*(8)~~ from Worksheet SPXBC**	**(7)*(8)~~(107)*(8)~~ from Worksheet SPXBE [not used for 3aST and 4aST]**	**(2)+(3)**	**from Table 12-16**	**Calibration Factor, C_i**	**(4)*(5)*(6)**
Total	13.031	0.761	14.062	0.003	1.00	0.042
Fatal and injury (FI)	—	—	—	—	1.00	0.042

(1) Predicted values prior to calibration

Worksheet SPXBJ—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

The predicted average crash frequency of multiple-vehicle predicted crashes and single-vehicle predicted crashes from Worksheets SPXBC and SPXBE are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the bicycle crash adjustment factor (see Table 12-17). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-bicycle collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SPXBJ. Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv} or Predicted $N_{bimv+sv}$ for aST(1)	**Predicted N_{bisv}(1)**	**Predicted N_{bi}(1)**	f_{bikei}		**Predicted N_{pedi}**
Crash Severity Level	**(7)*(8)~~(107)*(8)~~ from Worksheet SPXBC**	**(7)*(8)~~(107)*(8)~~ from Worksheet SPXBE [not used for 3aST and 4aST]**	**(2)+(3)**	**from Table 12-17**	**Calibration Factor, C_i**	**(4)*(5)*(6)**
Total	13.301	0.761	14.062	0.001	1.00	0.014
Fatal and injury (FI)	—	—	—	—	1.00	0.014

(1) Predicted values prior to calibration

Worksheet SPXBK—Crash Severity Distribution for Urban and Suburban Arterial Intersections

Worksheet SPXBK provides a summary of all collision types by severity level. Values from Worksheets SPXBD, SPXBF, SPXBG, and SPXBJ are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SPXBK. Crash Severity Distribution for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	**Property Damage Only (PDO)**	**Total**
Collision Type	**(3) from Worksheets SPXBD and SPXBF; (7) from SPXBG (or SPXBI) and SPXBJ**	**(5) from Worksheets SPXBD and SPXBF**	**(6) from Worksheets SPXBD and SPXBF; (7) from SPXBG (or SPXBI) and SPXBJ**
MULTIPLE-VEHICLE COLLISIONS			
Rear-end collisions (from Worksheet SPXBD)	2.320	6.054	8.374
Head-on collisions (from Worksheet SPXBD)	0.116	0.082	0.198
Angle collisions (from Worksheet SPXBD)	1.255	1.896	3.151
Sideswipe (from Worksheet SPXBD)	0.108	0.861	0.969
Other multiple-vehicle collision (from Worksheet SPXBD)	0.344	0.266	0.609
Subtotal	4.143	9.159	13.301
SINGLE-VEHICLE COLLISIONS			
Collision with parked vehicle (from Worksheet SPXBF)	0.000	0.000	0.000
Collision with animal (from Worksheet SPXBF)	0.000	0.001	0.001
Collision with fixed object (from Worksheet SPXBF)	0.064	0.209	0.273
Collision with other object (from Worksheet SPXBF)	0.000	0.003	0.003
Other single-vehicle collision (from Worksheet SPXBF)	0.165	0.257	0.422
Single-vehicle noncollision (from Worksheet SPXBF)	0.037	0.024	0.061
Collision with pedestrian (from Worksheet SPXBG or SPXBI)	0.042	0.000	0.042
Collision with bicycle (from Worksheet SPXBJ)	0.014	0.000	0.014
Subtotal	0.322	0.495	0.817
Total	4.465	9.654	14.119

Worksheet SPXBL—Summary Results for Urban and Suburban Arterial Intersections

Worksheet SPXBL presents a summary of the results.

Worksheet SPXBL. Summary Results for Urban and Suburban Arterial Intersections

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	(Total) from Worksheet SPXBK
Total	14.1
Fatal and injury (FI)	4.5
Property damage only (PDO)	9.6

12.13.8. Sample Problem XC

The Intersection
A five-leg signal-controlled intersection located on an urban arterial.

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

The Facts

- 5 approach legs
- AADT on the major road = 14,500 veh/day
- AADT on the minor road = 7,000 veh/day
- AADT on the fifth leg = 5,300 veh/day

Assumptions
Collision type distributions used are the default values from Tables 12-11 and 12-13 and Equations 12-30 and 12-31.

The calibration factor is assumed to be 1.00.

Results
Using the predictive method steps as outlined below, the predicted average crash frequency for the signalized intersection in Sample Problem XC is determined to be 7.5 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 XC, 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.
For a five-leg signalized intersection, SPF values for multiple-vehicle, single-vehicle, vehicle-pedestrian, and vehicle-bicycle collisions are determined. The calculations for total multiple- and single-vehicle collisions are presented below. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these two models.

Multiple-Vehicle Collisions
The SPF for multiple-vehicle collisions for a single five-leg signalized urban intersection is calculated from Equation 12-EMVA and Table 12-10 as follows:

$N_{bimv} = exp[a + b \times ln(AADT_{maj}) + c \times ln(AADT_{min}) + d \times ln(AADT_{fifth})]$

$N_{bimv\ (total)} = exp[-11.23 + 0.87 \times ln(14{,}500) + 0.36 \times ln(7{,}000) + 0.19 \times ln(5{,}300)]$
$= 6.841$ crashes/year

Single-Vehicle Crashes

The SPF for single-vehicle crashes for a single five-leg signalized intersection is calculated from Equation 12-ESVA and Table 12-12 as follows:

$N_{bisv} = exp[a + f \times ln(AADT_{total})]$

$N_{bisv\ (total)} = exp[-13.94 + 1.23 \times ln(14{,}500 + 7{,}000 + 5{,}300)]$
$= 0.247$ crashes/year

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.

Each CMF used in the calculation of the predicted average crash frequency of the intersection is calculated below. CMF_{1i} through CMF_{6i} are applied to multiple-vehicle collisions and single-vehicle crashes.

Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The predicted average crash frequency of an intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions) for SPF base conditions, N_{bi}, must be calculated in order to determine vehicle-pedestrian and vehicle-bicycle crashes. N_{bi} is determined from Equation 12-6 as follows:

$N_{bi} = N_{spf\ int} \times (CMF_{1i} \times CMF_{2i} \times \ldots \times CMF_{6i})$

From Equation 12-7, $N_{spf\ int}$ can be calculated as follows:

$N_{spf\ int} = N_{bimv} + N_{bisv} = 6.841 + 0.247 = 7.088$ crashes/year

The combined CMF value for Sample Problem XC is 1.00 since there are no CMFs for the five-leg signalized intersection predictive method.

$N_{bi} = 7.088 \times 1.00 = 7.088$ crashes/year

The SPF for vehicle-pedestrian collisions for a five-leg signalized intersection is calculated from Equation 12-30 as follows:

$N_{pedi} = N_{bi} \times f_{pedi}$

From Table 12-16, for a five-leg signalized intersection the pedestrian crash adjustment factor, $f_{pedi} = 0.031$.

$N_{pedi} = 7.088 \times 0.031 = 0.220$ crashes/year

The SPF for vehicle-bicycle collisions is calculated from Equation 12-31 as follows:

$N_{bikei} = N_{bi} \times f_{bikei}$

From Table 12-17, for a five-leg signalized intersection the bicycle crash adjustment factor, $f_{bikei} = 0.031$.

$N_{bikei} = 7.088 \times 0.031 = 0.220$ crashes/year

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

It is assumed in Sample Problem XC that a calibration factor, C_i, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency

The predicted average crash frequency is calculated from Equation 12-5 based on the results obtained in Steps 9 through 11 as follows:

$$N_{predicted\ int} = C_i \times (N_{bi} + N_{pedi} + N_{bikei})$$
$$= 1.00 \times (7.088 + 0.220 + 0.220)$$
$$= 7.528 \text{ crashes/year}$$

Worksheets

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for an intersection. To apply the predictive method steps to multiple intersections, a series of ~~9~~12 worksheets are provided for determining the predicted average crash frequency at intersections. The ~~9~~12 worksheets include:

- *Worksheet SPXCA (Corresponds to Worksheet 2A)*—General Information and Input Data for Urban and Suburban Arterial Intersections
- *Worksheet SPXCC (Corresponds to Worksheet 2C)*—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SPXCD (Corresponds to Worksheet 2D)*—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SPXCE (Corresponds to Worksheet 2E)*—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SPXCF (Corresponds to Worksheet 2F)*—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SPXCG (Corresponds to Worksheet 2G)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections
- *Worksheet SPXCJ (Corresponds to Worksheet 2J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections
- *Worksheet SPXCK (Corresponds to Worksheet 2K)*—Crash Severity Distribution for Urban and Suburban Arterial Intersections
- *Worksheet SPXCL (Corresponds to Worksheet 2L)*—Summary Results for Urban and Suburban Arterial Intersections

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheet SPXCA—General Information and Input Data for Urban and Suburban Arterial Intersections

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

Worksheet SPXCA. General Information and Input Data for Urban and Suburban Arterial 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, 3ST-HS, 3STT, 3aST, 3SG, 3SG-HS, 4ST, 4ST-HS, 4aST, 4SG, 4SG-HS, 5SG)	—	5SG
$AADT_{maj}$ (veh/day), ($AADT_{maj1}$ (veh/day) (for 3STT only)	—	14,500
$AADT_{maj2}$ (veh/day) (for 3STT only)	—	—
$AADT_{min}$ (veh/day)	—	7,000
$AADT_{fifth}$ (veh/day)	—	5,300
Intersection lighting (present/not present)	not present	N/A
Calibration factor, C_i	1.00	1.00
Data for unsignalized intersections only:	—	—
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	N/A
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	N/A
Horizontal curve radius (ft) [for 3STT only]	84	—
Horizontal curve length (ft) [for 3STT only]	100	—
Data for signalized intersections only:	—	—
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)	0	N/A
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)	0	N/A
Number of approaches with left-turn signal phasing	—	N/A
Number of approaches with right-turn-on-red prohibited	0	N/A
Type of left-turn signal phasing	permissive	N/A
Intersection red-light cameras (present/not present)	not present	N/A
Sum of all pedestrian crossing volumes (PedVol)	—	N/A
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	N/A
Number of bus stops within 300 m (1,000 ft) of the intersection	0	N/A
Schools within 300 m (1,000 ft) of the intersection (present/not present)	not present	N/A
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection	0	N/A

Worksheet SPXCC—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

The SPF for multiple-vehicle collisions at the intersection in Sample Problem XC is calculated using Equation 12-EMVA and entered into Column 4 of Worksheet SPXCC. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem XC (as the EB Method is not utilized). Column 5 of the worksheet adjusts the results in Column 4 to account for the site specific horizontal curve CMF. Column 6~~5~~ of the worksheet presents the proportions for crash severity levels calculated from the results in Column 5~~4~~. These proportions are used to adjust the initial SPF values (from Column 5~~4~~) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 7~~6~~. Column 8~~7~~ represents the combined CMF (1.00), and Column 9~~8~~ represents the calibration factor. Column 10~~9~~ calculates the predicted average crash frequency of multiple-vehicle crashes using the values in Column 7~~6~~, the combined CMF in Column 8~~7~~, and the calibration factor in Column 9~~8~~.

Worksheet SPXCC. Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections (Applicable to 3ST, 3ST-HS, 3STT, 3SG, 3SG-HS, 4ST, 4ST-HS, 4SG, 4SG-HS, 5SG)

(1)	(2)						(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	SPF Coefficients						Overdispersion Parameter, k	Initial N_{bimv}	Initial N_{bimv} Adjusted for Curve CMF		Adjusted N_{bimv}	Combined CMFs		Predicted N_{bimv}
	from Table 12-10													
Crash Severity Level	a	b	c	d	e	f~~F~~	from Table 12-10	from Equation 12-21, 12-EMVA, 12-EMVB, or 12-EMVC~~from Equation 12-EMVA~~	(4)*(7) from Worksheet SPXC~~2B~~	Proportion of Total Crashes [For 3STT, from Equation 12-EMVPROPB and 12-EMVPROPC]	$(5)_{total}$*(6)	(7)	Calibration Factor, C_i	(7)*(8)*(9)
Total	−11.23	0.87	0.36	-	--	--	0.46	6.841	6.841	1.000	6.841	1.00	1.00	6.841
Fatal and injury (FI)	-15.22	1.24	--	-	0.40	--	0.63	1.535	1.535	$(5)_{FI}/((5)_{FI}+(5)_{PDO})$ 0.220	1.508	1.00	1.00	1.508
Property damage only (PDO)	-10.92	0.75	0.39	-	--	--	0.48	5.429	5.429	$(6)_{total}-(6)_{FI}$ 0.780	5.333	1.00	1.00	5.333

Worksheet SPXCD—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

Worksheet SPXCD presents the default proportions for collision type (from Table 12-11) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for multiple-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle crashes (from Column 10~~9~~, Worksheet SPXCC) into components by crash severity and collision type.

Worksheet SPXCD. Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{bimv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{bimv\ (PDO)}$ (crashes/year)	Predicted $N_{bimv\ (total)}$ (crashes/year)
Collision Type	from Table 12-11 or 12-XB~~from Table 12-11~~	$(10)_{FI}$ from Worksheet SPXCC	from Table 12-11 or 12-XB~~from Table 12-11~~	$(10)_{PDO}$ from Worksheet SPXCC	$(10)_{PDO}$ from Worksheet SPXCC
Total	1.000	1.508 $(2)*(3)_{FI}$	1.000	5.333 $(4)*(5)_{PDO}$	6.841 (3)+(5)
Rear-end collision	0.425	0.641	0.430	2.293	2.934
Head-on collision	0.065	0.098	0.024	0.128	0.226
Angle collision	0.321	0.484	0.238	1.269	1.753
Sideswipe	0.049	0.074	0.169	0.901	0.975
Other multiple-vehicle collision	0.139	0.210	0.139	0.741	0.951

Worksheet SPXCE—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections

The SPF for single-vehicle crashes at the intersection in Sample Problem XC is calculated using Equation 12-ESVA for total, fatal-and-injury (FI), and property-damage-only (PDO) crashes and entered into Column 4 of Worksheet SPXCE. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2, and 3; however, the overdispersion parameter is not needed for Sample Problem XC (as the EB Method is not utilized). Column 5 of the worksheet adjusts the results in Column 4 to account for the site specific horizontal curve CMF. Column 6~~5~~ of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 5~~4~~) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 7~~6~~. Column 8~~7~~ represents the combined CMF (1.00), and Column 9~~8~~ represents the calibration factor. Column ~~9~~10 calculates the predicted average crash frequency of single-vehicle crashes using the values in Column 7~~6~~, the combined CMF in Column 8~~7~~, and the calibration factor in Column 9~~8~~.

Worksheet SPXCE. Single-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections (Applicable to 3ST, 3ST-HS, 3STT, 3SG, 3SG-HS, 4ST, 4ST-HS, 4SG, 4SG-HS, 5SG)

(1)	(2)					(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	SPF Coefficients					**Overdispersion Parameter, *k***	**Initial N_{bisv}**	**Initial N_{bisv} Adjusted for Curve CMF**		**Adjusted N_{bisv}**	**Combined CMFs**		**Predicted N_{bisv}**
	from Table 12-12						**from Equation 12-24, 12-ESVA, or 12-ESVB~~from Equation 12-ESVA~~**						
Crash Severity Level	**a~~A~~**	**b**	**c**	**f**	**g~~f~~**	**from Table 12-12**		**(4)*(7) from Worksheet 2B**	**Proportion of Total Crashes [not used for 3ST, 4ST, and 3STT]**	**(5)$_{total}$*(6) ~~[not used for 3ST, 4ST, and 3STT]~~**	**(7)**	**Calibration Factor, C_i**	**(7)*(8)*(9)**
Total	-13.94	-	-	1.23	- ~~1.23~~	0.34	0.247	0.247	1.000	0.247	1.00	1.00	0.247
Fatal and injury (FI)	-20.72	-	-	1.76	- ~~1.76~~	0.15	Equation 12-27 [3ST and 4ST only] ~~0.062~~	0.062	$(5)_{FI}/((5)_{FI}+(5)_{PDO})$	$(5)_{FI}$ [3ST, 4ST, 3STT only]	1.00	1.00	0.065
							0.062		0.264	0.065			
Property damage only (PDO)	-12.25	-	-	1.03	- ~~1.03~~	0.27	0.174	0.174	$(6)_{total}-(6)_{FI}$	$(7)_{total}-(7)_{FI}$ [3ST, 4ST, 3STT only]	1.00	1.00	0.182
									0.736	0.182			

Worksheet SPXCF—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections

Worksheet SPXCF presents the default proportions for collision type (from Table 12-13) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 10~~9~~, Worksheet SPXCE) into components by crash severity and collision type.

Worksheet SPXCF. Single-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	**Predicted $N_{bisv (FI)}$ (crashes/year)**	**Proportion of Collision Type $_{(PDO)}$**	**Predicted $N_{bisv (PDO)}$ (crashes/year)**	**Predicted $N_{bisv (total)}$ (crashes/year)**
Collision Type	**Table 12-13 or 12-XB~~Table 12-13~~**	**(10)$_{FI}$ from Worksheet SPXCE**	**Table 12-13 or 12-XB~~Table 12-13~~**	**(10)$_{PDO}$ from Worksheet SPXCE**	**(10)$_{PDO}$ from Worksheet SPXCE**
Total	1.000	0.065 (2)*(3)$_{FI}$	1.000	0.182 (4)*(5)$_{PDO}$	0.247 (3)+(5)
Collision with parked vehicle	0.000	0.000	0.055	0.010	0.010
Collision with animal	0.000	0.000	0.000	0.000	0.000
Collision with fixed object	0.310	0.020	0.205	0.037	0.057
Collision with other object	0.000	0.000	0.027	0.005	0.005
Other single-vehicle collision	0.621	0.040	0.712	0.129	0.170
Single-vehicle noncollision	0.069	0.004	0.000	0.000	0.004

Worksheet SPXCG—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections (except 3SG and 4SG)

The predicted average crash frequency of multiple-vehicle predicted crashes and single-vehicle predicted crashes from Worksheets SPXCC and SPXCE are entered into Columns 2 and 3 respectively. These values are summed in Column 4. ~~The predicted average crash frequency of multiple- and single-vehicle predicted crashes from Worksheet SPXC is entered into Column 2.~~ Column 5 contains the pedestrian crash adjustment factor (see Table 12-16). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SPXCG. Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv} or Predicted $N_{bimv+sv}$ for aST(1)	Predicted N_{bisv}(1)	Predicted N_{bi}(1)	f_{pedi}		*Predicted* N_{pedi}
Crash Severity Level	(7)*(8)~~(107)*(8)~~ from Worksheet SPXCC	(7)*(8)~~(107)*(8)~~ from Worksheet SPXCE [not used for 3aST and 4aST]	(2)+(3)	from Table 12-16	Calibration Factor, C_i	(4)*(5)*(6)
Total	6.841	0.247	7.088	0.0312	1.00	0.221
Fatal and injury (FI)	—	—	—	—	1.00	0.221

(1) Predicted values prior to calibration

Worksheet SPXCJ—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

The predicted average crash frequency of multiple-vehicle predicted crashes and single-vehicle predicted crashes from Worksheets SPXCC and SPXCE are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the bicycle crash adjustment factor (see Table 12-17). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-bicycle collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SPXCJ. Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv} or Predicted $N_{bimv+sv}$ for aST(1)	Predicted N_{bisv}(1)	Predicted N_{bi}(1)	f_{bikei}		Predicted N_{pedi}
Crash Severity Level	(7)*(8) ~~(107)*(8)~~ from Worksheet SPXCC	(7)*(8)~~(107)*(8)~~ from Worksheet SPXCE [not used for 3aST and 4aST]	(2)+(3)	from Table 12-17	Calibration Factor, C_i	(4)*(5)*(6)
Total	6.841	0.247	7.088	0.0309	1.00	0.219
Fatal and injury (FI)	—	—	—	—	1.00	0.219

(1) Predicted values prior to calibration

Worksheet SPXCK—Crash Severity Distribution for Urban and Suburban Arterial Intersections

Worksheet SPXCK provides a summary of all collision types by severity level. Values from Worksheets SPXCD, SPXCF, SPXCG, and SPXCJ are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SPXCK. Crash Severity Distribution for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	**Property Damage Only (PDO)**	**Total**
Collision Type	**(3) from Worksheets SPXCD and SPXCF; (7) from SPXDG (or SPXCI) and SPXCJ**	**(5) from Worksheets SPXCD and SPXCF**	**(6) from Worksheets SPXCD and SPXCF; (7) from SPXDG (or SPXCI) and SPXCJ**
MULTIPLE-VEHICLE COLLISIONS			
Rear-end collisions (from Worksheet SPXCD)	0.641	2.293	2.934
Head-on collisions (from Worksheet SPXCD)	0.098	0.128	0.226
Angle collisions (from Worksheet SPXCD)	0.484	1.269	1.753
Sideswipe (from Worksheet SPXCD)	0.074	0.901	0.975
Other multiple-vehicle collision (from Worksheet SPXCD)	0.210	0.741	0.951
Subtotal	1.506	5.333	6.839
SINGLE-VEHICLE COLLISIONS			
Collision with parked vehicle (from Worksheet SPXCF)	0.000	0.010	0.010
Collision with animal (from Worksheet SPXCF)	0.000	0.000	0.000
Collision with fixed object (from Worksheet SPXCF)	0.020	0.037	0.057
Collision with other object (from Worksheet SPXCF)	0.000	0.005	0.005
Other single-vehicle collision (from Worksheet SPXCF)	0.040	0.129	0.170
Single-vehicle noncollision (from Worksheet SPXCF)	0.004	0.000	0.004
Collision with pedestrian (from Worksheet SPXCG or SPXCI~~H~~)	0.221	0.000	0.221
Collision with bicycle (from Worksheet SPXCJ)	0.219	0.000	0.219
Subtotal	0.505	0.182	0.687
Total	2.011	5.515	7.526

Worksheet SPXCL—Summary Results for Urban and Suburban Arterial Intersections

Worksheet SPXCL presents a summary of the results.

Worksheet SPXCL. Summary Results for Urban and Suburban Arterial Intersections

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	(Total) from Worksheet SPXCK
Total	7.5
Fatal and injury (FI)	2.0
Property damage only (PDO)	5.5

~~12.13.5.~~12.13.9. Sample Problem 5

The Project

A project of interest consists of four sites located on an urban arterial: a three-lane TWLTL segment; a four-lane divided segment; a three-leg intersection with minor-road stop control; and a four-leg signalized intersection. (This project is a compilation of roadway segments and intersections from Sample Problems 1 through 4.)

The Question

What is the expected crash frequency of the project for a particular year incorporating both the predicted crash frequencies from Sample Problems 1 through 4 and the observed crash frequencies using the site-specific EB Method?

The Facts

- 2 roadway segments (3T segment, 4D segment)
- 2 intersections (3ST intersection, 4SG intersection)
- 34 observed crashes (3T segment: 7 multiple-vehicle nondriveway, 4 single-vehicle, 2 multiple-vehicle driveway related; 4D: 6 multiple-vehicle nondriveway, 3 single-vehicle, 1 multiple-vehicle driveway related; 3ST: 2 multiple-vehicle, 3 single-vehicle; 4SG 6 multiple-vehicle, 0 single-vehicle)

Outline of Solution

To calculate the expected average crash frequency, site-specific observed crash frequencies are combined with predicted 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 Part C, Appendix A.2.4.

Results

The expected average crash frequency for the project is 25.4 crashes per year (rounded to one decimal place).

Worksheets

To apply the site-specific EB Method to multiple roadway segments and intersections on an urban or suburban arterial combined, three worksheets are provided for determining the expected average crash frequency. The three worksheets include:

- *Worksheet SP5A (Corresponds to Worksheet 3A)*—Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Urban and Suburban Arterials.
- *Worksheet SP5B (Corresponds to Worksheet 3B)*—Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials.

- *Worksheet SP5C (Corresponds to Worksheet 3C)*—Site-Specific EB Method Summary Results for Urban and Suburban Arterials

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheets SP5A—Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Urban and Suburban Arterials.

The predicted average crash frequencies by severity level and collision type determined in Sample Problems 1 through 4 are entered into Columns 2 through 4 of Worksheet SP5A. Column 5 presents the observed crash frequencies by site and collision 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 A 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 SP5A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Collision Type/Site Type	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, k	Weighted Adjustment, w	Expected Average Crash Frequency, $N_{expected\ (vehicle)}$
	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$			Equation A-5	Equation A-4
ROADWAY SEGMENTS							
Multiple-Vehicle Nondriveway							
Segment 1	4.967	1.196	3.771	7	0.66	0.234	6.524
Segment 2	2.524	0.702	1.822	6	1.32	0.231	5.197
Single-Vehicle							
Segment 1	1.182	0.338	0.844	4	1.37	0.382	2.924
Segment 2	0.485	0.085	0.401	3	0.86	0.706	1.224
Multiple-Vehicle Driveway-Related							
Segment 1	0.734	0.179	0.555	2	1.10	0.553	1.300
Segment 2	0.149	0.042	0.107	1	1.39	0.828	0.295
INTERSECTIONS							
Multiple-Vehicle							
Intersection 1	1.268	0.405	0.862	2	0.80	0.496	1.637
Intersection 2	2.658	0.845	1.812	6	0.39	0.491	4.359
Single-Vehicle							
Intersection 1	0.234	0.072	0.162	3	1.14	0.789	0.818
Intersection 2	0.196	0.056	0.140	0	0.36	0.934	0.183
Combined (Sum of Column)	14.397	3.920	10.476	34	—	—	24.461

Column 7—Weighted Adjustment

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

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

Multiple-Vehicle Nondriveway Collisions

Segment 1

$$w = \frac{1}{1 + 0.66 \times (4.967)} = 0.234$$

Segment 2

$$w = \frac{1}{1 + 1.32 \times (2.524)} = 0.231$$

Single-Vehicle Crashes

Segment 1

$$w = \frac{1}{1 + 1.37 \times (1.182)} = 0.382$$

Segment 2

$$w = \frac{1}{1 + 0.86 \times (0.485)} = 0.706$$

Multiple-Vehicle Driveway Related Collisions

Segment 1

$$w = \frac{1}{1 + 1.10 \times (0.734)} = 0.553$$

Segment 2

$$w = \frac{1}{1 + 1.39 \times (0.149)} = 0.828$$

Multiple-Vehicle Collisions

Intersection 1

$$w = \frac{1}{1+0.80\times(1.268)} = 0.496$$

Intersection 2

$$w = \frac{1}{1+0.39\times(2.658)} = 0.491$$

Single-Vehicle Crashes

Intersection 1

$$w = \frac{1}{1+1.149\times(0.234)} = 0.789$$

Intersection 2

$$w = \frac{1}{1+0.36\times(0.196)} = 0.934$$

Column 8—Expected Average Crash Frequency

The estimate of expected average crash frequency, N_{expected}, is calculated using Equation A-4 as follows:

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

Multiple-Vehicle Nondriveway Collisions

Segment 1 $N_{\text{expected}} = 0.234\times 4.967 + (1-0.234)\times 7 = 6.524$

Segment 2 $N_{\text{expected}} = 0.231\times 2.524 + (1-0.231)\times 6 = 5.197$

Single-Vehicle Crashes

Segment 1 $N_{\text{expected}} = 0.382\times 1.182 + (1-0.382)\times 4 = 2.924$

Segment 2 $N_{\text{expected}} = 0.706\times 0.485 + (1-0.706)\times 3 = 1.224$

Multiple-Vehicle Driveway Related Collisions

Segment 1 $N_{\text{expected}} = 0.553\times 0.734 + (1-0.553)\times 2 = 1.300$

Segment 2 $N_{\text{expected}} = 0.828\times 0.149 + (1-0.828)\times 1 = 0.295$

Multiple-Vehicle Collisions

Intersection 1 $N_{\text{expected}} = 0.496\times 1.268 + (1-0.496)\times 2 = 1.637$

Intersection 2 $N_{\text{expected}} = 0.491\times 2.658 + (1-0.491)\times 6 = 4.359$

Single-Vehicle Crashes

Intersection 1 $N_{\text{expected}} = 0.789 \times 0.234 + (1 - 0.789) \times 3 = 0.818$

Intersection 2 $N_{\text{expected}} = 0.934 \times 0.196 + (1 - 0.934) \times 0 = 0.183$

Worksheets SP5B—Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

Worksheet SP5B provides a summary of the vehicle-pedestrian and vehicle-bicycle crashes determined in Sample Problems 1 through 4.

Worksheet SP5B. Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

(1)	(2)	(3)
Site Type	N_{ped}	N_{bike}
ROADWAY SEGMENTS		
Segment 1	0.089	0.048
Segment 2	0.212	0.041
INTERSECTIONS		
Intersection 1	0.032	0.024
Intersection 2	0.475	0.043
Combined (Sum of Column)	0.808	0.156

Worksheets SP5C—Site-Specific EB Method Summary Results for Urban and Suburban Arterials

Worksheet SP5C presents a summary of the results. Column 5 calculates the expected average crash frequency by severity level for vehicle crashes only by applying the proportion of predicted average crash frequency by severity level (Column 2) to the expected average crash frequency calculated using the site-specific EB Method. Column 6 calculates the total expected average crash frequency by severity level using the values in Column 3, 4, and 5.

Worksheet SP5C. Site-Specific EB Method Summary Results for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	N_{ped}	N_{bike}	$N_{expected\ (vehicle)}$	$N_{expected}$
Total	$(2)_{comb}$ Worksheet SP5A	$(2)_{comb}$ Worksheet SP5B	$(3)_{comb}$ Worksheet SP5B	$(13)_{comb}$ Worksheet SP5A	(3)+(4)+(5)
	14.397	0.808	0.156	24.461	25.4
Fatal and injury (FI)	$(3)_{comb}$ Worksheet SP5A	$(2)_{comb}$ Worksheet SP5B	$(3)_{comb}$ Worksheet SP5B	$(5)_{total}*(2)_{FI}/(2)$total	(3)+(4)+(5)
	3.920	0.808	0.156	6.660	7.6
Property damage only (PDO)	$(4)_{comb}$ Worksheet SP5A	—	—	$(5)_{total}*(2)_{PDO}/(2)_{total}$	(3)+(4)+(5)
	10.476	0.000	0.000	17.800	17.8

~~12.13.6.~~12.13.10. Sample Problem 6

The Project
A project of interest consists of four sites located on an urban arterial: a three-lane TWLTL segment; a four-lane divided segment; a three-leg intersection with minor-road stop control; and a four-leg signalized intersection. (This project is a compilation of roadway segments and intersections from Sample Problems 1 through 4.)

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 through 4 and the observed crash frequencies using the **project-level EB Method?**

The Facts

- 2 roadway segments (3T segment, 4D segment)
- 2 intersection (3ST intersection, 4SG intersection)
- 34 observed crashes (but no information is available to attribute specific crashes to specific sites)

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 Part C, Appendix A.2.5.

Results
The expected average crash frequency for the project is 26.0 crashes per year (rounded to one decimal place).

Worksheets

To apply the project-level EB Method to multiple roadway segments and intersections on an urban or suburban arterial combined, three worksheets are provided for determining the expected average crash frequency. The three worksheets include:

- *Worksheet SP6A (Corresponds to Worksheet 4A)*—Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Urban and Suburban Arterials
- *Worksheet SP6B (Corresponds to Worksheet 4B)*—Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials
- *Worksheet SP6C (Corresponds to Worksheet 4C)*—Project-EB Method Summary Results for Urban and Suburban Arterials

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheets SP6A—Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Urban and Suburban Arterials

The predicted average crash frequencies by severity level and collision type, excluding vehicle-pedestrian and vehicle-bicycle collisions, determined in Sample Problems 1 through 4 are entered in Columns 2 through 4 of Worksheet SP6A. 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 calculates N_{w1}. Equations A-10 through A-14 from Part C, Appendix A 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. Part C, Appendix A.2.5 defines all the variables used in this worksheet. Detailed calculations of Columns 9 through 13 are provided below.

Worksheet SP6A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Predicted Crashes					$N_{predicted\ w0}$	$N_{predicted\ w1}$	w_0	N_0	w_1	N_1	$N_{expected/comb\ (vehicle)}$
Collision Type/Site Type	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$	Observed Crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, k	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												
Multiple-Vehicle Nondriveway												
Segment 1	4.967	1.196	3.771	—	0.66	16.283	1.811	—	—	—	—	—
Segment 2	2.524	0.702	1.822	—	1.32	8.409	1.825	—	—	—	—	—
Single-Vehicle												
Segment 1	1.182	0.338	0.844	—	1.37	1.914	1.273	—	—	—	—	—
Segment 2	0.485	0.085	0.401	—	0.86	0.202	0.646	—	—	—	—	—
Multiple-Vehicle Driveway-Related												
Segment 1	0.734	0.179	0.555	—	1.10	0.593	0.899	—	—	—	—	—
Segment 2	0.149	0.042	0.107	—	1.39	0.031	0.455	—	—	—	—	—
INTERSECTIONS												
Multiple-Vehicle												
Intersection 1	1.268	0.405	0.862	—	0.80	1.286	1.007	—	—	—	—	—
Intersection 2	2.658	0.845	1.812	—	0.39	2.755	1.018	—	—	—	—	—
Single-Vehicle												
Intersection 1	0.234	0.072	0.162	—	1.14	0.062	0.516	—	—	—	—	—
Intersection 2	0.196	0.056	0.140	—	0.36	0.014	0.266	—	—	—	—	—
Combined (Sum of Column)	14.397	3.920	10.476	34	—	31.549	9.716	0.313	27.864	0.597	22.297	25.080

Note: $N_{predicted\ w0}$ = Predicted number of total crashes assuming that crash frequencies are statistically independent

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

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

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

Column 9—w_0
The weight placed on predicted crash frequency under the assumption that crashes frequencies for different roadway elements are statistically independent, w_0, is calculated using Equation A-10 as follows:

$$w_0 = \frac{1}{1 + \frac{N_{\text{predicted } w0}}{N_{\text{predicted (total)}}}} = \frac{1}{1 + \frac{31.549}{14.397}} = 0.313$$

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 as follows:

$$N_0 = w_0 \times N_{\text{predicted(total)}} + (1 - w_0) \times N_{\text{observed(total)}} = 0.313 \times 14.397 + (1 - 0.313) \times 34 = 27.864$$

Column 11—w_1
The weight placed on predicted crash frequency under the assumption that crashes frequencies for different roadway elements are perfectly correlated, w_1, is calculated using Equation A-12 as follows:

$$w_1 = \frac{1}{1 + \frac{N_{\text{predicted } w1}}{N_{\text{predicted (total)}}}} = \frac{1}{1 + \frac{9.716}{14.397}} = 0.597$$

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 as follows:

$$N_1 = w_1 \times N_{\text{predicted (total)}} + (1 - w_1) \times N_{\text{observed (total)}} = 0.597 \times 14.397 + (1 - 0.597) \times 34 = 22.297$$

Column 13—$N_{\text{expected}/comb}$
The expected average crash frequency based of combined sites, $N_{\text{expected}/comb}$, is calculated using Equation A-14 as follows:

$$N_{\text{expected}/comb} = \frac{N_0 + N_1}{2}$$
$$= \frac{27.864 + 22.297}{2}$$
$$= 25.080$$

Worksheets SP6B—Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

Worksheet SP6B provides a summary of the vehicle-pedestrian and vehicle-bicycle crashes determined in Sample Problems 1 through 4.

Worksheet SP6B. Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

(1)	(2)	(3)
Site Type	N_{ped}	N_{bike}
ROADWAY SEGMENTS		
Segment 1	0.089	0.048
Segment 2	0.212	0.041
INTERSECTIONS		
Intersection 1	0.032	0.024
Intersection 2	0.475	0.043
Combined (Sum of Column)	0.808	0.156

Worksheets SP6C—Project-Level EB Method Summary Results for Urban and Suburban Arterials

Worksheet SP6C presents a summary of the results. Column 5 calculates the expected average crash frequency by severity level for vehicle crashes only by applying the proportion of predicted average crash frequency by severity level (Column 2) to the expected average crash frequency calculated using the project-level EB Method. Column 6 calculates the total expected average crash frequency by severity level using the values in Column 3, 4, and 5.

Worksheet SP6C. Project-Level EB Method Summary Results for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	N_{ped}	N_{bike}	$N_{expected/comb\ (vehicle)}$	$N_{expected}$
Total	$(2)_{comb}$ Worksheet SP6A	$(2)_{comb}$ Worksheet SP6B	$(3)_{comb}$ Worksheet SP6B	$(13)_{comb}$ Worksheet SP6A	(3)+(4)+(5)
	14.397	0.808	0.156	25.080	26.0
Fatal and injury (FI)	$(3)_{comb}$ Worksheet SP6A	$(2)_{comb}$ Worksheet SP6B	$(3)_{comb}$ Worksheet SP6B	$(5)_{total}*(2)_{FI}/(2)_{total}$	(3)+(4)+(5)
	3.920	0.808	0.156	6.829	7.8
Property damage only (PDO)	$(4)_{comb}$ Worksheet SP6A	—	—	$(5)_{total}*(2)_{PDO}/(2)_{total}$	(3)+(4)+(5)
	10.476	0.000	0.000	18.250	18.3

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APPENDIX 12A. WORKSHEETS FOR PREDICTIVE METHOD FOR URBAN AND SUBURBAN ARTERIALS

Worksheet 1A. General Information and Input Data for Urban and Suburban Roadway Segments

General Information	**Location Information**	
Analyst	Roadway	
Agency or Company	Roadway Section	
Date Performed	Jurisdiction	
	Analysis Year	
Input Data	**Base Conditions**	**Site Conditions**
Road type (2U, 3T, 4U, 4D, 5T)	—	
Length of segment, *L* (mi)	—	
AADT (veh/day)	—	
Type of on-street parking (none/parallel/angle)	none	
Proportion of curb length with on-street parking	—	
Median width (ft)	15	
Lighting (present / not present)	not present	
Auto speed enforcement (present/not present)	not present	
Major commercial driveways (number)	—	
Minor commercial driveways (number)	—	
Major industrial/institutional driveways (number)	—	
Minor industrial/institutional driveways (number)	—	
Major residential driveways (number)	—	
Minor residential driveways (number)	—	
Other driveways (number)	—	
Speed Category	—	
Roadside fixed object density (fixed objects/mi)	not present	
Offset to roadside fixed objects (ft)	not present	
Calibration Factor, C_r	1.0	

Worksheet 1B. Crash Modification Factors for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
CMF for On-Street Parking	**CMF for Roadside Fixed Objects**	**CMF for Median Width**	**CMF for Lighting**	**CMF for Auto Speed Enforcement**	**Combined CMF**
CMF_{1r}	CMF_{2r}	CMF_{3r}	CMF_{4r}	CMF_{5r}	CMF_{comb}
from Equation 12-32	from Equation 12-33	from Table 12-22	from Equation 12-34	from Section 12.7.1	(1)*(2)*(3)*(4)*(5)

Worksheet 1C. Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
Crash Severity Level	**SPF Coefficients**		**Overdispersion Parameter, *k***	**Initial N_{brmv}**	**Proportion of Total Crashes**	**Adjusted N_{brmv}**	**Combined CMFs**	**Calibration Factor**	**Predicted N_{brmv}**
	from Table 12-3		**from Table 12-3**	**from Equation 12-10**		**$(4)_{total}$*(5)**	**(6) from Worksheet 1B**	**C_r**	**(6)*(7)*(8)**
	a	**b**							
Total									
Fatal and injury (FI)					$(4)_{FI}/((4)_{FI}+(4)_{PDO})$				
Property damage only (PDO)					$(5)_{total}-(5)_{FI}$				

Worksheet 1D. Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{brmv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{brmv\ (PDO)}$ (crashes/year)	Predicted $N_{brmv\ (total)}$ (crashes/year)
Collision Type	from Table 12-4	$(9)_{FI}$ from Worksheet 1C	from Table 12-4	$(9)_{PDO}$ from Worksheet 1C	$(9)_{total}$ from Worksheet 1C
Total	1.000	$(2)*(3)_{FI}$	1.000	$(4)*(5)_{PDO}$	(3)+(5)
Rear-end collision					
Head-on collision					
Angle collision					
Sideswipe, same direction					
Sideswipe, opposite direction					
Other multiple-vehicle collision					

Worksheet 1E. Single-Vehicle Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
	SPF Coefficients		Overdispersion Parameter, *k*	Initial N_{brsv}		Adjusted N_{brsv}	Combined CMFs	Calibration Factor	Predicted N_{brsv}
	from Table 12-5								
Crash Severity Level	a	b	from Table 12-5	from Equation 12-13	Proportion of Total Crashes	$(4)_{total}*(5)$	(6) from Worksheet 1B	C_r	(6)*(7)*(8)
Total									
Fatal and injury (FI)					$(4)_{FI}/((4)_{FI}+(4)_{PDO})$				
Property damage only (PDO)					$(5)_{total}-(5)_{FI}$				

Worksheet 1F. Single-Vehicle Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{brsv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{brsv\ (PDO)}$ (crashes/year)	Predicted $N_{brsv\ (total)}$ (crashes/year)
Collision Type	from Table 12-6	$(9)_{FI}$ from Worksheet 1E	from Table 12-6	$(9)_{PDO}$ from Worksheet 1E	$(9)_{total}$ from Worksheet 1E
Total	1.000	$(2)*(3)_{FI}$	1.000	$(4)*(5)_{PDO}$	(3)+(5)
Collision with animal					
Collision with fixed object					
Collision with other object					
Other single-vehicle collision					

Worksheet 1G. Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
		Crashes per Driveway per Year, N_j	Coefficient for Traffic Adjustment, t	Initial N_{brdwy}	Overdispersion Parameter, k
Driveway Type	Number of Driveways, n_j	from Table 12-7	from Table 12-7	Equation 12-16 $n_j*N_j*(AADT/15{,}000)t$	from Table 12-7
Major commercial					—
Minor commercial					
Major industrial/institutional					
Minor industrial/institutional					
Major residential					
Minor residential					
Other					
Total	—	—	—		

Worksheet 1H. Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Initial N_{brdwy}	Proportion of Total Crashes (f_{dwy})	Adjusted N_{brdwy}	Combined CMFs		Predicted N_{brdwy}
Crash Severity Level	$(5)_{total}$ from Worksheet 1G	from Table 12-7	$(2)_{total}$ *(3)	(6) from Worksheet 1B	Calibration Factor, C_r	(4)*(5)*(6)
Total						
Fatal and injury (FI)	—					
Property damage only (PDO)	—					

Worksheet 1I. Vehicle-Pedestrian Collisions for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted N_{brmv}	Predicted N_{brsv}	Predicted N_{brdwy}	Predicted N_{br}	f_{pedr}		Predicted N_{pedr}
Crash Severity Level	(9) from Worksheet 1C	(9) from Worksheet 1E	(7) from Worksheet 1H	(2)+(3)+(4)	from Table 12-8	Calibration Factor, C_r	(5)*(6)*(7)
Total							
Fatal and injury (FI)	—	—	—	—	—		

Worksheet 1J. Vehicle-Bicycle Collisions for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted N_{brmv}	Predicted N_{brsv}	Predicted N_{brdwy}	Predicted N_{br}	f_{biker}		Predicted N_{biker}
Crash Severity Level	(9) from Worksheet 1C	(9) from Worksheet 1E	(7) from Worksheet 1H	(2)+(3)+(4)	from Table 12-9	Calibration Factor, C_r	(5)*(6)*(7)
Total							
Fatal and injury	—	—	—	—	—		

Worksheet 1K. Crash Severity Distribution for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	**Property Damage Only (PDO)**	**Total**
Collision Type	**(3) from Worksheets 1D and 1F; (7) from Worksheet 1H; and (8) from Worksheets 1I and 1J**	**(5) from Worksheets 1D and 1F; and (7) from Worksheet 1H**	**(6) from Worksheets 1D and 1F; (7) from Worksheet 1H; and (8) from Worksheets 1I and 1J**
MULTIPLE-VEHICLE			
Rear-end collisions (from Worksheet 1D)			
Head-on collisions (from Worksheet 1D)			
Angle collisions (from Worksheet 1D)			
Sideswipe, same direction (from Worksheet 1D)			
Sideswipe, opposite direction (from Worksheet 1D)			
Driveway-related collisions (from Worksheet 1H)			
Other multiple-vehicle collision (from Worksheet 1D)			
Subtotal			
SINGLE-VEHICLE			
Collision with animal (from Worksheet 1F)			
Collision with fixed object (from Worksheet 1F)			
Collision with other object (from Worksheet 1F)			
Other single-vehicle collision (from Worksheet 1F)			
Collision with pedestrian (from Worksheet 1I)			
Collision with bicycle (from Worksheet 1J)			
Subtotal			
Total			

Worksheet 1L. Summary Results for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
	Predicted Average Crash Frequency, $N_{predicted\ rs}$ (crashes/year)		Crash Rate (crashes/mi/year)
Crash Severity Level	(total) from Worksheet 1K	Roadway Segment Length, L (mi)	(2)/(3)
Total			
Fatal and injury (FI)			
Property damage only (PDO)			

Worksheet 2A. General Information and Input Data for Urban and Suburban Arterial 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, 3ST-HS, 3STT, 3aST, 3SG, 3SG-HS, 4ST, 4ST-HS, 4aST, 4SG, 4SG-HS, 5SG)~~(3ST, 3SG, 4ST, 4SG)~~	—	
$AADT_{maj}$ (veh/day), ($AADT_{maj1}$ for 3STT)	—	
$AADT_{maj2}$ (veh/day), (3STT only)	—	
$AADT_{min}$ (veh/day)	—	
$AADT_{fifth}$ (veh/day)	—	
Intersection lighting (present/not present)	not present	
Calibration factor, C_i	1.00	
Data for unsignalized intersections only:	—	
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	
Horizontal curve radius (ft) [for 3STT only]	84	
Horizontal curve length (ft) [for 3STT only]	100	
Data for signalized intersections only:	—	
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)	0	
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)	0	
Number of approaches with left-turn signal phasing	—	
Number of approaches with right-turn-on-red prohibited	0	
Type of left-turn signal phasing	permissive	
Intersection red-light cameras (present/not present)	not present	
Sum of all pedestrian crossing volumes (PedVol)	—	
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	
Number of bus stops within 300 m (1,000 ft) of the intersection	0	
Schools within 300 m (1,000 ft) of the intersection (present/not present)	not present	
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection	0	

Worksheet 2B. Crash Modification Factors for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(~~7~~8)
CMF for Left-Turn Lanes	**CMF for Left-Turn Signal Phasing**	**CMF for Right-Turn Lanes**	**CMF for Right-Turn-on-Red**	**CMF for Lighting**	**CMF for Red-Light Cameras**	**CMF for Horizontal Curves**	**Combined CMF**
CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{5i}	CMF_{6i}	CMF_{7i}	CMF_{comb}
from Table 12-24	from Table 12-25	from Table 12-26	from Equation 12-35	from Equation 12-36	from Equation 12-37	From Equation 12-CMF	(1)*(2)*(3)*(4)*(5)*(6)

Worksheet 2C. Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections (Applicable to 3ST, 3ST-HS, 3STT, 3SG, 3SG-HS, 4ST, 4ST-HS, 4SG, 4SG-HS, 5SG)

(1)	(2)						(3)	(4)	(5)	(~~5~~6)	(~~6~~7)	(~~7~~8)	(~~8~~9)	(~~9~~10)
	SPF Coefficients						Overdispersion Parameter, k	Initial N_{bimv}	Initial N_{bimv} Adjusted for Curve CMF		Adjusted N_{bimv}	Combined CMFs		Predicted N_{bimv}
	from Table 12-10							from Equation 12-21~~22~~, 12-EMVA~~, or~~ 12-EMVB, or 12-EMVC	(4)*(7) from Worksheet 2B	Proportion of Total Crashes [For 3STT, from Equation 12-EMVPROPB and 12-EMVPROPC]				
Crash Severity Level	a	b	c_i ~~e(FI)~~	d	e	~~d~~f	from Table 12-10				(~~4~~5)$_{total}$*(~~5~~6)	(~~7~~8) from Worksheet 2B	Calibration Factor, C_i	(~~6~~7)*(~~7~~8)*(~~8~~9)
Total														
Fatal and injury (FI)										(~~4~~5)$_{FI}$/((~~4~~5)$_{FI}$+(~~4~~5)$_{PDO}$)				
Property damage only (PDO)										(~~5~~6)$_{total}$–(~~5~~6)$_{FI}$				

Worksheet 2C. Total Collisions by Severity Level for Urban and Suburban Arterial Intersections (Applicable to 3aST and 4aST)

(1)	(2)				(3)	(4)	(5)	(6) ~~(5)~~	(7) ~~(6)~~	(8) ~~(7)~~	(9) ~~(8)~~	(10) ~~(9)~~
	SPF Coefficients				Overdispersion Parameter, k	Initial $N_{bimv+sv}$	Initial N_{bimv} Adjusted for Curve CMF		Adjusted $N_{bimv+sv}$	Combined CMFs		Predicted $N_{bimv+sv}$
	from Table 12-XA					from Equation 12-MV+SVA or 12-MV+SVB	(4)*(7) from Worksheet SPXAB					
Crash Severity Level	a	b/~~f~~	c	f~~d~~	from Table 12-XA			Proportion of Total Crashes	~~(4)$_{total}$~~*(5)	(8~~7~~) from Worksheet 2B	Calibration Factor, C_i	(7~~6~~)*(8~~7~~)*(9~~8~~)
Total												
Fatal and injury (FI)								(5~~4~~)$_{FI}$/((4~~5~~)$_{FI}$+(4~~5~~)$_{PDO}$)				
Property damage only (PDO)								(5~~6~~)$_{total}$–(5~~6~~)$_{FI}$				

Worksheet 2D. Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	**Predicted** $N_{bimv\ (FI)}$ **(crashes/year)**	**Proportion of Collision Type** $_{(PDO)}$	**Predicted** $N_{bimv\ (PDO)}$ **(crashes/year)**	**Predicted** $N_{bimv\ (total)}$ **(crashes/year)**
Collision Type	**from Table 12-11 or 12-XB**	**(~~9~~10)** $_{FI}$ **from Worksheet 2C**	**from Table 12-11 or 12-XB**	**(~~9~~10)** $_{PDO}$ **from Worksheet 2C**	**(~~9~~10)** $_{\cancel{PDO}total}$ **from Worksheet 2C**
Total	1.000	(2)*(3) $_{FI}$	1.000	(4)*(5) $_{PDO}$	(3)+(5)
Rear-end collision					
Head-on collision					
Angle collision					
Sideswipe					
Other multiple-vehicle collision					

Worksheet 2E. Single-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections (Applicable to 3ST, 3ST-HS, 3STT, 3SG, 3SG-HS, 4ST, 4ST-HS, 4SG, 4SG-HS, 5SG)

(1)	(2)					(3)	(4)	(5)	(~~5~~6)	(~~6~~7)	(~~7~~8)	(~~8~~9)	(~~9~~10)
	SPF Coefficients					**Overdispersion Parameter, *k***	**Initial N_{bisv}**	**Initial N_{bisv} Adjusted for Curve CMF**		**Adjusted N_{bisv}**	**Combined CMFs**		**Predicted N_{bisv}**
	from Table 12-12						**from Equation 12-24~~25, or~~ 12-ESVA, or 12-ESVB~~; (FI) from Equation 12-25 or 12-27~~**	**(4)*(7) from Worksheet 2B**					
Crash Severity Level	**a**	**b ~~b~~ ~~f~~**	**c ~~e~~**	**f**	**g**	**from Table 12-12**			**Proportion of Total Crashes [not used for 3ST, 4ST, and 3STT]**	**(~~4~~5)$_{total}$*(~~5~~6) ~~[not used for 3ST, 4ST, and 3STT]~~**	**(~~7~~8) from Worksheet 2B**	**Calibration Factor, C_i**	**(~~6~~7)*(~~7~~8)*(~~8~~9)**
Total													
Fatal and injury (FI)							Equation 12-27 [3ST and 4ST only]		(~~4~~5)$_{FI}$/((~~4~~5)$_{FI}$+(~~4~~5)$_{PDO}$)	(5)$_{FI}$ [for 3ST, 4ST, 3STT ~~only~~]			
Property damage only (PDO)									(~~5~~6)$_{total}$−(~~5~~6)$_{FI}$	(7)$_{total}$-(7)$_{FI}$ [for 3ST, 4ST, 3STT ~~only~~]			

Worksheet 2F. Single-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type *(FI)*	**Predicted** $N_{bisv\ (FI)}$ **(crashes/year)**	**Proportion of Collision Type** *(PDO)*	**Predicted** N_{bisv} *(PDO)* **(crashes/year)**	**Predicted** $N_{bisv\ (total)}$ **(crashes/year)**
Collision Type	**Table 12-13 or 12-XB**	**(~~9~~10)$_{FI}$ from Worksheet 2E**	**Table 12-13 or 12-XB**	**(~~9~~10)$_{PDO}$ from Worksheet 2E**	**(~~9~~10) ~~PDO~~total from Worksheet 2E**
Total	1.000	(2)*(3)$_{FI}$	1.000	(4)*(5)$_{PDO}$	(3)+(5)
Collision with parked vehicle					
Collision with animal					
Collision with fixed object					
Collision with other object					
Other single-vehicle collision					
Single-vehicle noncollision					

Worksheet 2G. Vehicle-Pedestrian Collisions for Urban and Suburban Arterial ~~Stop-Controlled~~ Intersections (Applicable to 3ST, 3ST-HS, 3STT, 3aST, 3SG-HS, 4ST, 4ST-HS, 4aST, 4SG-HS, and 5SG)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv} **or Predicted** $N_{bimv+sv}$ **for aST**(1)	**Predicted** N_{bisv}(1)	**Predicted** N_{bi}(1)	f_{pedi}		**Predicted** N_{pedi}
Crash Severity Level	**(7)*(8)~~(107)*(8)(9)~~ from Worksheet 2C**	**(7)*(8) ~~(107)*(8) (9)~~ from Worksheet 2E [not used for 3aST and 4aST]**	**(2)+(3)**	**from Table 12-16**	**Calibration Factor,** C_i	**(4)*(5)*(6)**
Total						
Fatal and injury (FI)	—	—	—	—		

(1) Predicted values prior to calibration

Worksheet 2H. Crash Modification Factors for Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections (Applicable to 3SG and 4SG)

(1)	(2)	(3)	(4)
CMF for Bus Stops	**CMF for Schools**	**CMF for Alcohol Sales Establishments**	**Combined CMF**
CMF_{1p}	CMF_{2p}	CMF_{3p}	
from Table 12-28	**from Table 12-29**	**from Table 12-30**	**(1)*(2)*(3)**

Worksheet 2I. Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections (Applicable to 3SG and 4SG)

(1)	(2)					(3)	(4)	(5)	(6)	(7)
	SPF Coefficients						$N_{pedbase}$	Combined CMF		Predicted N_{pedi}
	from Table 12-14									
Crash Severity Level	a	b	c	d	e	Overdispersion Parameter, *k*	from Equation 12-30	(4) from Worksheet 2H	Calibration Factor, C_i	(8)*(9)*(10)
Total										
Fatal and injury (FI)	—	—	—	—	—	—	—	—		

Worksheet 2J. Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv} or Predicted $N_{bimv+sv}$ for aST(1)	Predicted N_{bisv}(1)	Predicted N_{bi}(1)	f_{bikei}		Predicted N_{pedi}
Crash Severity Level	(7)*(8)~~(9)~~ from Worksheet 2C	(~~10~~7)*(8) ~~(9)~~ from Worksheet 2E [not used for 3aST and 4aST]	(2)+(3)	from Table 12-17	Calibration Factor, C_i	(4)*(5)*(6)
Total						
Fatal and injury (FI)	—	—	—	—		

(1) Predicted values prior to calibration

Worksheet 2K. Crash Severity Distribution for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	**Property Damage Only (PDO)**	**Total**
Collision Type	**(3) from Worksheets 2D and 2F; (7) from Worksheets 2G (or 2I) and 2J**	**(5) from Worksheets 2D and 2F**	**(6) from Worksheets 2D and 2F; (7) from Worksheets 2G (or 2I) and 2J**
MULTIPLE-VEHICLE COLLISIONS			
Rear-end collisions (from Worksheet 2D)			
Head-on collisions (from Worksheet 2D)			
Angle collisions (from Worksheet 2D)			
Sideswipe (from Worksheet 2D)			
Other multiple-vehicle collision (from Worksheet 2D)			
Subtotal			
SINGLE-VEHICLE COLLISIONS			
Collision with parked vehicle (from Worksheet 2F)			
Collision with animal (from Worksheet 2F)			
Collision with fixed object (from Worksheet 2F)			
Collision with other object (from Worksheet 2F)			
Other single-vehicle collision (from Worksheet 2F)			
Single-vehicle noncollision (from Worksheet 2F)			
Collision with pedestrian (from Worksheet 2G or 2I)			
Collision with bicycle (from Worksheet 2J)			
Subtotal			
Total			

Worksheet 2L. Summary Results for Urban and Suburban Arterial Intersections

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	**(Total) from Worksheet 2K**
Total	
Fatal and injury (FI)	
Property damage only (PDO)	

Worksheet 3A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Collision Type/Site Type	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, k	Weighted Adjustment, w	Expected Average Crash Frequency, $N_{expected}$ (vehicle)
	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$			Equation A-5	Equation A-4
ROADWAY SEGMENTS							
Multiple-Vehicle Nondriveway							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
Single-Vehicle							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
Multiple-Vehicle Driveway-Related							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
INTERSECTIONS							
Multiple-Vehicle							
Intersection 1							
Intersection 2							
Intersection 3							
Intersection 4							
Single-Vehicle							
Intersection 1							
Intersection 2							
Intersection 3							
Intersection 4							
Combined (Sum of Column)					—	—	

Worksheet 3B. Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

(1)	(2)	(3)
Site Type	N_{ped}	N_{bike}
ROADWAY SEGMENTS		
Segment 1		
Segment 2		
Segment 3		
Segment 4		
INTERSECTIONS		
Intersection 1		
Intersection 2		
Intersection 3		
Intersection 4		
Combined (Sum of Column)		

Worksheet 3C. Site-Specific EB Method Summary Results for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	N_{ped}	N_{bike}	$N_{expected\ (vehicle)}$	$N_{expected}$
Total	$(2)_{comb}$ Worksheet 3A	$(2)_{comb}$ Worksheet 3B	$(3)_{comb}$ Worksheet 3B	$(13)_{comb}$ Worksheet 3A	(3)+(4)+(5)
Fatal and injury (FI)	$(3)_{comb}$ Worksheet 3A	$(2)_{comb}$ Worksheet 3B	$(3)_{comb}$ Worksheet 3B	$(5)_{total}*(2)_{FI}/(2)_{total}$	(3)+(4)+(5)
Property damage only (PDO)	$(4)_{comb}$ Worksheet 3A	— 0.000	— 0.000	$(5)_{total}*(2)_{PDO}/(2)_{total}$	(3)+(4)+(5)

Worksheet 4A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Predicted Crashes					$N_{predicted\ w0}$	$N_{predicted\ w1}$	w_0	N_0	w_1	N_1	$N_{expected/comb\ (vehicle)}$
Collision Type/Site Type	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$	Observed Crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, k	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												
Multiple-Vehicle Nondriveway												
Segment 1				—				—	—	—	—	—
Segment 2				—				—	—	—	—	—
Segment 3				—				—	—	—	—	—
Segment 4				—				—	—	—	—	—
Single-Vehicle												
Segment 1				—				—	—	—	—	—
Segment 2				—				—	—	—	—	—
Segment 3				—				—	—	—	—	—
Segment 4				—				—	—	—	—	—
Multiple-Vehicle Driveway-Related												
Segment 1				—				—	—	—	—	—
Segment 2				—				—	—	—	—	—
Segment 3				—				—	—	—	—	—
Segment 4				—				—	—	—	—	—

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	Predicted Crashes					$N_{\text{predicted } wo}$	$N_{\text{predicted } w1}$	w_o	N_o	w_1	N_1	$N_{\text{expected}/comb \text{ (vehicle)}}$
Collision Type/Site Type	$N_{\text{predicted (total)}}$	$N_{\text{predicted }(FI)}$	$N_{\text{predicted }(PDO)}$	**Observed Crashes, N_{observed} (crashes/year)**	**Overdispersion Parameter, *k***	**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**
INTERSECTIONS												
Multiple-Vehicle												
Intersection 1				—				—	—	—	—	—
Intersection 2				—				—	—	—	—	—
Intersection 3				—				—	—	—	—	—
Intersection 4				—				—	—	—	—	—
Single-Vehicle												
Intersection 1				—				—	—	—		—
Intersection 2				—				—	—	—		—
Intersection 3				—				—	—	—		—
Intersection 4				—				—	—	—		—
Combined (Sum of Column)												

Worksheet 4B. Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

(1)	(2)	(3)
Site Type	N_{ped}	N_{bike}
ROADWAY SEGMENTS		
Segment 1		
Segment 2		
Segment 3		
Segment 4		
INTERSECTIONS		
Intersection 1		
Intersection 2		
Intersection 3		
Intersection 4		
Combined (Sum of Column)		

Worksheet 4C. Project-Level EB Method Summary Results for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	N_{ped}	N_{bike}	$N_{expected/comb\ (vehicle)}$	$N_{expected}$
Total	$(2)_{comb}$ Worksheet 4A	$(2)_{comb}$ Worksheet 4B	$(3)_{comb}$ Worksheet 4B	$(13)_{comb}$ Worksheet 4A	(3)+(4)+(5)
Fatal and injury (FI)	$(3)_{comb}$ Worksheet 4A	$(2)_{comb}$ Worksheet 4B	$(3)_{comb}$ Worksheet 4B	$(5)_{total}*(2)_{FI}/(2)_{total}$	(3)+(4)+(5)
Property damage only (PDO)	$(4)_{comb}$ Worksheet 4A	—	—	$(5)_{total}*(2)_{PDO}/(2)_{total}$	(3)+(4)+(5)
		0.000	0.000		

CHAPTER 19. PREDICTIVE METHOD FOR RAMPS

19.1. INTRODUCTION

This chapter presents the predictive method for ramps used to connect two or more roadways at an interchange. The method is also applicable to collector-distributor (C-D) roadways that connect with ramps and one or more roadways at an interchange. A general introduction to the *Highway Safety Manual* (HSM) predictive method is provided in Part C—Introduction and Applications Guidance.

The predictive methodology for ramps provides a structured methodology to estimate the expected average crash frequency (in total, by crash type, or by crash severity) for a ramp with known characteristics. Crashes involving vehicles of all types are included in the estimate. The predictive method can be applied to an existing ramp, a design alternative for an existing ramp, a new ramp, or for alternative traffic volume projections. An estimate can be made of expected average crash frequency for a prior time period (i.e., what did or would have occurred) or a future time period (i.e., what is expected to occur). The development of the predictive method in this chapter is documented by Bonneson et al. (1). This chapter was modified for the second edition of the HSM to include crash prediction methodologies for crossroad ramp terminals at single-point diamond interchanges and crossroad ramp terminals at tight diamond interchanges based on NCHRP Project 17-68 (*3*).

This chapter presents the following information about the predictive method for ramps:

- a concise overview of the predictive method,
- the definitions of the site types addressed by the predictive method,
- a step-by-step description of the predictive method,
- details for dividing a ramp into individual evaluation sites,~~.~~
- safety performance functions (SPFs) for ramps,
- crash modification factors (CMFs) for ramps,
- severity distribution functions (SDFs) for ramps,
- limitations of the predictive method, and
- sample problems illustrating the application of the predictive method.

19.2. OVERVIEW OF THE PREDICTIVE METHOD

The predictive method provides an 18-step procedure to estimate the expected average crash frequency (in total, by crash type, or by crash severity) for an entire ramp or C-D road. The gore point of the speed-change lane is used to define the beginning (or ending) point of a ramp or C-D road.

The predictive method is used to evaluate an entire ramp, C-D road, or site. A site is a ramp segment, a C-D road segment, or crossroad ramp terminal. A crossroad ramp terminal is a controlled terminal between a ramp and a crossroad. A crossroad speed-change lane (i.e., an uncontrolled terminal between a ramp and a crossroad) is not addressed by the method.

The predictive method is applicable to ramps or C-D roads in the vicinity of an interchange. The interchange may connect a freeway and a crossroad (service interchange) or two freeways (system interchange). The method is applicable to ramps and C-D roads that are one-way roadways.

The predictive method is used to estimate the expected number of crashes for an individual site. This estimate can be summed for all sites to compute the expected number of crashes for the entire ramp or C-D road. The estimate represents a given time period of interest (in years) during which the geometric design and traffic control features are unchanged and traffic volumes are known or forecasted. The expected average crash frequency is obtained by dividing the expected number of crashes by the number of years during the time period of interest. The estimate is obtained by combining the prediction from the predictive model with observed crash data using the empirical Bayes (EB) Method.

The predictive models used in this chapter are described in detail in Section 19.3. The variables that comprise the predictive models include a series of subscripts to describe precisely the conditions to which they apply. These subscripts are described in detail in later sections of this chapter. For this section, it is sufficient to use "place-holder" subscripts such as *w*, *x*, *y*, *z*, and *m*. The subscript *w* is a place-holder for specific site-type subscripts that define the equation's application (e.g., it is replaced with "*rps*" when needed to indicate that the equation applies to a ramp segment). Similarly, *x* is a place-holder for segment cross-section or intersection control-type subscripts, *y* is a place-holder for crash-type subscripts, *z* is a place holder for crash severity, and *m* is a place-holder for a specific geometric design or traffic control feature.

The predictive models used in this chapter to determine the predicted average crash frequency are of the general form shown in Equation 19-1.

$$N_{p,w,x,y,z} = N_{spf,w,x,y,z} \times \left(CMF_{1,w,x,y,z} \times CMF_{2,w,x,y,z} \times \ldots \times CMF_{m,w,x,y,z} \right) \times C_{w,x,y,z} \quad (19\text{-}1)$$

Where:

$N_{p,w,x,y,z}$ = predicted average crash frequency for a specific year for site type *w*, cross section or control type *x*, crash type *y*, and severity *z* (crashes/yr);

$N_{spf,w,x,y,z}$ = predicted average crash frequency determined for base conditions of the SPF developed for site type *w*, cross section or control type *x*, crash type *y*, and severity *z* (crashes/yr);

$CMF_{m,w,x,y,z}$ = crash modification factors specific to site type *w*, cross section or control type *x*, crash type *y*, and severity *z* for specific geometric design and traffic control feature *m*; and

$C_{w,x,y,z}$ = calibration factor to adjust SPF for local conditions for site type *w*, cross section or control type *x*, crash type *y*, and severity *z*.

The predictive models provide estimates of the predicted average crash frequency in total, by crash type, or by crash severity. A default distribution of crash type is included in the predictive method. It is used with the predictive models to quantify the crash frequency for each of several crash types. The models predict fatal-and-injury crash frequency and property-damage-only crash frequency. A severity distribution function is available for most site types to further quantify the crash frequency by the following severity levels: fatal, incapacitating injury, non-incapacitating injury, and possible injury. A default distribution of crash severity is included for crossroad ramp terminals at single-point diamond interchanges and crossroad ramp terminals at tight diamond interchanges.

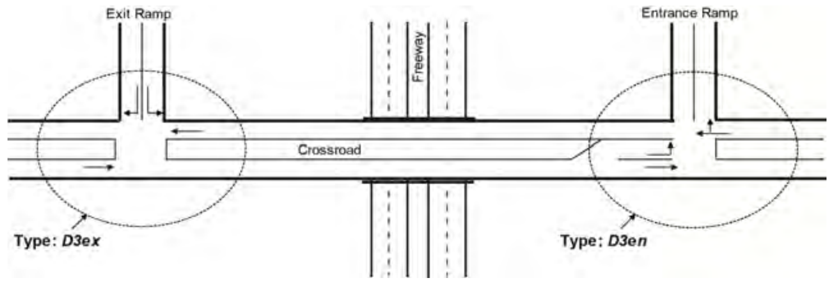
19.3. RAMPS—DEFINITIONS AND PREDICTIVE MODELS

This section provides the definitions of the site types discussed in this chapter. It also describes the predictive models for each of the site types.

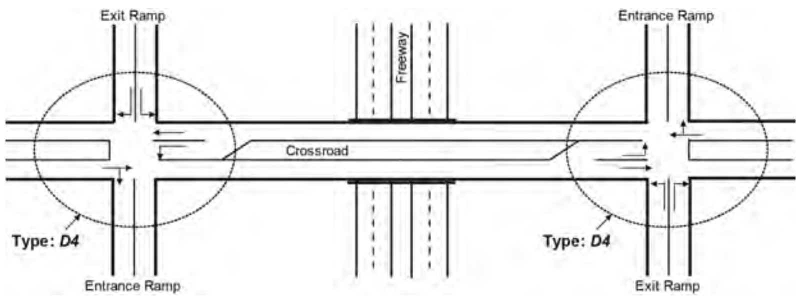
19.3.1. Definition of Ramp Site Types

The predictive method in this chapter applies to the following site types: entrance ramp segment with one or two lanes, exit ramp segment with one or two lanes, C-D road segment with one or two lanes, and crossroad ramp terminal. Connector ramp segments are represented using one of these site types.

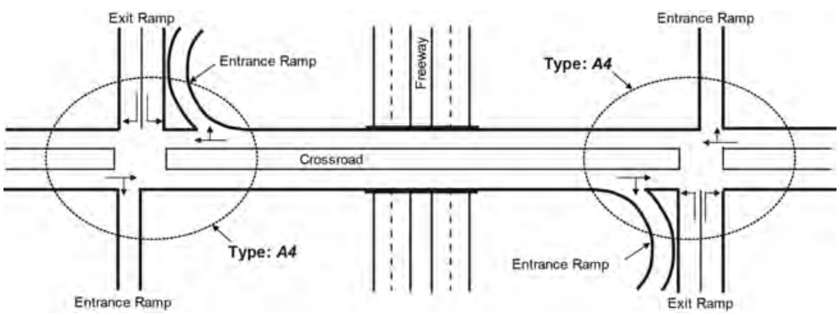
There are many different configurations of crossroad ramp terminals used at interchanges. For this reason, the definition of "site type" is broadened when applied to crossroad ramp terminals to be specific to each configuration. The more common configurations are identified in Figure 19-1.



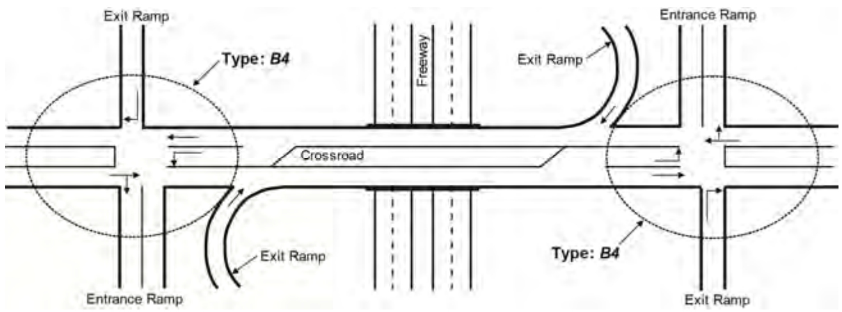
a. Three-Leg Ramp Terminal with Diagonal Exit or Entrance Ramp (*D3ex* and *D3en*)



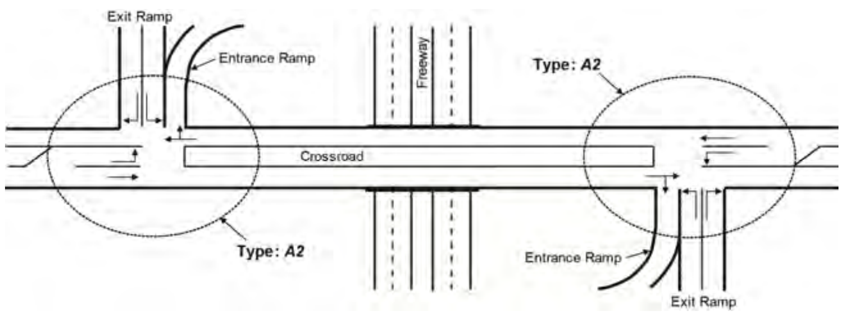
b. Four-Leg Ramp Terminal with Diagonal Ramps (*D4*)



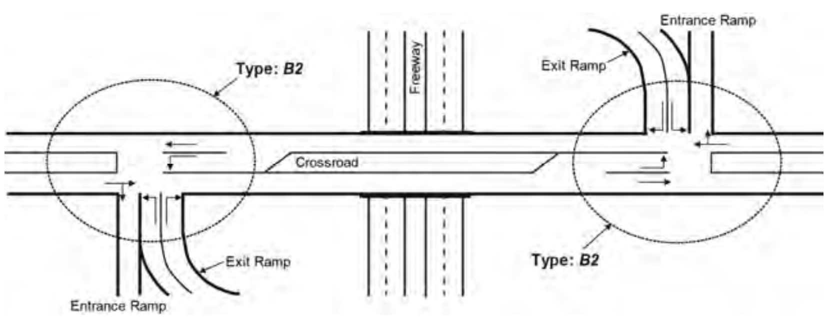
c. Four-Leg Ramp Terminal at Four-Quadrant Partial Cloverleaf A (*A4*)



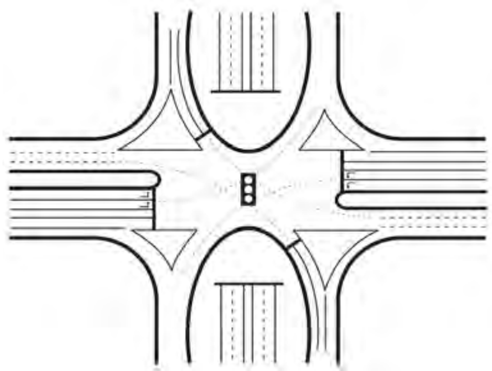
d. Four-Leg Ramp Terminal at Four-Quadrant Partial Cloverleaf B (*B4*)



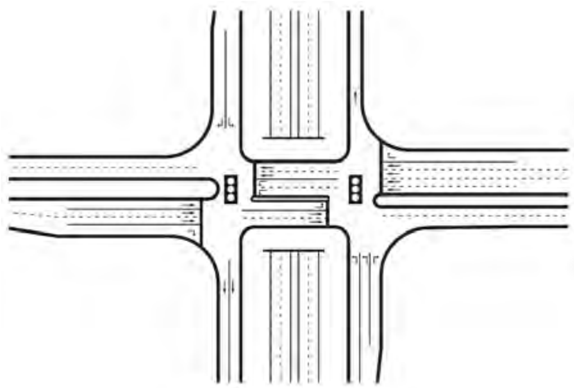
e. Three-Leg Ramp Terminal at Two-Quadrant Partial Cloverleaf A (*A2*)



f. Three-Leg Ramp Terminal at Two-Quadrant Partial Cloverleaf B (*B2*)



g. Ramp Terminal at Single-Point Diamond Interchange~~s~~ (*SP*)



h. Ramp Terminal at Tight Diamond Interchange (*TD*)

Figure 19-1. Ramp Terminal Configurations

Differences among the terminals shown in Figure 19-1 reflect the number of ramp legs, number of left-turn movements, and location of crossroad left-turn storage (i.e., inside or outside of the interchange). Although not specifically shown, control type (i.e., signalized or stop controlled) and distance between terminals ~~is~~ are also ~~an~~ important factors in characterizing a crossroad ramp terminal.

Classifying an area as urban, suburban, or rural is subject to the roadway characteristics, surrounding population, and surrounding land uses, and is at the analyst'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 where the population is less 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.

Table 19-1 identifies the urban ramp and C-D road segment configurations for which SPFs have been developed. A second set of SPFs have been developed for rural ramps and C-D road segments with one lane (they are not shown in the table, but use the same nomenclature). The SPFs are used to estimate the predicted average crash frequency by crash type and crash severity. These estimates are added to yield the total predicted average crash frequency for an individual site.

Table 19-1. Urban Ramp and Collector-Distributor Road Segment SPFs

Site Type (w)	Cross Section (x)	Crash Type (y)	Crash Severity (z)	SPF
Ramp segments (*rps*)	One-lane entrance ramp (*1EN*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf,\,rps,\,1EN,\,mv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,rps,\,1EN,\,mv,\,pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf,\,rps,\,1EN,\,sv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,rps,\,1EN,\,sv,\,pdo}$
	Two-lane entrance ramp (*2EN*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf,\,rps,\,2EN,\,mv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,rps,\,2EN,\,mv,\,pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf,\,rps,\,2EN,\,sv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,rps,\,2EN,\,sv,\,pdo}$
	One-lane exit ramp (*1EX*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf,\,rps,\,1EX,\,mv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,rps,\,1EX,\,mv,\,pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf,\,rps,\,1EX,\,sv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,rps,\,1EX,\,sv,\,pdo}$
	Two-lane exit ramp (*2EX*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf,\,rps,\,2EX,\,mv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,rps,\,2EX,\,mv,\,pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf,\,rps,\,2EX,\,sv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,rps,\,2EX,\,sv,\,pdo}$
C-D road segments (*cds*)	One-lane C-D road (*1*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf,\,cds,\,1,\,mv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,cds,\,1,\,mv,\,pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf,\,cds,\,1,\,sv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,cds,\,1,\,sv,\,pdo}$
	Two-lane C-D road (*2*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$N_{spf,\,cds,\,2,\,mv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,cds,\,2,\,mv,\,pdo}$
		Single vehicle (*sv*)	Fatal and injury (*fi*)	$N_{spf,\,cds,\,2,\,sv,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,cds,\,2,\,sv,\,pdo}$

The ramp segment and C-D road segment are defined as follows:

- *One-lane segment*—a length of roadway consisting of one through lane with a continuous cross section providing one direction of travel.
- *Two-lane segment*—a length of roadway consisting of two through lanes with a continuous cross section providing one direction of travel.

Table 19-2 identifies the urban crossroad ramp terminal configurations for which SPFs have been developed for three-leg terminals with a diagonal exit ramp. A second set of SPFs have been developed for rural three-leg terminals with either stop control, or signal control and two, three, or four lanes on the crossroad (they are not shown in the table, but use the same nomenclature). The SPFs are used to estimate the predicted average crash frequency by crash severity. These estimates are added to yield the total predicted average crash frequency for an individual site.

Table 19-2. Urban Crossroad Ramp Terminal SPFs for Three-Leg Terminals with a Diagonal Exit Ramp

Site Type (w)	Cross Section and Control Type (x)	Crash Type (y)	Crash Severity (z)	SPF
Three-leg terminals with diagonal exit ramp (*D3ex*),	One-way stop control; 2, 3, or 4 lane crossroad (*ST*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\,w,\,ST,\,at,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,w,\,ST,\,at,\,pdo}$
	Signal control, 2-lane crossroad (*SG2*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\,w,\,SG2,\,at,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,w,\,SG2,\,at,\,pdo}$
	Signal control, 3-lane crossroad (*SG3*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\,w,\,SG3,\,at,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,w,\,SG3,\,at,\,pdo}$
	Signal control, 4-lane crossroad (*SG4*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\,w,\,SG4,\,at,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,w,\,SG4,\,at,\,pdo}$
	Signal control, 5-lane crossroad (*SG5*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\,w,\,SG5,\,at,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,w,\,SG5,\,at,\,pdo}$
	Signal control, 6-lane crossroad (*SG6*)	All types (*at*)	Fatal and injury (*fi*)	$N_{spf,\,w,\,SG6,\,at,\,fi}$
			Property damage only (*pdo*)	$N_{spf,\,w,\,SG6,\,at,\,pdo}$

One set of urban SPFs (and one set of rural SPFs) for the configurations shown in Table 19-2 have also been developed for each of the following six site types (they also use the same nomenclature shown in the table).

- Three-leg terminals with diagonal entrance ramp (*D3en*),
- Four-leg terminals with diagonal ramps (*D4*),
- Four-leg terminals at four-quadrant partial cloverleaf A (*A4*),
- Four-leg terminals at four-quadrant partial cloverleaf B (*B4*),
- Three-leg terminals at two-quadrant partial cloverleaf A (*A2*),
- Three-leg terminals at two-quadrant partial cloverleaf B (*B2*).

Sets of SPFs have also been developed for crossroad ramp terminals at single-point diamond interchanges (*SP*) and crossroad ramp terminals at tight diamond interchanges (TD). These SPFs are used to estimate the predicted average crash frequency for all types (*at*) of crashes for two different severity levels: fatal and injury (*fi*) and property damage only (*pdo*). If an interchange is a single-point diamond or tight diamond, the interchange-specific crossroad ramp terminal SPFs are used instead of classifying each terminal by number of legs.

For the purposes of evaluation, a crossroad ramp terminal's "site type" is defined in terms of its configuration. The terminal configurations addressed in the predictive method are shown in Figure 19-1. These terminals are further categorized by crossroad cross section and the type of traffic control used at the terminal. Stop-controlled terminals have a stop sign on the ramp approach to the intersection, and no stop or yield sign on the crossroad approaches. Signal-controlled terminals have traffic signals on the ramp and crossroad approaches. The SPFs for crossroad ramp terminals at single-point diamond and tight diamond interchanges in this chapter are applicable to signalized terminals at four-leg single-point and tight diamond interchanges. The cross section and control type notation for crossroad ramp terminals at single-point diamond interchanges defines the number of right-turn movements from the exit ramps to the crossroad that are designed as free-flow: zero (*FF0*), one (*FF1*), or both (*FF2*). Crossroad ramp terminals at tight diamond interchanges are not further categorized by crossroad cross section or type of control specific to any of the movements.

19.3.2. Predictive Model for Ramp Segments

In general, a predictive model is used to compute the predicted average crash frequency for a site. It combines with the SPF, CMFs, and a calibration factor. The predicted quantity can describe crash frequency in total, by crash type, or by crash severity. This section describes the predictive model for ramp and C-D road segments. The next section describes the predictive model for crossroad ramp terminals.

The predictive model for ramp and C-D road segments is used to estimate the predicted average crash frequency of segment crashes (i.e., the estimate does not include ramp-terminal-related crashes). Segment crashes include crashes that occur in the segment and either (a) away from the crossroad ramp terminal or (b) within the limits of the crossroad ramp terminal but not related to the terminal. That is, the predictive model estimate includes crashes that would occur regardless of whether the crossroad ramp terminal is present.

The predictive model for entrance ramps (and connector ramps at service interchanges that serve motorists traveling from the crossroad to the freeway) is presented in Equation 19-2. This equation consists of four terms, where each of Equation 19-3 to Equation 19-6 correspond to one term.

$$N_{p,rps,nEN,at,as} = N_{p,rps,nEN,mv,fi} + N_{p,rps,nEN,sv,fi} + N_{p,rps,nEN,mv,pdo} + N_{p,rps,nEN,sv,pdo} \tag{19-2}$$

$$N_{p,rps,nEN,mv,fi} = C_{rps,EN,mv,fi} \times N_{spf,rps,nEN,mv,fi} \times \left(CMF_{1,rps,ac,mv,fi} \times \ldots \times CMF_{m,rps,ac,mv,fi}\right) \times \left(CMF_{1,rps,ac,at,fi} \times \ldots \times CMF_{m,rps,ac,at,fi}\right) \tag{19-3}$$

$$N_{p,rps,nEN,sv,fi} = C_{rps,EN,sv,fi} \times N_{spf,rps,nEN,sv,fi} \times \left(CMF_{1,rps,ac,sv,fi} \times \ldots \times CMF_{m,rps,ac,sv,fi}\right) \times \left(CMF_{1,rps,ac,at,fi} \times \ldots \times CMF_{m,rps,ac,at,fi}\right) \tag{19-4}$$

$$N_{p,rps,nEN,mv,pdo} = C_{rps,EN,mv,pdo} \times N_{spf,rps,nEN,mv,pdo} \times \left(CMF_{1,rps,ac,mv,pdo} \times \ldots \times CMF_{m,rps,ac,mv,pdo}\right) \times \left(CMF_{1,rps,ac,at,pdo} \times \ldots \times CMF_{m,rps,ac,at,pdo}\right) \tag{19-5}$$

$$N_{p,rps,nEN,sv,pdo} = C_{rps,EN,sv,pdo} \times N_{spf,rps,nEN,sv,pdo} \times \left(CMF_{1,rps,ac,sv,pdo} \times \ldots \times CMF_{m,rps,ac,sv,pdo}\right) \times \left(CMF_{1,rps,ac,at,pdo} \times \ldots \times CMF_{m,rps,ac,at,pdo}\right) \tag{19-6}$$

Where:

$N_{p,\,rps,\,nEN,\,y,\,z}$ = predicted average crash frequency of an entrance ramp segment with *n* lanes, crash type *y* ($y = sv$: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* ($z = fi$: fatal and injury, *pdo*: property damage only, *as*: all severities) (crashes/yr);

$C_{rps,\,EN,\,y,\,z}$ = calibration factor for entrance ramp segments with any lanes, crash type *y* ($y = sv$: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* ($z = fi$: fatal and injury, *pdo*: property damage only);

$N_{spf,\,rps,\,nEN,\,y,\,z}$ = predicted average crash frequency of an entrance ramp segment with base conditions, *n* lanes, crash type *y* ($y = sv$: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* ($z = fi$: fatal and injury, *pdo*: property damage only) (crashes/yr); and

$CMF_{m,\,rps,\,ac,\,y,\,z}$ = crash modification factor for a ramp segment with any cross section *ac*, feature *m*, crash type *y* ($y = sv$: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* ($z = fi$: fatal and injury, *pdo*: property damage only).

The predictive model for exit ramps (and connector ramps at service interchanges that serve motorists traveling from the freeway to the crossroad) is identical to that for entrance ramps except that the subscript “EX” is substituted for “EN” in Equation 19-2 to Equation 19-6.

Equation 19-2 shows that entrance ramp segment crash frequency is estimated as the sum of four components: **fatal-and-injury multiple-vehicle crash frequency, fatal-and-injury single-vehicle crash frequency, property-damage-only multiple-vehicle crash frequency, and property-damage-only single-vehicle crash frequency**.

Different CMFs are used in Equation 19-3 to Equation 19-6. The first terms in parentheses in each equation recognizes that the influence of some features is unique to each crash type. In contrast, the second term in parentheses in these equations recognizes that some features have a similar influence on all crash types. All CMFs are unique to crash severity.

Equation 19-3 and Equation 19-4 are used to estimate the fatal-and-injury crash frequency. Equation 19-5 and Equation 19-6 are used to estimate the property-damage-only crash frequency.

The predictive model for C-D roads (and connector ramps at system interchanges) is presented in Equation 19-7. This equation consists of four terms, where each of Equation 19-8 to Equation 19-11 correspond to one term.

$$N_{p,cds,n,at,as} = N_{p,cds,n,mv,fi} + N_{p,cds,n,sv,fi} + N_{p,cds,n,mv,pdo} + N_{p,cds,n,sv,pdo} \tag{19-7}$$

$$\begin{aligned} N_{p,cds,n,mv,fi} = {} & C_{cds,ac,mv,fi} \times N_{spf,cds,n,mv,fi} \times \left(CMF_{1,cds,ac,mv,fi} \times \cdots \times CMF_{m,cds,ac,mv,fi}\right) \\ & \times \left(CMF_{1,cds,ac,at,fi} \times \cdots \times CMF_{m,cds,ac,at,fi}\right) \end{aligned} \tag{19-8}$$

$$\begin{aligned} N_{p,cds,n,sv,fi} = {} & C_{cds,ac,sv,fi} \times N_{spf,cds,n,sv,fi} \times \left(CMF_{1,cds,ac,sv,fi} \times \cdots \times CMF_{m,cds,ac,sv,fi}\right) \\ & \times \left(CMF_{1,rps,ac,at,fi} \times \cdots \times CMF_{m,rps,ac,at,fi}\right) \end{aligned} \tag{19-9}$$

$$\begin{aligned} N_{p,cds,n,mv,pdo} = {} & C_{cds,ac,mv,pdo} \times N_{spf,cds,n,mv,pdo} \times \left(CMF_{1,cds,ac,mv,pdo} \times \cdots \times CMF_{m,cds,ac,mv,pdo}\right) \\ & \times \left(CMF_{1,cds,ac,at,pdo} \times \cdots \times CMF_{m,cds,ac,at,pdo}\right) \end{aligned} \tag{19-10}$$

$$\begin{aligned} N_{p,cds,n,sv,pdo} = {} & C_{cds,ac,sv,pdo} \times N_{spf,cds,n,sv,pdo} \times \left(CMF_{1,cds,ac,sv,pdo} \times \cdots \times CMF_{m,cds,ac,sv,pdo}\right) \\ & \times \left(CMF_{1,cds,ac,at,pdo} \times \cdots \times CMF_{m,cds,ac,at,pdo}\right) \end{aligned} \tag{19-11}$$

Where:

$N_{p,\,cds,\,n,\,y,\,z}$ = predicted average crash frequency of a C-D road segment with *n* lanes, crash type *y* ($y = sv$: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* ($z = fi$: fatal and injury, *pdo*:

property damage only, *as*: all severities) (crashes/yr);

$C_{cds,\,ac,\,y,\,z}$ = calibration factor for C-D road segments with any cross section *ac*, crash type *y* ($y = sv$: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* ($z = fi$: fatal and injury, *pdo*: property damage only);

$N_{spf,\,cds,\,n,\,y,\,z}$ = predicted average crash frequency of a C-D road segment with base conditions, *n* lanes, crash type *y* ($y = sv$: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* ($z = fi$: fatal and injury, *pdo*: property damage only) (crashes/yr); and

$CMF_{m,\,cds,\,ac,\,y,\,z}$ = crash modification factor for a C-D road segment with any cross section *ac*, feature *m*, crash type *y* ($y = sv$: single vehicle, *mv*: multiple vehicle, *at*: all types), and severity *z* ($z = fi$: fatal and injury, *pdo*: property damage only.

The interpretation of these equations is similar to that described previously for ramp entrance segments.

The SPFs for ramp and C-D road segments are presented in Section 19.6.1. The associated CMFs are presented in Section 19.7.1. Similarly, the associated SDFs are presented in Section 19.8.1. A procedure for establishing the value of the calibration factor is described in Section B.1 of Appendix B.

19.3.3. Predictive Model for Ramp Terminals

The predictive model for crossroad ramp terminals is used to compute the predicted average crash frequency for a crossroad ramp terminal. Terminal-related crashes include (a) all crashes that occur within the limits of the intersection (i.e., at-intersection crashes) and (b) crashes that occur on the ramp or crossroad legs and are attributed to the presence of an intersection (i.e., intersection-related crashes).

The predictive model for one-way stop-controlled crossroad ramp terminals is presented in Equation 19-12. This equation consists of two terms, where each of Equation 19-13 and Equation 19-14 correspond to one term.

$$N_{p,w,ST,at,as} = N_{p,w,ST,at,fi} + N_{p,w,ST,at,pdo} \qquad (19\text{-}12)$$

$$N_{p,w,ST,at,fi} = C_{aS,ST,at,fi} \times N_{spf,w,ST,at,fi} \times \left(CMF_{1,aS,ST,at,fi} \times \ldots \times CMF_{m,aS,ST,at,fi}\right) \qquad (19\text{-}13)$$

$$N_{p,w,ST,at,pdo} = C_{aS,ST,at,pdo} \times N_{spf,w,ST,at,pdo} \times \left(CMF_{1,aS,ST,at,pdo} \times \ldots \times CMF_{m,aS,ST,at,pdo}\right) \qquad (19\text{-}14)$$

Where:

$N_{p,\,w,\,ST,\,at,\,z}$ = predicted average crash frequency of a stop-controlled crossroad ramp terminal of site type *w* (*w = D3ex, D3en, D4, A4, B4, A2, B2*), all crash types *at*, and severity *z* (*z = fi*: fatal and injury, *pdo*: property damage only, *as*: all severities) (crashes/yr);

$C_{aS,\,ST,\,at,\,z}$ = calibration factor for a stop-controlled crossroad ramp terminal (any site type *aS*) with all crash types *at* and severity *z* (*z = fi*: fatal and injury, *pdo*: property damage only);

$N_{spf,\,w,\,ST,\,at,\,z}$ = predicted average crash frequency of a one-way stop-controlled crossroad ramp terminal of site type *w* (*w = D3ex, D3en, D4, A4, B4, A2, B2*) with base conditions, all crash types *at*, and severity *z* (*z = fi*: fatal and injury, *pdo*: property damage only) (crashes/yr); and

$CMF_{m,\,aS,\,ST,\,at,\,z}$ = crash modification factor for a stop-controlled crossroad ramp terminal (any site type *aS*) with feature *m*, all crash types *at*, and severity *z* (*z = fi*: fatal and injury, *pdo*: property damage only).

The seven site types (i.e., *D3ex*, *D3en*, *D4*, *A4*, *B4*, *A2*, *B2*) are shown in Figure 19-1.

Equation 19-12 shows that crossroad ramp terminal crash frequency is estimated as the sum of two components: predicted average fatal-and-injury crash frequency and predicted average property-damage-only crash frequency.

Different CMFs are used in Equation 19-13 and Equation 19-14. The term in parentheses in each equation recognizes that the influence of some features is unique to the type of control used at the terminal. All CMFs are unique to crash severity.

The predictive model for signal-controlled crossroad ramp terminals is presented in Equation 19-15. This equation consists of two terms, where each of Equation 19-16 and Equation 19-17 correspond to one term.

$$N_{p,w,SGn,at,as} = N_{p,w,SGn,at,fi} + N_{p,w,SGn,at,pdo} \quad (19\text{-}15)$$

$$N_{p,w,SGn,at,fi} = C_{aS,SG,at,fi} \times N_{spf,w,SGn,at,fi} \times (CMF_{1,aS,SGn,at,fi} \times \ldots \times CMF_{m,aS,SGn,at,fi}) \quad (19\text{-}16)$$

$$N_{p,w,SGn,at,pdo} = C_{aS,SG,at,pdo} \times N_{spf,w,SGn,at,pdo} \times (CMF_{1,aS,SGn,at,pdo} \times \ldots \times CMF_{m,aS,SGn,at,pdo}) \quad (19\text{-}17)$$

Where:

$N_{p,w,SGn,at,z}$ = predicted average crash frequency of a signal-controlled crossroad ramp terminal of site type *w* (*w* = *D3ex, D3en, D4, A4, B4, A2, B2, SP, TD*) with *n* crossroad lanes, all crash types *at*, and severity *z* ($z = fi$: fatal and injury, *pdo*: property damage only, *as*: all severities) (crashes/yr);

$C_{aS,SG,at,z}$ = calibration factor for a signal-controlled crossroad ramp terminal (any site type *aS*) with all crash types *at* and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only);

$N_{spf,w,SGn,at,z}$ = predicted average crash frequency of a signal-controlled crossroad ramp terminal of site type *w* (*w* = *D3ex, D3en, D4, A4, B4, A2, B2, SP, TD*) with base conditions, *n* crossroad lanes, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr); and

$CMF_{m,aS,SGn,at,z}$ = crash modification factor for a signal-controlled crossroad ramp terminal (any site type *aS*) on a crossroad with *n* lanes, feature *m*, all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only).

The SPFs for crossroad ramp terminals are presented in Section 19.6.2. The associated CMFs are presented in Section 19.7.2. Similarly, the associated SDFs are presented in Section 19.8.2. A procedure for establishing the value of the calibration factor is described in Section B.1 of Appendix B.

19.4. PREDICTIVE METHOD FOR RAMPS AND RAMP TERMINALS

This section describes the predictive method for ramps, C-D roads, and ramp terminals. It consists of two sections. The first section provides a step-by-step description of the predictive method. The second section describes the geometric design features, traffic control features, and traffic volume data needed to apply the predictive method.

19.4.1. Step-by-Step Description of the Predictive Method

The predictive method for ramps is shown in Figure 19-2. Applying the predictive method yields an estimate of the expected average crash frequency (in total, by crash type, or by crash severity) for an entire ramp or C-D road. The predictive models described in this chapter are applied in Steps 9, 10, and 11 of the predictive method. The information needed to apply each step is provided in this section.

There are 18 steps in the predictive method. In some situations, certain steps will not be needed because data are 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 time period to allow for comparison).

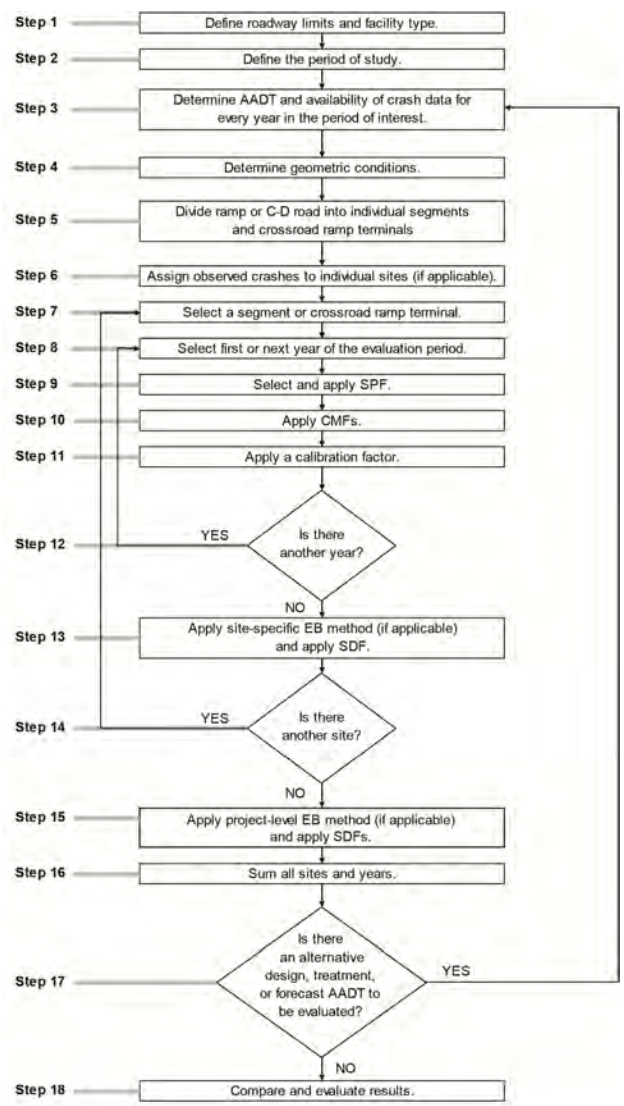


Figure 19-2. The HSM Predictive Method

The following discussion explains the details of each step of the method as applied to ramps.

Step 1—Define the limits of the project.
A project can be all of the ramps and C-D roads in the vicinity of an interchange, an entire ramp, an entire C-D road, or an individual site. A site is a crossroad ramp terminal, a homogeneous ramp segment, or a homogeneous C-D road segment. A site is further categorized by its cross section or control type. A description of the specific site types is provided in Section 19.3.1.

The project limits are defined in this step. They will depend on the purpose of the study. The study may be limited to one specific site, or to a group of contiguous sites. Alternatively, the limits can be expanded to include all of the ramps, C-D roads, and crossroad ramp terminals in the vicinity of an interchange. For comparative analysis of design alternatives, the project limits should be the same for all alternatives.

The analyst should identify (or establish) a reference line for each ramp and C-D road. This line is defined as the right edge of traveled way in the direction of travel. All lengths along the roadway are determined using this line. The location of the reference line is shown in subsequent figures (e.g., Figure 19-4). Locations along this line are specified using a linear referencing system, and are identified using the label "ramp-mile *X*," where the number for *X* has units of miles (e.g., ramp-mile 1.4).

Step 2—Define the period of interest.
The *study period* is defined as the consecutive years for which an estimate of the expected average crash frequency is desired. The *crash period* is defined as the consecutive years for which observed crash data are available. The *evaluation period* is defined as the combined set of years represented by the study period and crash period. Every year in the evaluation period is evaluated using the predictive method. All periods are measured in years.

If the EB Method is not used, then the study period is the same as the evaluation period. The EB Method is discussed in more detail in Step 3.

If the EB Method is used and the crash period is not fully included in the study period, then the predictive models need to be applied to the study years *plus* each year of the crash period not represented in the study period. In this situation, the evaluation period includes the study period and any additional years represented by the crash data but not in the study period. For example, let the study period be defined as the years 2010, 2011, and 2012. If crash data are available for 2008, 2009, and 2010, then the evaluation period is 2008, 2009, 2010, 2011, and 2012.

The study period can represent either a past time period or a future time period. Whether the predictive method is used for a past or future period depends upon the purpose of the study. The study period may be:

- A past period for:
  - An existing ramp or C-D road. If observed crash data are available, the study period 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 ramp or C-D road for which alternative geometric design or traffic control features are proposed (for near-term conditions) and site traffic volumes are known.
- A future period for:
  - An existing ramp or C-D road for a future period where forecast traffic volumes are available.
  - An existing ramp or C-D road for which alternative geometric design or traffic control features are proposed and forecast traffic volumes are available.
  - A new ramp or C-D road that does not currently exist but is proposed for construction and for which forecast traffic volumes are available.

Step 3—For the study period, determine the availability of AADT volumes and, for an existing project, the availability of observed crash data (to determine whether the EB Method is applicable).

Traffic volume data are acquired in this step. Also, a decision is made whether the EB Method will be applied. If it will be applied, then it must also be decided whether the site-specific or project-level EB Method will be applied. If the EB Method will be applied, then the observed crash data are also acquired in this step.

Determining Traffic Volumes
The SPFs used in Step 9 (and some CMFs in Step 10) include annual average daily traffic (AADT) volume as a variable. For a past period, the AADT volume may be determined by using automated recorder data, or estimated by a sample survey. For a future period, the AADT volume may be a forecast estimate based on appropriate land use planning and traffic volume forecasting models.

The AADT volume of the ramp is needed for each ramp segment. The AADT volume of the C-D road is needed for the evaluation of each C-D road segment.

For each crossroad ramp terminal, one AADT value is needed for each intersecting leg. Thus, for a four-leg ramp terminal, the following values are needed: AADT volume of the crossroad leg "inside" the interchange, AADT volume of the crossroad leg "outside" of the interchange, AADT volume of the exit ramp, and AADT volume of the entrance ramp. The inside crossroad leg is the leg that is on the side of the ramp terminal nearest to the freeway. The outside crossroad leg is on the other side of the ramp terminal. For single-point diamond and tight diamond crossroad ramp terminals, the AADT of the crossroad and the sum of the AADTs for all four ramps are needed.

The AADT volumes are needed for each year of the evaluation period. The AADT volume for a given year represents an annual average daily 24-hour traffic volume. The ramp and C-D road segment AADT volume is a one-way volume. The crossroad segment AADT volume is a two-way volume (i.e., total of both travel directions).

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 volume for each missing year is interpolated or extrapolated, as appropriate. If there is not an established procedure for doing this, the following rules may be applied within the predictive method to estimate the AADT volumes for years when such data are not available. If these rules are applied, the fact that some AADT volumes are estimated should be documented with the analysis results.

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

Determining Availability of Observed Crash Data
Where an existing site (or an alternative condition for an existing site) is being considered, the EB Method can be used to obtain a more reliable estimate of the expected average crash frequency. The EB Method is applicable when crash data are available for the entire project, or for its individual sites. Crash data may be obtained directly from the jurisdiction's crash report system. At least two years of crash data are desirable to apply the EB Method. The EB Method (and criteria to determine whether the EB Method is applicable) is presented in Section B.2 in Appendix B.

The EB Method can be applied at the site-specific level or at the project level. At the site-specific level, crash data are assigned to specific sites in Step 6. The site-specific EB Method is applied in Step 13. At the project level, crash data are assigned to a group of sites (typically because they cannot be assigned to individual sites). The project-level EB Method is applied in Step 15. In general, the best results will be obtained if the site-specific EB Method is used. Guidance to determine whether the site-specific or project-level EB Method is applicable is presented in Section B.2.2 in Appendix B.

Step 4—Determine geometric design features, traffic control features, and site characteristics for all sites in the project limits.
A range of data is needed to apply a predictive model. These data are used in the SPFs and CMFs to estimate the predicted average crash frequency for the selected site and year. These data represent the geometric design features, traffic control features, and traffic demand characteristics that have been found to have some relationship to safety. These data are needed for each site in the project limits. They are needed for the study period and, if applicable, the crash period. The specific data, and means by which they are measured or obtained, is described in Section 19.4.2.

Step 5—Divide the roadway into sites.
Using the information from Step 1 and Step 4, the ramp or C-D road is divided into individual sites, consisting of individual homogeneous segments and ramp terminals. The procedure for dividing the ramp or C-D road into individual segments is provided in Section 19.5.

Step 6—Assign observed crashes to the individual sites (if applicable).
Step 6 applies if it was determined in Step 3 that the site-specific EB Method is applicable. If the site-specific EB Method is not applicable, then proceed to Step 7. In this step, the observed crash data are assigned to the individual sites. Specific criteria for assigning crashes to individual sites are presented in Section B.2.3 in Appendix B.

Step 7—Select the first or next individual site in the project limits. If there are no more sites to be evaluated, proceed to Step 15.
Steps 7 through 14 are repeated for each site within the project limits identified in Step 1.

Any site can be selected for evaluation because each site is considered to be independent of the other sites. However, good practice is to select the sites in an orderly manner, such as in the order of their physical occurrence in the direction of travel.

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 13.
Steps 8 through 12 are repeated for each year in the evaluation period for the selected site.

The individual years of the evaluation period are analyzed one year at a time because the SPFs and some CMFs are dependent on AADT volume, which may change from year to year.

Step 9—For the selected site, determine and apply the appropriate SPF.
The SPF determines the predicted average crash frequency for a site whose features match the SPF's base conditions. The SPFs (and their base conditions) are described in Section 19.6.

Determine the appropriate SPF for the selected site based on its site type and cross section (or traffic control). This SPF is then used to compute the crash frequency for the selected year using the AADT volume for that year, as determined in Step 3.

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs.
Collectively, the CMFs are used in the predictive model to adjust the SPF estimate from Step 9 such that the resulting predicted average crash frequency accurately reflects the geometric design and traffic control features of the selected site. The available CMFs are described in Section 19.7.

All CMFs presented in this chapter have the same base conditions as the SPFs in this chapter. Only the CMFs presented in Section 19.7 may be used as part of the predictive method described in this chapter.

For the selected site, determine the appropriate CMFs for the site type, geometric design features, and traffic control features present. The CMF's designation by crash type and severity must match that of the SPF with which it is used (unless indicated otherwise in the CMF description). The CMFs for the selected site are calculated using (a) the AADT volume determined in Step 3 for the selected year and (b) the geometric design and traffic control features determined in Step 4.

Multiply the result from Step 9 by the appropriate CMFs.

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
The SPFs and CMFs in this chapter have each been developed with data from specific jurisdictions and time periods. Calibration to local conditions will account for any differences between these conditions and those present at the selected sites. A calibration factor is applied to each SPF in the predictive method. Detailed guidance for the development of calibration factors is included in Section B.1 of Appendix B.

Multiply the result from Step 10 by the calibration factor to obtain the predicted average crash frequency.

Step 12—If there is another year to be evaluated in the evaluation period for the selected site, return to Step 8. Otherwise, proceed to Step 13.
This step creates a loop from Step 8 through Step 12 that is repeated for each year of the evaluation period for the selected site.

Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.
The site-specific EB Method combines the predicted average crash frequency computed in Step 11 with the observed crash frequency of the selected site. It produces a more statistically reliable estimate of the site's expected average crash frequency. The procedure for applying the site-specific EB Method is provided in Section B.2.4 of Appendix B.

The decision to apply the site-specific EB Method was determined in Step 3. If the EB Method is not used, then the estimate of expected average crash frequency for each year of the study period is limited to the predicted average crash frequency for that year, as computed in Step 11.

If the EB Method is used, then the expected average crash frequency is equal to the estimate obtained from the EB Method. An estimate is obtained for each year of the crash period (i.e., the period for which the observed crash data are available). The individual years of the crash period are analyzed one year at a time because the SPFs and some CMFs are dependent on AADT volume, which may change from year to year.

Apply the site-specific EB Method to a future time period, if appropriate.
Section B.2.6 in Appendix B provides a procedure for converting the estimates from the EB Method to any years in the study period that are not represented in the crash period (e.g., future years). This approach gives consideration to any differences in traffic volume, geometry, or traffic control between the study period and the crash period. This procedure yields the expected average crash frequency for each year of the study period.

Apply the severity distribution functions (SDFs), if desired.
The SDFs can be used to compute the expected average crash frequency for each of the following severity levels: fatal, incapacitating injury, non-incapacitating injury, and possible injury. Each SDF includes variables that describe the geometric design and traffic control features of a site. In this manner, the computed distribution gives consideration to the features present at the selected site. The SDFs are described in Section 19.8. They can benefit from being updated based on local data as part of the calibration process. Detailed guidance for the development of the SDF calibration factor is included in Section B.1.4 of Appendix B.

Apply the crash type distribution, if desired.
Each predictive model includes a default distribution of crash type. This distribution can be used to compute the expected average crash frequency for each of ten crash types (e.g., head-on, fixed object). The distribution is presented in Section 19.6. It can benefit from being updated based on local data as part of the calibration process.

Step 14—If there is another site to be evaluated, return to Step 7; otherwise, proceed to Step 15.
This step creates a loop from Step 7 through Step 14 that is repeated for each site of interest.

Step 15—Apply the project-level EB Method (if applicable) and apply SDFs.
The activities undertaken during this step are the same as undertaken for Step 13 but they occur at the project level (i.e., entire ramp, entire C-D road, or interchange). They are based on estimating the project-level predicted average

crash frequency. This crash frequency is computed for each year during the crash period. It is computed as the sum of the predicted average crash frequency for all sites (as computed in Step 11).

The project-level EB Method combines the project-level predicted average crash frequency with the observed crash frequency for all sites within the project limits. It produces a more statistically reliable estimate of the project-level expected average crash frequency. The procedure for applying the project-level EB Method is provided in Section B.2.5 of Appendix B.

The decision to apply the project-level EB Method was determined in Step 3. If this method is not used, then the project-level expected average crash frequency for each year of the study period is limited to the project-level predicted average crash frequency for that year, as computed in Step 11.

If the EB Method is used, then the project-level expected average crash frequency is equal to the estimate obtained from the EB Method. An estimate is obtained for each year of the crash period (i.e., the period for which the observed crash data are available). The individual years of the crash period are analyzed one year at a time because the SPFs and some CMFs are dependent on AADT volume, which may change from year to year.

Apply the project-level EB Method to a future time period, if appropriate.
Follow the same guidance as provided in Step 13 using the estimate from the project-level EB Method.

Apply the severity distribution functions, if desired.
Follow the same guidance as provided in Step 13 using the estimate from the project-level EB Method.

Apply the crash type distribution, if desired.
Follow the same guidance as provided in Step 13 using the estimate from the project-level EB Method.

Step 16—Sum all sites and years in the study to estimate total crash frequency.
One outcome of the predictive method is the total expected average crash frequency. The term “total” indicates that the estimate includes all crash types and severities. It is computed from an estimate of the total expected number of crashes, which represents the sum of the total expected average crash frequency for each site and for each year in the study period. The total expected number of crashes during the study period is calculated using Equation 19-18:

$$N^*_{e,aS,ac,at,as} = \sum_{j=1}^{n_s} \left(\sum_{i=1}^{all\ sites} N_{e,rps(i),ac,at,as,j} + \sum_{i=1}^{all\ sites} N_{e,cds(i),ac,at,as,j} + \sum_{i=1}^{all\ sites} N_{e,w(i),ac,at,as,j} \right) \quad (19\text{-}18)$$

Where:

$N^*_{e,\,aS,\,ac,\,at,\,as}$ = total expected number of crashes for all sites *aS* and all years in the study period (includes all cross sections and control types *ac*, all crash types *at*, and all severities *as*) (crashes);

n_s = number of years in the study period (yr);

$N_{e,\,rps(i),\,ac,\,at,\,as,\,j}$ = expected average crash frequency of ramp segment *i* for year *j* (includes all cross sections *ac*, all crash types *at*, and all severities *as*) (crashes/yr);

$N_{e,\,cds(i),\,ac,\,at,\,as,\,j}$ = expected average crash frequency of C-D road segment *i* for year *j* (includes all cross sections *ac*, all crash types *at*, and all severities *as*) (crashes/yr); and

$N_{e,\,w(i),\,ac,\,at,\,as,\,j}$ = expected average crash frequency of crossroad ramp terminal *i* of site type *w(i)* (*w = D3ex, D3en, D4, A4, B4, A2, B2, SP, TD*) for year *j* (includes all control types *ac*, all crash types *at*, and all severities *as*) (crashes/yr).

Equation 19-18 is used to compute the total expected number of crashes estimated to occur in the project limits during the study period. The summation of crashes for each terminal type, cross section, control type, crash type, and severity for each site and year is not shown in mathematic terms, but it is implied by the subscripts *w*, *ac*, *at*, and *as*, respectively.

Equation 19-19 is used to estimate the overall expected average crash frequency within the project limits during the study period.

$$N_{e,aS,ac,at,as} = \frac{N^{*}_{e,aS,ac,at,as}}{n_s} \tag{19-19}$$

Where:

$N_{e, aS, ac, at, as}$ = overall expected average crash frequency for all sites *aS* and all years in the study period (includes all cross sections and control types *ac*, all crash types *at*, and all severities *as*) (crashes/yr).

Step 17—Determine if there is an alternative design, treatment, or forecast AADT to be evaluated.
Steps 3 through 17 are repeated as appropriate for the same project limits but for alternative conditions, treatments, periods of interest, or forecast AADT volumes.

Step 18—Compare and evaluate results.
The predictive method is used to provide a statistically reliable estimate of the expected average crash frequency (in total, or by crash type and severity) for the specified project limits, study period, geometric design and traffic control features, and known or estimated AADT volume.

19.4.2. Data Needed to Apply the Predictive Method

The input data needed for the predictive models are identified in this section. These data represent the geometric design features, traffic control features, and traffic demand characteristics that have been found to have some relationship to safety. They are identified by bullet in this section, and are listed in Table B-2 of Appendix B.

The input data are needed for each site in the project limits. Criteria for defining site boundaries are described in Section 19.5.

The data are described in two subsections. The first subsection describes input data for ramp and C-D road segments. The second subsection describes input data for crossroad ramp terminals.

Features of Ramp and C-D Road Segments
The input data needed for ramp and C-D road segments is described in this subsection. There are several data identified in this section that describe a length along the roadway (e.g., segment length, curve length, weaving section length, etc.). *All of these lengths are measured along the reference line*, which is the right edge of traveled way in the direction of travel. Points that do not lie on the reference line must be projected onto the reference line (along a perpendicular line if the alignment is straight, or along a radial line if the alignment is curved) to facilitate length determination. These dimensions can be obtained from field measurements, a plan set, or aerial photographs.

- *Number of through lanes*—The total number of through lanes in the segment. Rural ramp segments are limited to one lane. Urban ramp segments are limited to two lanes. A segment with a lane-add (or lane-drop) taper is considered to have the same number of through lanes as the roadway just downstream of the lane-add (or lane-drop) taper. If the segment ends at a ramp terminal, then the number of through lanes is not based on the lane assignment, or lane markings, at the terminal.

  Do not include any high-occupancy vehicle (HOV) bypass lanes.

  Do not include any auxiliary lanes that are associated with a C-D road weaving section, unless the weaving section length exceeds 0.30 mi (1,600 ft). If this length is exceeded, then the auxiliary lane is counted as a through lane that starts as a lane-add ramp entrance and ends as a lane-drop ramp exit.

Do not include any auxiliary lanes that are developed as a turn bay (for queued vehicle storage) at the crossroad ramp terminal.

Do not include the speed-change lane that is associated with a second ramp that merges with (or diverges from) the subject ramp, unless its length exceeds 0.19 mi (1,000 ft). If this length is exceeded, then the speed-change lane is counted as a through lane that starts as a lane-add ramp entrance and ends as a lane drop by taper (or starts as a lane add by taper and ends as a lane-drop ramp exit).

This guidance is illustrated in Figure 19-3 using a portion of an exit ramp. The portion is shown to end at the crossroad ramp terminal. It consists of three segments. The first segment ends at the lane add section and has one lane. The second segment ends at the start of the bay taper and has two lanes. The third segment ends at the crossroad. Four lanes are shown at the downstream end of this segment, but two of the lanes are in turn bays and are not included in the determination of the number of through lanes for the segment. Thus, this segment is considered to have two lanes (= 4 − 2) for this application.

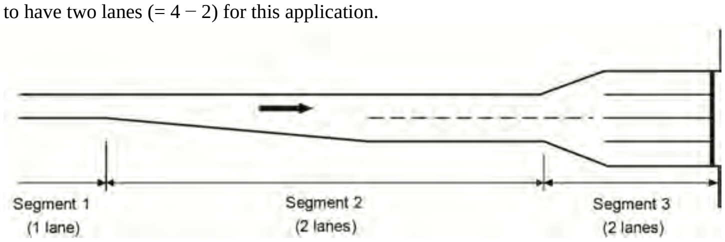


Figure 19-3. Determination of Number of Lanes for Ramp Segments

- Length of ramp or C-D road segment.
- *Average traffic speed on the freeway during off-peak periods of the typical day*—This speed is used to compute the speed for each curve (if any) that is present on the ramp. If better information is not available, then this speed can be estimated as the freeway's maximum speed limit.
- *Type of traffic control used at the crossroad ramp terminal to regulate intersecting traffic (none, yield, stop, signal)*—The term "None" is appropriate if the ramp intersects the crossroad as a speed-change lane or as a lane added (or lane dropped).
- *Presence of a horizontal curve prior to (or in) the subject segment*—Curves located prior to the segment influence the speed on the subject segment. For each curve located prior to (or in) the segment, the following data are needed:
  - *Length of curve*—Curve length is measured along the reference line from the point where the tangent ends and the curve begins (the PC) to the point where the curve ends and the tangent begins (the PT).

    If the curve has spiral transitions, then measure from the "effective" PC point to the "effective" PT point. The effective PC point is located midway between the TS and SC, where the TS is the point of change from tangent to spiral and the SC is the point of change from spiral to circular curve. The effective PT is located midway between the CS and ST, where CS is the point of change from circular curve to spiral and ST is the point of change from spiral to tangent.

    If the curve is continued from a curve on an intersecting alignment, then consider only the curve length on the subject alignment. For example, if the subject ramp diverges from another ramp and the curvature from the originating ramp continues into the subject ramp, then the curve on the subject ramp is considered to start at the beginning of the subject ramp (i.e., at the gore point).
  - *Radius of curve*—The radius is defined by the right edge of traveled way. If the curve has spiral transitions, then use the radius of the central circular portion of the curve.

- *Length of curve in segment*—The length of the curve within the boundaries of the segment. This length cannot exceed the segment length or the curve length.
- *Ramp-mile of beginning of curve in direction of travel*—This value equals the distance from ramp-mile 0.0 to the point where the tangent ends and the curve begins. Ramp-mile locations are measured along the right edge of the ramp traveled way in the direction of travel (in the absence of tapers and speed-change lanes, this edge coincides with the right edge of traveled way). These locations are established for this application, and may or may not coincide with the mileposts (or stations) established for the ramp's design.

  The gore point will often be used to define ramp-mile 0.0 for a ramp or C-D road. The gore point is located where the pair of solid white pavement edge markings that separate the ramp from the intersecting roadway are 2.0 ft apart. If the markings do not extend to a point where they are 2.0 ft apart, then the gore point is found by extrapolating both markings until the extrapolated portion is 2.0 ft apart. This point is shown in the top part of Figure 19-4.

  For exit ramps and C-D roads that diverge from the freeway (and entrance ramps that diverge from the crossroad using a speed-change lane), ramp-mile 0.0 is located where the gore point projects onto the ramp reference line. The ramp reference line is defined as the right edge of the ramp traveled way.

  For entrance ramps that intersect the crossroad, ramp-mile 0.0 is located where the ramp reference line intersects with the near edge of traveled way of the crossroad. This point is shown in the bottom part of Figure 19-4.

  If two or more ramps merge such that there is a choice of two or more points at which ramp-mile 0.0 could be established for curves downstream of the merge point, then establish ramp-mile 0.0 for these curves on the ramp with the highest volume.

  If the subject curve is preceded by a spiral transition, then measure to the "effective" curve beginning point. This point is located midway between the TS and SC, where the TS is the point of change from tangent to spiral and the SC is the point of change from spiral to circular curve.

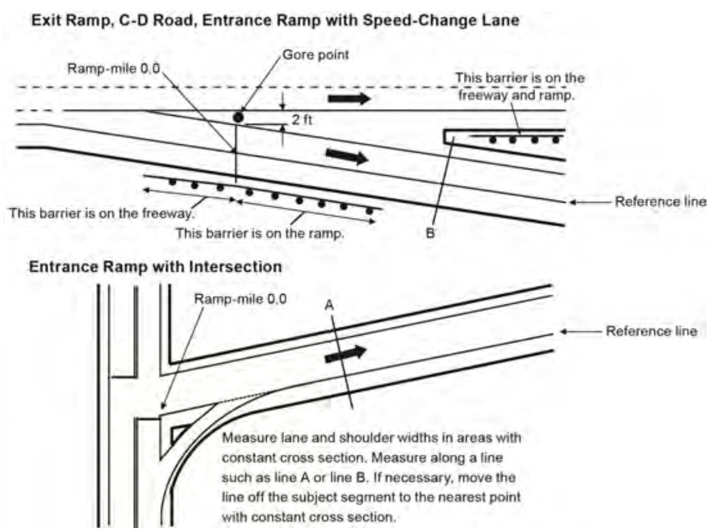


Figure 19-4. Starting Location on Ramps and C-D Roads

- *Widths of lanes, right shoulder, and left shoulder*—These elements represent an average for the segment. These widths should be measured where the cross section is constant, such as along line A or B shown in Figure 19-4. They should not be measured where one or more edges are discontinuous or tapered. If a width varies along the segment (but not enough to justify beginning a new segment), then compute the length-weighted average width. Rules for defining segment boundaries are provided in Section 19.5.2.
  - *Lane width*—This width is computed as an average for all through lanes.
  - *Shoulder width*—This width represents only the paved width.
- *Length of (and offset to) the right-side barrier and the left-side barrier*—Measured separately for each short piece of barrier and for barrier that continues for the length of the segment (and beyond). Each piece is represented once for a site. Barrier length is measured along the reference line. Offset is measured from the nearest edge of traveled way to the barrier face.

  Figure 19-5 illustrates these measurements for a barrier element protecting a sign support on the right side of a ramp with right shoulder width W_{rs}. The barrier element has a portion of its length that is parallel to the ramp and a portion of its length that is tapered away from the ramp. To evaluate this element, separate it into two pieces, as shown in Figure 19-5. Each piece is represented by its average offset $W_{off,r,i}$ and length $L_{rb,i}$. Barrier pieces with the same offset can be combined by adding their length and using their common offset.

  A barrier is associated with a ramp if its offset from the near edge of traveled way is 30 ft or less. Barrier adjacent to the freeway but also within 30 ft of the ramp traveled way should also be associated with the ramp. The determination of whether a barrier is adjacent to a freeway speed-change lane or a ramp is based on the gore point, as shown in Figure 19-4.

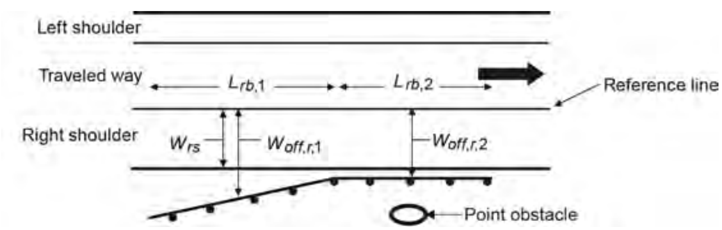


Figure 19-5. Barrier Variables

- Presence of an entrance speed-change lane (due to a second merging ramp)—If a speed-change lane is present, then the length of the speed-change lane *in the segment* is needed. Guidance for measuring this length is provided in the following list.
  - Speed-change lane length in the segment is measured between the segment's beginning and ending points. It cannot exceed the length of the segment, regardless of the length of the speed-change lane. It cannot exceed the length of the speed-change lane.
  - Speed-change lane length is measured along the edge of the subject ramp's traveled way from the gore point to the taper point. The gore point is located where the pair of solid white pavement edge markings that separate the subject ramp from the intersecting ramp are 2.0 ft apart. If the markings do not extend to a point where they are 2.0 ft apart, then the gore point is found by extrapolating both markings until the extrapolated portion is 2.0 ft apart. This point is shown in Figure 19-6.
  - The taper point is located where the outside edge marking of the intersecting ramp intersects the subject ramp's outside edge marking. It marks the point where the taper ends (or begins) as shown in Figure 19-6.

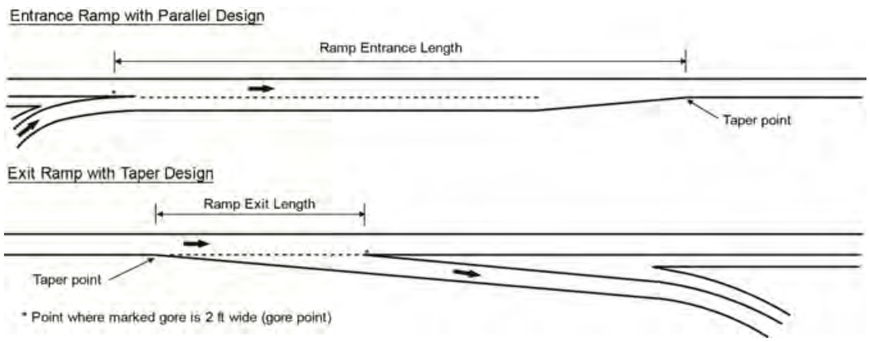


Figure 19-6. Speed-Change Lane Location on Ramps and C-D Roads

- *Presence of an exit speed-change lane (due to a second diverging ramp)*—If a speed-change lane is present, then the length of the speed-change lane *in the segment* is needed. Guidance for measuring this length is the same as for entrance speed-change lanes.
- *Lane added to the ramp or C-D road (not as a result of a second merging ramp)*—If a lane is added, then the length of the taper *in the segment* is needed. Guidance for measuring this length is provided in the following list:
  - *Length of taper in the segment*—This length is measured between the segment's beginning and ending points. This length cannot exceed the length of the segment. This length cannot exceed the taper length.
  - *Taper length*—This length is measured along the edge of the ramp traveled way from the point where the traveled way width first begins changing to the point where this width first stops changing. Traveled way width is measured between the solid white pavement edge lines.
- *Lane dropped from the ramp or C-D road (not as a result of a second diverging ramp)*—If a lane is dropped, then the length of the taper *in the segment* is needed. Guidance for measuring this length is the same as for the lane add case.
- *Presence of a weaving section on a C-D road segment*—If the segment is partially or wholly within a weaving section then the following data are needed:
  - *Weaving section length*—This length is measured along the edge of the C-D road traveled way from the gore point of the ramp entrance to the gore point of the next ramp exit, as shown in Figure 19-7. The gore point is located where the pair of solid white pavement edge markings that separate the ramp from the C-D road are 2.0 ft apart. If the markings do not extend to a point where they are 2.0 ft apart, then the gore point is found by extrapolating both markings until the extrapolated portion is 2.0 ft apart. If the measured gore-to-gore distance exceeds 0.30 mi (1,600 ft), then a weaving section is not considered to exist. Rather, the entrance ramp is a "lane add" and the exit ramp is a "lane drop."

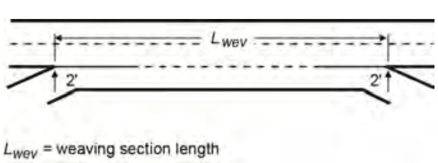


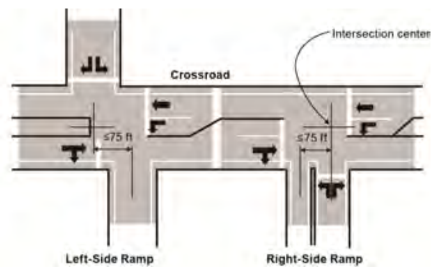
Figure 19-7. C-D Road Weaving Section Length

- *Length of weaving section located in the segment, between the segment's beginning and ending points*—This length cannot exceed the length of the segment. This length cannot exceed the length of the weaving section.

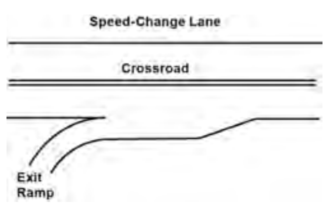
- Segment AADT volume.

Features of Crossroad Ramp Terminals

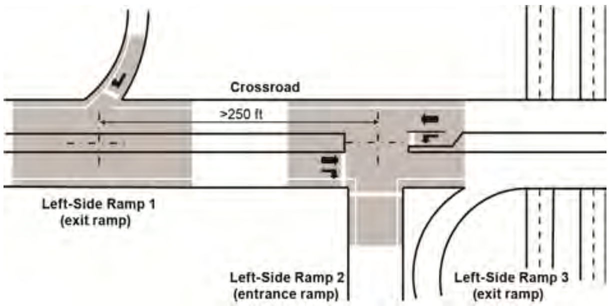
The input data that describe a crossroad ramp terminal are described in this subsection. The phrase "crossroad ramp terminal" refers to a controlled terminal between the ramp and crossroad. This type of terminal is addressed by the predictive method. A terminal where the ramp merges with (or diverges from) the crossroad as a speed-change lane is not addressed by the predictive method. Figures 19-8a and 19-8b illustrate these two terminal types. Crossroad ramp terminals at single-point diamond interchanges are characterized by one intersection through which traffic movements are made. Figure 19-8d illustrates this crossroad ramp terminal type, which extends along the crossroad to points 100 ft beyond the gore or curb returns of the outermost ramp connections. Crossroad ramp terminals at tight diamond interchanges are characterized by two at-grade intersections spaced between 200 ft and 400 ft apart, through which all at-grade traffic movements are made. An additional characteristic of the tight diamond interchange is exclusive left-turn lanes for movements from the crossroad to the freeway, which are developed in advance of the upstream ramp terminal. The two intersections of the tight diamond crossroad ramp terminal are signalized to operate as one. Figure 19-8e illustrates this crossroad ramp terminal type, which extends along the crossroad to points 100 ft beyond the gore or curb returns of the outermost ramp connections.



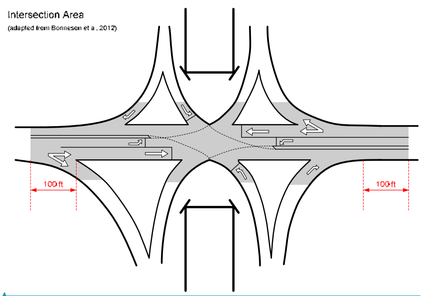
a. Four-Leg Intersection and Three-Leg Intersection



b. Speed-Change Lane

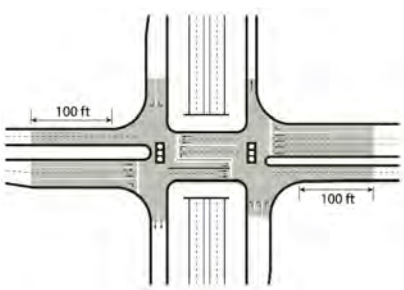


c. Two Three-Leg Intersections and a Speed-Change Lane



Field Code Changed

d. Crossroad Ramp Terminal Definition for Single-Point Diamond



~~d.~~e. Crosroad Ramp Terminal Definition for Tight Diamond

Figure 19-8. Illustrative Ramp Terminals

~~If~~ In cases that are not crossroad ramp terminals of single-point diamond interchanges or tight-diamond interchanges, but where the crossroad intersects two ramps that are relatively near one another, there may be some question as to whether the two ramps are part of one intersection or two separate intersections (for the purpose of applying the predictive method). The following guidance is offered to help with this decision; however, some engineering judgment may also be required.

If the centerlines of the two ramps are offset by 75 ft or less, and they are configured to function as one intersection, then both ramps are considered to be part of the same intersection. This point is illustrated in Figure 19-8a for the left-side ramp and the right-side ramp at an interchange. Two intersections are shown in this figure.

If the two ramps are offset by more than 250 ft and are not part of a tight diamond interchange, then each ramp terminal is considered to form a separate intersection. This point is illustrated in Figure 19-8c for the left-side ramps at a four-quadrant partial cloverleaf B interchange. Two intersections are shown in this figure.

Occasionally, the ramp offset is between 75 and 250 ft. In this situation, engineering judgment is required to determine whether the two ramps function as one or two intersections. Factors considered in making this determination will include the intersection control, traffic volume level, traffic movements being served (see Figure 19-1), channelization, average queue length, and pavement markings. Higher volume conditions often dictate that the two ramps are controlled as one signalized intersection. Ramp offsets in this range are typically avoided for new designs.

A description of the following geometric design and traffic control features is needed to use the CMFs associated with the predictive model for crossroad ramp terminals:

- Ramp terminal configuration, as described in Figure 19-1.
- *Ramp terminal control type (signal, one-way stop control, all-way stop control)*—The predictive models are calibrated to address signal control and one-way stop control, where the ramp is stop controlled. An interim predictive model is provided in Section 19.10 for all-way stop control.
- *Presence of a non-ramp public street leg at the terminal (signal control)*—This situation occurs occasionally. When it does, the public street leg is opposite from one ramp, and the other ramp either does not exist or is located at some distance from the subject ramp terminal such that it is not part of the terminal. This information is needed only for signalized terminals.
- *Exit ramp skew angle (one-way stop control)*—Skew angle equals 90 minus the intersection angle (in degrees). These angles are shown in Figure 19-9. The intersection angle is the acute angle between the crossroad centerline and a line along the center of an imaginary vehicle stopped at the end of the ramp (i.e., where it joins the crossroad). The vehicle is centered in the traveled way and behind the stop line. If vehicles can exit the ramp as left- or right-turn movements, then use a left-turning vehicle as the vehicle of reference. This information is needed only for terminals with one-way stop control. At a *B4* terminal configuration, the skew angle represents that for the diagonal exit ramp (not the loop exit ramp).

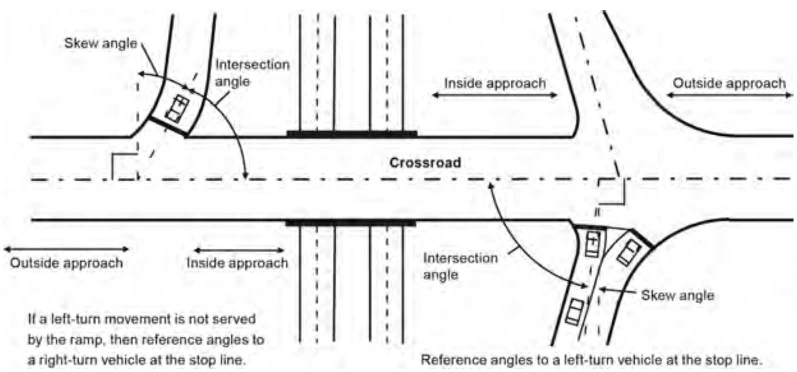


Figure 19-9. Exit Ramp Skew Angle

- *Distance to the next public street intersection on the outside crossroad leg*—This data element represents the distance between the subject ramp terminal and the nearest public street intersection located in a direction away from the freeway (measured along the crossroad from subject terminal center to intersection center).
- *Distance to the adjacent ramp terminal*—This data element represents the distance between the subject ramp terminal and the adjacent ramp terminal (measured along the crossroad from terminal center to terminal center). If there is no adjacent ramp terminal, then use the distance to the next public street intersection (located on the crossroad in the direction opposite to the intersection described in the previous bullet).
- *Presence of protected left-turn operation (signal control)*—This information is needed for each crossroad left-turn movement that exists at the terminal. An affirmative response is indicated if the left-turn operates as protected only. If it operates as permissive or protected-permissive, then the response is negative. This information is needed only for signalized terminals.
- *Exit ramp right-turn control type*—This information is needed only for the exit ramp (at terminals with an exit ramp). It is focused on the right-turn movement, which may have a different control type than the left-turn movement. Control types considered include: free flow, merge, yield, stop, and signal (where free-flow and merge operation are recognized to represent “no control”). The free-flow type is associated with an accepting (or auxiliary) lane on the crossroad for the right-turn movement. The merge type is associated with a speed-change lane for the right-turn movement.
- *Crossroad median width*—This width is measured along a line perpendicular to the centerline of the crossroad in the vicinity of the intersection. If no median exists, then a width of 0.0 ft is used in the predictive model. If a raised curb is present, then the width is measured from face-of-curb to face-of-curb. If a raised curb is not present, then the width is measured between the near edge of traveled way for the two opposing travel directions. If a left-turn bay is present, then the median width includes the width of the left-turn bay. It is measured from the lane line delineating the bay to the face-of-curb adjacent to (or the near edge of traveled way for) the opposing travel direction. If the median width is different on the two crossroad legs, then use an average of the two widths.
- *Number of through lanes on the inside crossroad approach*—Number of lanes (shared or exclusive) serving through traffic on the crossroad approach that is nearest to the freeway (i.e., the inside approach), as shown in Figure 19-9. This variable includes only lanes that continue through the intersection. Count the lanes along the crosswalk (or the logical location of the crosswalk if it is not marked).
- *Number of through lanes on the outside crossroad approach*—Number of lanes (shared or exclusive) serving through traffic on the crossroad approach that is more distant from the freeway (i.e., the outside approach), as shown in Figure 19-9. This variable includes only lanes that continue through the intersection. Count the lanes along the crosswalk (or the logical location of the crosswalk if it is not marked).
- *Number of lanes on the exit ramp leg at the terminal*—Lanes can serve any movement (left, right, or through). If right-turn channelization is provided, then count the lanes at the last point where all exiting movements are joined (i.e., count at the channelization gore point). All lanes counted must be fully developed for 100 ft or more before they intersect the crossroad. If a lane’s development length is less than 100 ft, then it is not counted as a lane for this application. The lane (or lanes) associated with the loop exit ramp at a *B4* terminal configuration are *not* included in this count.
- *Presence of right-turn channelization on the inside crossroad approach (signal control)*—This channelization creates a turning roadway that serves right-turn vehicles. It is separated from the intersection by a triangular channelizing island (delineated by markings or raised curb). The gore point at the upstream end of the island must be within 200 ft of the downstream stop line for right-turn channelization to be considered “present.” If this distance exceeds 200 ft, then the right-turn movement is served by a ramp roadway that is separate from the intersection (i.e., it should be evaluated as a ramp). The right-turn movement can be free-flow, stop, or yield controlled. This information is needed only for signalized terminals.
- *Presence of right-turn channelization on the outside crossroad approach (signal control)*—The guidance provided in the previous bullet also applies to this variable. It is needed only for signalized terminals.
- *Presence of right-turn channelization on the exit ramp approach (signal control)*—The guidance provided in the previous bullet also applies to this variable. It is needed only for signalized terminals. The presence of right-turn

channelization on the loop exit ramp at a *B4* terminal configuration is *not* considered when determining this input data.

- *Presence of a left-turn lane (or bay) on the inside crossroad approach*—The lane (or bay) can have one or two lanes. A lane (or bay) is considered to be present when it (a) is for the exclusive use of a turn movement, (b) extends 100 ft or more back from the stop line, and (c) ends at the intersection stop line.
- *Presence of a left-turn lane (or bay) on the outside crossroad approach*—The guidance provided in the previous bullet also applies to this variable.
- *Width of left-turn lane (or bay) on the inside crossroad approach*—This variable represents the total width of all lanes that exclusively serve turning vehicles on the subject approach. It is measured from the near edge of traveled way of the adjacent through lane to the near lane marking (or curb face) that delineates the median.
- *Width of left-turn lane (or bay) on the outside crossroad approach*—The guidance provided in the previous bullet also applies to this variable.
- *Presence of a right-turn lane (or bay) on the inside crossroad approach*—The lane (or bay) can have one or two lanes. A lane (or bay) is considered to be present when it (a) is for the exclusive use of a turn movement, (b) extends 100 ft or more back from the stop line, and (c) satisfies one of the following rules:
    - If the bay or turn lane does not have island channelization at the intersection, then it must end at the intersection stop line.
    - If the bay or turn lane has island channelization at the intersection, then the bay or turn lane must have (a) stop, yield, or signal control at its downstream end, and (b) an exit gore point that is within 200 ft of the intersection.
- *Presence of a right-turn lane (or bay) on the outside crossroad approach*—The guidance provided in the previous bullet also applies to this variable.
- *Number of driveways on the outside crossroad leg (signal control)*—This number represents the count of unsignalized driveways on the outside crossroad leg and within 250 ft of the ramp terminal. The count is taken on both sides of the leg (i.e., it is a two-way total). The count should only include “active” driveways (i.e., those driveways with an average daily volume of 10 veh/day or more). This information is needed only for signalized terminals.
- *Number of public street approaches on the outside crossroad leg*—This number represents the count of unsignalized public street approaches on the outside crossroad leg and within 250 ft of the ramp terminal. The count is taken on both sides of the leg (i.e., it is a two-way total). If a public street approach is present at the terminal, then it is not counted for this entry. Rather, it is identified as being present using the “Presence of a non-ramp public street leg at the terminal” data that was discussed previously.
- *AADT volume for the inside crossroad leg, AADT volume for the outside crossroad leg, AADT volume for each ramp leg*—The inside crossroad leg is the leg that is on the side of the ramp terminal nearest to the freeway. The outside crossroad leg is on the other side of the ramp terminal. The AADT of the loop ramp at a terminal with a either an *A4* or *B4* configuration is not needed (or used in the calculations).

19.5. RAMP SEGMENTS AND RAMP TERMINALS

This section consists of three subsections. Section 19.5.1 defines ramp segments, C-D road segments, and crossroad ramp terminals. Section 19.5.2 provides guidelines for segmenting the ramp or C-D road. The assignment of crashes to sites is discussed in Section 19.5.3.

19.5.1. Definition of Ramp Segment and Ramp Terminal

When using the predictive method, the ramps and C-D roads within the defined project limits are divided into individual sites. A site is a homogeneous ramp segment, a homogeneous C-D road segment, or a crossroad ramp terminal.

Four ramps and one C-D road are shown in Figure 19-10. This figure represents one side of an interchange. Each ramp is shown to consist of one segment. The C-D road is divided into five segments. The ramp segments are labeled R_{en1}, R_{en2}, R_{ex3}, and R_{ex4}. The C-D road segments are labeled CD_1 to CD_5. Two of the C-D road segments include a speed-change lane with a ramp. A third C-D road segment includes two speed-change lanes associated with the two loop ramps. The C-D road is not shown to have a weaving section; however, the predictive models can address C-D roads with or without a weaving section.

One example crossroad ramp terminal is shown in Figure 19-10. It is labeled "*In*" and is noted to have an influence area that extends 250 ft in each direction along the crossroad and ramps. The terminal has four legs—two crossroad legs and two ramp legs. Given the presence of the loop ramps, it is likely that this terminal serves only right-turn maneuvers to and from the crossroad. In the case of a single-point diamond interchange, the influence area extends from the single intersection to points 100 ft beyond the gore or curb returns of the outermost ramp connections. Similarly, in the case of a tight diamond interchange, the influence area extends from each of the two intersections to points 100 ft beyond the gore or curb returns of the outermost ramp connections.

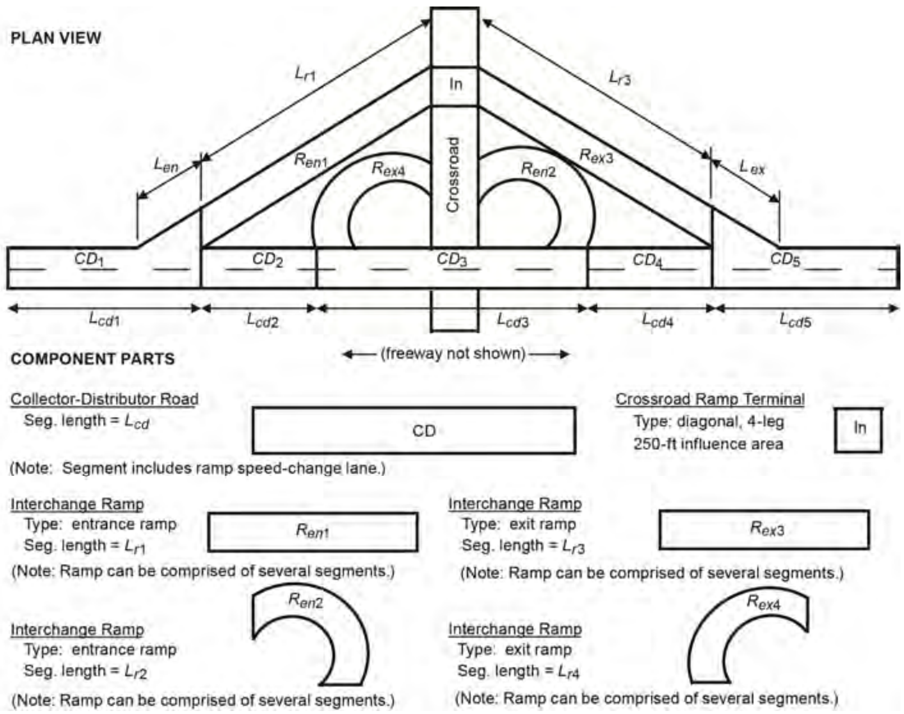


Figure 19-10. Illustrative Ramp Segments and Ramp Terminals

19.5.2. Segmentation Process

The segmentation process produces a set of segments of varying length, each of which is homogenous with respect to characteristics such as traffic volume, key geometric design features, and traffic control features. A new homogeneous ramp or C-D road segment begins where there is a change in at least one of the following characteristics of the roadway:

- *Number of through lanes*—Begin segment at the gore point if the lane is added or dropped at a ramp or C-D road. Begin segment at the upstream start of taper if the lane is added or dropped by taper. Guidance in this regard is described in the text accompanying Figure 19-3.
- *Lane width*—Measure the lane width at successive points along the roadway. Compute an average lane width for each point and round this average to the nearest 0.5 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 12.5 to 13.0 ft).
- *Right shoulder width*—Measure the right shoulder width at successive points along the roadway. Round the measured shoulder width at each point to the nearest 1.0 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 4 to 5 ft).
- *Left shoulder width*—Measure the left shoulder width at successive points along the roadway. Round the measured shoulder width at each point to the nearest 1.0 ft. Begin a new segment if the rounded value for the current point changes from that of the previous point (e.g., from 4 to 3 ft).
- *Merging ramp or C-D road presence*—Begin segment at the gore point.
- *Diverging ramp or C-D road presence*—Begin segment at the gore point.

The presence of a horizontal curve does not necessarily define ramp or C-D road segment boundaries. This approach represents a difference with the process described in Chaper 10, where a curve does define segment boundaries.

When a segment begins or ends at a crossroad ramp terminal, the length of the segment is measured from the near edge of the crossroad traveled way (shown as ramp-mile 0.0 in the lower half of Figure 19-4). When a segment begins or ends at a terminal formed by a merging or diverging ramp or C-D road, then the length of the segment is measured from the gore point, as shown in Figure 19-4. A ramp or C-D road segment can include no more than one ramp entrance (i.e., merge with a second ramp) and one ramp exit (i.e., diverge with a second ramp).

Guidance regarding the location of the lane and shoulder width measurement points is provided in Figure 19-4. Each width represents an average for the segment. The rounded lane and shoulder width values are used solely to determine segment boundaries. Once these boundaries are determined, the unrounded values for the segment are then used for all subsequent calculations in the predictive method.

19.5.3. Crash Assignment to Sites

Observed crash counts are assigned to the individual sites to apply the site-specific EB Method. Any crashes that occur on a ramp or C-D road are classified as either intersection-related or segment-related crashes. The intersection-related crashes are assigned to the corresponding crossroad ramp terminal. The predictive model for crossroad ramp terminals estimates the frequency of these crashes. The segment-related crashes are assigned to the corresponding ramp or C-D road segment. The ramp segment predictive model estimates the frequency of these crashes. The procedure for assignment of crashes to individual sites is presented in Section B.2.3 in Appendix B.

Speed-change lanes can occur at locations where ramp segments and C-D road segments connect, or where two ramp segments connect. For the predictive method, these speed-change lanes are considered to be part of the ramp or C-D road segment. Crashes occurring in these speed-change lanes are assigned to the segment.

19.6. SAFETY PERFORMANCE FUNCTIONS

When using the predictive method, the appropriate safety performance functions (SPFs) are used to estimate the predicted average crash frequency of a site with base conditions. Each SPF was developed as a regression model using observed crash data for a set of similar sites as the dependent variable. The SPFs, like all regression models, estimate the value of the dependent variable as a function of a set of independent variables. The independent variables for the ramp and C-D road segment SPFs include the segment AADT volume, segment length, and area type (i.e., rural or urban). The independent variables for the crossroad ramp terminal SPFs include the AADT volume of the intersection legs and area type. The SPFs in this chapter are summarized in Table 19-3.

Table 19-3. Ramp Safety Performance Functions

Site Type (*w*)	Cross Section and Control Type (*x*)	Crash Type (*y*)	SPF Equations
Ramp segments (*rps*)	Ramp entrance, *n* lanes (*nEN*)	Multiple vehicle (*mv*)	Equation 19-20
		Single vehicle (*sv*)	Equation 19-24
	Ramp exit, *n* lanes (*nEX*)	Multiple vehicle (*mv*)	Equation 19-20
		Single vehicle (*sv*)	Equation 19-24
C-D road segments (*cds*)	*n* lanes (*n*)	Multiple vehicle (*mv*)	Equation 19-22
		Single vehicle (*sv*)	Equation 19-26
Three-leg terminals with diagonal exit ramp (*D3ex*)	One-way stop control (*ST*)	All types (*at*)	Equation 19-31
	Signal control, *n* lanes (*SGn*)	All types (*at*)	Equation 19-28
Three-leg terminals with diagonal entrance ramp (*D3en*)	One-way stop control (*ST*)	All types (*at*)	Equation 19-31
	Signal control, *n* lanes (*SGn*)	All types (*at*)	Equation 19-28
Four-leg terminals with diagonal ramps (*D4*)	One-way stop control (*ST*)	All types (*at*)	Equation 19-31
	Signal control, *n* lanes (*SGn*)	All types (*at*)	Equation 19-28
Four-leg terminals at four-quadrant partial cloverleaf A (*A4*)	One-way stop control (*ST*)	All types (*at*)	Equation 19-31
	Signal control, *n* lanes (*SGn*)	All types (*at*)	Equation 19-28
Four-leg terminals at four-quadrant partial cloverleaf B (*B4*)	One-way stop control (*ST*)	All types (*at*)	Equation 19-31
	Signal control, *n* lanes (*SGn*)	All types (*at*)	Equation 19-28
Three-leg terminals at two-quadrant partial cloverleaf A (*A2*)	One-way stop control (*ST*)	All types (*at*)	Equation 19-31
	Signal control, *n* lanes (*SGn*)	All types (*at*)	Equation 19-28
Three-leg terminals at two-quadrant partial cloverleaf B (*B2*)	One-way stop control (*ST*)	All types (*at*)	Equation 19-31
	Signal control, *n* lanes (*SGn*)	All types (*at*)	Equation 19-28
Crossroad ramp terminals at single-point diamond interchanges (SP)	Free-flow right turns from exit ramp to crossroad	All types (*at*)	Equation 19-XA
Crossroad ramp terminals at tight diamond interchanges (TD)	Signal control	All types (at)	Equation 19-XB

A detailed discussion of SPFs and their use in the HSM is presented in Sections 3.5.2 and C.6.3 of the *Highway Safety Manual*.

Some transportation agencies may have performed statistically sound studies to develop their own jurisdiction-specific SPFs. These SPFs may be substituted for the SPFs presented in this chapter. Criteria for the development of SPFs for use in the predictive method are addressed in the calibration procedure presented in Section B.1.2 in Appendix B.

Each SPF 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 that is discussed in Section B.2 in Appendix B.

19.6.1. Safety Performance Functions for Ramp Segments

The SPFs for ramp and C-D road segments are presented in this section. Specifically, SPFs are provided for ramp and C-D road segments with 1 or 2 through lanes. The range of AADT volume for which these SPFs are applicable is shown in Table 19-4. Application of the SPFs to sites with AADT volumes substantially outside these ranges may not provide reliable results.

Table 19-4. Applicable AADT Volume Ranges for Ramp SPFs

Area Type	Cross Section (Through Lanes) (x)	Applicable AADT Volume Range (veh/day)
Rural	1	0 to 7,000
Urban	1	0 to 18,000
	2	0 to 32,000

Other types of ramp and C-D road segments may be found at interchanges, but they are not addressed by the predictive model described in this chapter.

Multiple-Vehicle Crashes on Ramp Segments

The base conditions for the SPFs for multiple-vehicle crashes on ramp segments are presented in the following list (the variables are defined in Section 19.4.2):

- Length of horizontal curve 0.0 mi (i.e., not present)
- Lane width 14 ft
- Right shoulder width (paved) 8 ft
- Left shoulder width (paved) 4 ft
- Length of right-side barrier 0.0 mi (i.e., not present)
- Length of left-side barrier 0.0 mi (i.e., not present)
- Length of lane add or drop 0.0 mi (i.e., not present)
- Length of ramp speed-change lane 0.0 mi (i.e., not present)

The SPFs for multiple-vehicle crashes on ramp segments are represented using the following equation:

$$N_{spf,rps,x,mv,z} = L_r \times \exp\left(a + b \times \ln[c \times AADT_r] + d\,[c \times AADT_r]\right) \quad (19\text{-}20)$$

Where:

$N_{spf,rps,x,mv,z}$ = predicted average multiple-vehicle crash frequency of a ramp segment with base conditions, cross section x ($x = nEN$: n-lane entrance ramp, nEX: n-lane exit ramp), and severity z ($z = fi$: fatal and injury, pdo: property damage only) (crashes/yr);

L_r = length of ramp segment (mi);

$AADT_r$ = AADT volume of ramp segment (veh/day);

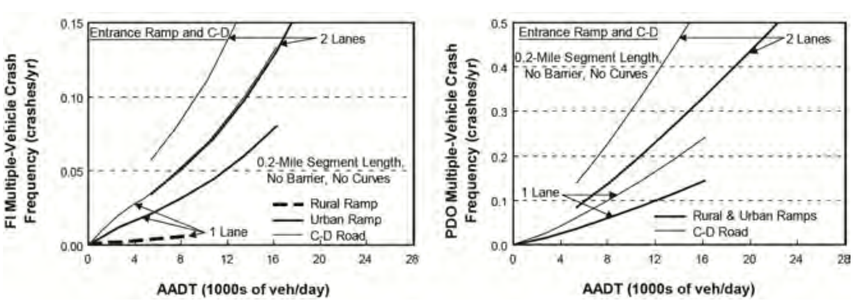
a, b, d = regression coefficients; and

c = AADT scale coefficient.

The SPF coefficients and inverse dispersion parameter are provided in Table 19-5. The SPFs are illustrated in Figure 19-11 and Figure 19-12.

Table 19-5. SPF Coefficients for Multiple-Vehicle Crashes on Ramp Segments

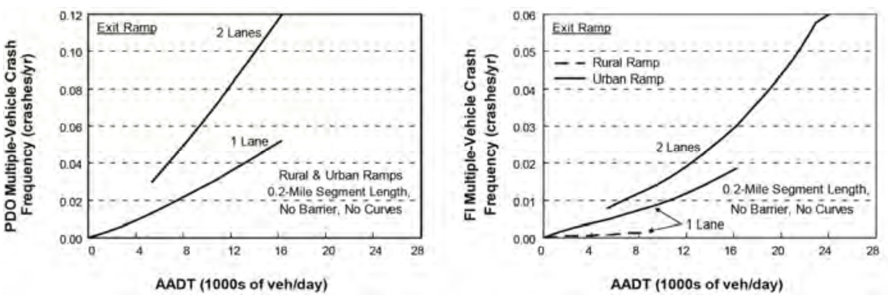
Crash Severity (*z*)	Area Type	Cross Section (*x*)	SPF Coefficient *a*	*b*	*c*	*d*	Inverse Dispersion Parameter $K_{rps,x,mv,z}$ (mi^{-1})
Fatal and injury (*fi*)	Rural	One-lane entrance (*1EN*)	–5.226	0.524	0.001	0.0699	14.6
		One-lane exit (*1EX*)	–6.692	0.524	0.001	0.0699	14.6
	Urban	One-lane entrance (*1EN*)	–3.505	0.524	0.001	0.0699	14.6
		One-lane exit (*1EX*)	–4.971	0.524	0.001	0.0699	14.6
		Two-lane entrance (*2EN*)	–3.023	0.524	0.001	0.0699	14.6
		Two-lane exit (*2EX*)	–4.489	0.524	0.001	0.0699	14.6
Property damage only (*pdo*)	Rural	One-lane entrance (*1EN*)	–3.819	1.256	0.001	0.00	12.7
		One-lane exit (*1EX*)	–4.851	1.256	0.001	0.00	12.7
	Urban	One-lane entrance (*1EN*)	–3.819	1.256	0.001	0.00	12.7
		One-lane exit (*1EX*)	–4.851	1.256	0.001	0.00	12.7
		Two-lane entrance (*2EN*)	–2.983	1.256	0.001	0.00	12.7
		Two-lane exit (*2EX*)	–4.015	1.256	0.001	0.00	12.7



a. Fatal-and-Injury Crash Frequency

b. Property-Damage-Only Crash Frequency

Figure 19-11. Graphical Form of the SPFs for Multiple-Vehicle Crashes on Entrance Ramp Segments



a. Fatal-and-Injury Crash Frequency

b. Property-Damage-Only Crash Frequency

Figure 19-12. Graphical Form of the SPFs for Multiple-Vehicle Crashes on Exit Ramp Segments

The value of the overdispersion parameter associated with the SPFs for ramp segments is determined as a function of the segment length. This value is computed using Equation 19-21.

$$k_{rps,x,mv,z} = \frac{1.0}{K_{rps,x,mv,z} \times L_r} \qquad (19\text{-}21)$$

Where:

$k_{rps,\,x,\,mv,\,z}$ = overdispersion parameter for ramp segments with cross section *x*, multiple-vehicle crashes *mv*, and severity *z*; and

$K_{rps,\,x,\,mv,\,z}$ = inverse dispersion parameter for ramp segments with cross section *x*, multiple-vehicle crashes *mv*, and severity *z* (mi^{-1}).

The crash frequency obtained from Equation 19-20 can be multiplied by the proportions in Table 19-6 to estimate the predicted average multiple-vehicle crash frequency by crash type category.

Table 19-6. Default Distribution of Multiple-Vehicle Crashes by Crash Type for Ramp and C-D Road Segments

		Proportion of Crashes by Severity	
Area Type	Crash Type Category	Fatal and Injury	Property Damage Only
Rural or urban	Head-on	0.015	0.009
	Right-angle	0.010	0.005
	Rear-end	0.707	0.550
	Sideswipe	0.129	0.335
	Other multiple-vehicle crashes	0.139	0.101

Multiple-Vehicle Crashes on C-D Road Segments

The base conditions for the SPFs for multiple-vehicle crashes on C-D road segments are the same as those for multiple-vehicle crashes on ramp segments, as described in the preceding subsection. One additional base condition for this SPF is that there is no weaving section present.

The SPFs for multiple-vehicle crashes on C-D road segments are represented using the following equation:

$$N_{spf,cds,n,mv,z} = L_{cd} \times \exp\left(a + b \times \ln[c \times AADT_c] + d[c \times AADT_c]\right) \quad (19\text{-}22)$$

Where:

$N_{spf, cds, n, mv, z}$ = predicted average multiple-vehicle crash frequency of a C-D road segment with base conditions, n lanes, and severity z ($z = fi$: fatal and injury, pdo: property damage only) (crashes/yr);

L_{cd} = length of C-D road segment (mi); and

$AADT_c$ = AADT volume of C-D road segment (veh/day).

The SPF coefficients and inverse dispersion parameter are provided in Table 19-7. The SPFs are illustrated in Figure 19-11.

Table 19-7. SPF Coefficients for Multiple-Vehicle Crashes on C-D Road Segments

Crash Severity (z)	Area Type	Number of Through Lanes (n)	SPF Coefficient a	b	c	d	Inverse Dispersion Parameter $K_{cds, x, mv, z}$ (mi^{-1})
Fatal and injury (fi)	Rural	1	–4.718	0.524	0.001	0.0699	14.6
	Urban	1	–2.997	0.524	0.001	0.0699	14.6
		2	–2.515	0.524	0.001	0.0699	14.6
Property damage only (pdo)	Rural	1	–3.311	1.256	0.001	0.00	12.7
	Urban	1	–3.311	1.256	0.001	0.00	12.7
		2	–2.475	1.256	0.001	0.00	12.7

The value of the overdispersion parameter associated with the SPFs for C-D road segments is determined as a function of the segment length. This value is computed using Equation 19-23.

$$k_{cds,x,mv,z} = \frac{1.0}{K_{cds,x,mv,z} \times L_{cd}} \quad (19\text{-}23)$$

Where:

$k_{cds, x, mv, z}$ = overdispersion parameter for C-D road segments with cross section x, multiple-vehicle crashes mv, and severity z; and

$K_{cds, x, mv, z}$ = inverse dispersion parameter for C-D road segments with cross section x, multiple-vehicle crashes mv, and severity z (mi^{-1}).

The crash frequency obtained from Equation 19-22 can be multiplied by the proportions in Table 19-6 to estimate the predicted average multiple-vehicle crash frequency by crash type category.

Single-Vehicle Crashes on Ramp Segments

With one exception, the base conditions for the SPFs for single-vehicle crashes on ramp segments are the same as those for multiple-vehicle crashes on ramp segments, as described in a preceding subsection. The “ramp speed-change lane presence” condition does not apply to the single-vehicle SPFs.

The SPFs for single-vehicle crashes on ramp segments are represented with the following equation:

$$N_{spf,rps,x,sv,z} = L_r \times \exp\left(a + b \times \ln[c \times AADT_r]\right) \quad (19\text{-}24)$$

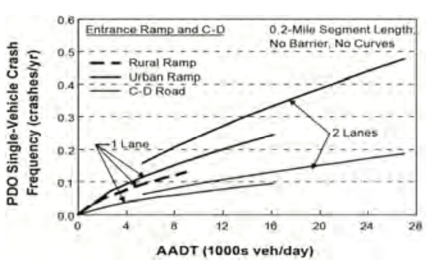
Where:

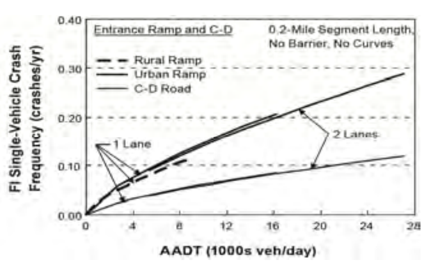
$N_{spf,\, rps,\, x,\, sv,\, z}$ = predicted average single-vehicle crash frequency of a ramp segment with base conditions, cross section x (x = *nEN*: *n*-lane entrance ramp, *nEX*: *n*-lane exit ramp), and severity z (z = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr).

The SPF coefficients and inverse dispersion parameter are provided in Table 19-8. The SPFs are illustrated in Figure 19-13 and Figure 19-14.

Table 19-8. SPF Coefficients for Single-Vehicle Crashes on Ramp Segments

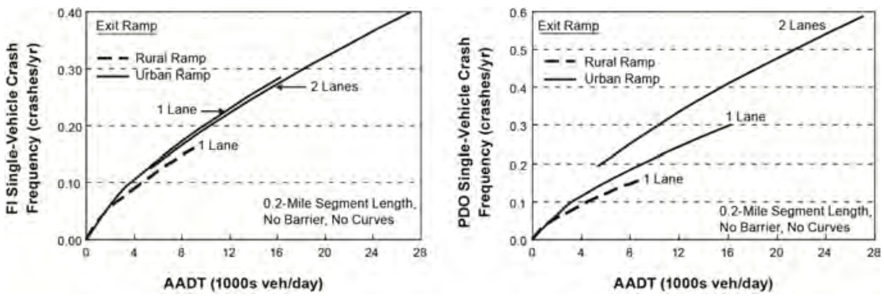
Crash Severity (z)	Area Type	Cross Section (x)	SPF Coefficient a	SPF Coefficient b	SPF Coefficient c	Inverse Dispersion Parameter $K_{rps,x,sv,z}$ (mi^{-1})
Fatal and injury (*fi*)	Rural	One-lane entrance (*1EN*)	–2.120	0.718	0.001	7.91
		One-lane exit (*1EX*)	–1.799	0.718	0.001	7.91
	Urban	One-lane entrance (*1EN*)	–1.966	0.718	0.001	7.91
		One-lane exit (*1EX*)	–1.645	0.718	0.001	7.91
		Two-lane entrance (*2EN*)	–1.999	0.718	0.001	7.91
		Two-lane exit (*2EX*)	–1.678	0.718	0.001	7.91
Property damage only (*pdo*)	Rural	One-lane entrance (*1EN*)	–1.946	0.689	0.001	9.77
		One-lane exit (*1EX*)	–1.739	0.689	0.001	9.77
	Urban	One-lane entrance (*1EN*)	–1.715	0.689	0.001	9.77
		One-lane exit (*1EX*)	–1.508	0.689	0.001	9.77
		Two-lane entrance (*2EN*)	–1.400	0.689	0.001	9.77
		Two-lane exit (*2EX*)	–1.193	0.689	0.001	9.77





a. Fatal-and-Injury Crash Frequency b. Property-Damage-Only Crash Frequency

Figure 19-13. Graphical Form of the SPFs for Single-Vehicle Crashes on Entrance Ramp Segments



a. Fatal-and-Injury Crash Frequency b. Property-Damage-Only Crash Frequency

Figure 19-14. Graphical Form of the SPFs for Single-Vehicle Crashes on Exit Ramp Segments

The value of the overdispersion parameter associated with the SPFs for ramp segments is determined as a function of the segment length. This value is computed using Equation 19-25.

$$k_{rps,x,sv,z} = \frac{1.0}{K_{rps,x,sv,z} \times L_r} \qquad (19\text{-}25)$$

Where:

$k_{rps,x,sv,z}$ = overdispersion parameter for ramp segments with cross section *x*, single-vehicle crashes *mv*, and severity *z*; and

$K_{rps,x,sv,z}$ = inverse dispersion parameter for ramp segments with cross section *x*, single-vehicle crashes *mv*, and severity *z* (mi^{-1}).

The crash frequency obtained from Equation 19-24 can be multiplied by the proportions in Table 19-9 to estimate the predicted average single-vehicle crash frequency by crash type category.

Table 19-9. Default Distribution of Single-Vehicle Crashes by Crash Type for Ramp and C-D Road Segments

Area Type	Crash Type Category	Proportion of Crashes by Severity	
		Fatal and Injury	Property Damage Only
Rural	Crash with animal	0.012	0.022
	Crash with fixed object	0.422	0.538
	Crash with other object	0.000	0.011
	Crash with parked vehicle	0.024	0.055
	Other single-vehicle crashes	0.542	0.374
Urban	Crash with animal	0.003	0.005
	Crash with fixed object	0.718	0.834
	Crash with other object	0.015	0.023
	Crash with parked vehicle	0.012	0.012
	Other single-vehicle crashes	0.252	0.126

Single-Vehicle Crashes on C-D Road Segments

With one exception, the base conditions for the SPFs for single-vehicle crashes on C-D road segments are the same as those for multiple-vehicle crashes on ramp segments, as described in a preceding subsection. The "ramp speed-change lane presence" condition does not apply to the single-vehicle SPFs. One additional base condition for this SPF is that there is no weaving section present.

The SPFs for single-vehicle crashes on C-D road segments are represented with the following equation:

$$N_{spf,cds,n,sv,z} = L_{cd} \times \exp(a + b \times \ln[c \times AADT_c]) \tag{19-26}$$

Where:

$N_{spf,cds,n,sv,z}$ = predicted average single-vehicle crash frequency of a C-D road segment with base conditions, n lanes, and severity z ($z = fi$: fatal and injury, *pdo*: property damage only) (crashes/yr).

The SPF coefficients and inverse dispersion parameter are provided in Table 19-10. The SPFs are illustrated in Figure 19-13.

Table 19-10. SPF Coefficients for Single-Vehicle Crashes on C-D Road Segments

Crash Severity (z)	Area Type	Number of Through Lanes (n)	SPF Coefficient a	SPF Coefficient b	SPF Coefficient c	Inverse Dispersion Parameter $K_{cds,n,sv,z}$ (mi^{-1})
Fatal and injury (*fi*)	Rural	1	–3.002	0.718	0.001	7.91
	Urban	1	–2.848	0.718	0.001	7.91
		2	–2.881	0.718	0.001	7.91
Property damage only (*pdo*)	Rural	1	–2.890	0.689	0.001	9.77
	Urban	1	–2.659	0.689	0.001	9.77
		2	–2.344	0.689	0.001	9.77

The value of the overdispersion parameter associated with the SPFs for C-D road segments is determined as a function of the segment length. This value is computed using Equation 19-27.

$$k_{cds,n,sv,z} = \frac{1.0}{K_{cds,n,sv,z} \times L_{cd}} \tag{19-27}$$

Where:

$k_{cds,x,sv,z}$ = overdispersion parameter for C-D road segments with cross section x, single-vehicle crashes *mv*, and severity z; and

$K_{cds,x,sv,z}$ = inverse dispersion parameter for C-D road segments with cross section x, single-vehicle crashes *mv*, and severity z (mi^{-1}).

The crash frequency obtained from Equation 19-26 can be multiplied by the proportions in Table 19-9 to estimate the predicted average single-vehicle crash frequency by crash type category.

19.6.2. Safety Performance Functions for Ramp Terminals

The SPFs for crossroad ramp terminals are presented in this section. Specifically, SPFs are provided for crossroad ramp terminals with 2 to 6 crossroad through lanes (total of both travel directions). The range of AADT volume for which these SPFs are applicable is shown in Table 19-11. Application of the SPFs to sites with AADT volumes substantially outside these ranges may not provide reliable results.

Other types of crossroad ramp terminal configurations may be found at interchanges, but they are not addressed by the predictive model described in this chapter.

Table 19-11. Applicable AADT Volume Ranges for Crossroad Ramp Terminal SPFs

		Applicable AADT Volume Range (veh/day)	
Site Type (*w*)	Control Type (*x*)	Crossroad	Total All Ramps
Three-leg terminals with diagonal exit ramp (*D3ex*)	Stop control (*ST*)	0 to 22,000	0 to 8,000
	Signal control (*SG*)	0 to 34,000	0 to 16,000
Three-leg terminals with diagonal entrance ramp (*D3en*)	Stop control (*ST*)	0 to 22,000	0 to 15,000
	Signal control (*SG*)	0 to 29,000	0 to 21,000
Four-leg terminals with diagonal ramps (*D4*)	Stop control (*ST*)	0 to 18,000	0 to 10,000
	Signal control (*SG*)	0 to 47,000	0 to 31,000
Four-leg terminals at four-quadrant partial cloverleaf A (*A4*)	Stop control (*ST*)	0 to 21,000	0 to 12,000
	Signal control (*SG*)	0 to 71,000	0 to 30,000
Four-leg terminals at four-quadrant partial cloverleaf B (*B4*)	Stop control (*ST*)	0 to 20,000	0 to 12,000
	Signal control (*SG*)	0 to 45,000	0 to 29,000
Three-leg terminals at two-quadrant partial cloverleaf A (*A2*)	Stop control (*ST*)	0 to 17,000	0 to 12,000
	Signal control (*SG*)	0 to 46,000	0 to 25,000
Three-leg terminals at two-quadrant partial cloverleaf B (*B2*)	Stop control (*ST*)	0 to 26,000	0 to 14,000
	Signal control (*SG*)	0 to 44,000	0 to 22,000
Crossroad ramp terminals at single-point diamond interchanges (*SP*)	No free-flow right turns from exit ramp to crossroad (*FF0*)	0 to 70,000	0 to 80,000
	One free-flow right turn from exit ramp to crossroad (*FF1*)	0 to 70,000	0 to 80,000
	Two free-flow right turns from exit ramp to crossroad (*FF2*)	0 to 70,000	0 to 80,000
Crossroad ramp terminals at tight diamond interchanges (TD)	Signal control (SG)	0 to 51,000	0 to 74,000

Signal-Controlled Crossroad Ramp Terminals

The base conditions for the signalized crossroad ramp terminal SPFs are presented in the following list (the variables are defined in Section 19.4.2):

- Crossroad left-turn lane (or bay) — Not present
- Crossroad right-turn lane (or bay) — Not present
- Public street approach presence — No public street approaches present

▪ Driveway presence	No driveways present
▪ Distance to adjacent intersection	No adjacent ramp or public street intersection within 6 mi
▪ Median width (on crossroad)	12 ft
▪ Protected left-turn phase	Not present on either crossroad approach leg
▪ Channelized right turn on crossroad	Not present
▪ Channelized right turn on exit ramp	Not present
▪ Non-ramp public street leg	Not present

The SPFs for crashes at signalized crossroad ramp terminals are presented using the following equation:

$$N_{spf,w,SGn,at,z} = \exp\left(a + b \times \ln[c \times AADT_{xrd}] + d \times \ln[c \times AADT_{ex} + c \times AADT_{en}]\right) \qquad (19\text{-}28)$$

with

$$AADT_{xrd} = 0.5 \times (AADT_{in} + AADT_{out}) \qquad (19\text{-}29)$$

Where:

$N_{spf,w,SGn,at,z}$ = predicted average crash frequency of a signal-controlled crossroad ramp terminal of site type *w* (*w = 3ex, D3en, D4, A4, B4, A2, B2*) with base conditions, *n* crossroad lanes, all crash types *at*, and severity *z* (*z = fi*: fatal and injury, *pdo*: property damage only) (crashes/yr);

$AADT_{xrd}$ = AADT volume for the crossroad (veh/day);

$AADT_{ex}$ = AADT volume for the exit ramp (veh/day);

$AADT_{en}$ = AADT volume for the entrance ramp (veh/day);

$AADT_{in}$ = AADT volume for the crossroad leg between ramps (veh/day); and

$AADT_{out}$ = AADT volume for the crossroad leg outside of interchange (veh/day).

The SPF coefficients and inverse dispersion parameter are provided in Table 19-12 through Table 19-15. The SPFs are illustrated in Figure 19-15 through Figure 19-18. The AADT volume of the loop exit ramp at a *B4* terminal configuration is not included in $AADT_{ex}$. Similarly, the AADT volume of the loop entrance ramp at an *A4* configuration is not included in $AADT_{en}$.

The exit ramp capacity CMF is combined with the SPF for fatal-and-injury crashes to create the trend lines shown in the figures for fatal-and-injury crashes. This CMF is a function of exit ramp volume, number of exit ramp lanes, and the traffic control for the exit ramp right turn. These variables in combination do not readily lend themselves to the specification of a representative base condition. For this reason, the CMF is combined with the SPF for the graphical presentation. The exit ramp capacity CMF is described in Section 19.7.2.

Table 19-12. SPF Coefficients for Crashes at Signalized Ramp Terminals–Three-Leg Terminal at Two-Quadrant Partial Cloverleaf A or B (*A2*, *B2*)

Crash Severity (*z*)	Area Type	Number of Crossroad Through Lanes (*n*)	SPF Coefficient *a*	*b*	*c*	*d*	Inverse Dispersion Parameter $K_{w, SGn, at, z}$
Fatal and injury (*fi*)	Rural or urban	2	–0.458	0.325	0.001	0.212	2.17
		3	–0.298	0.325	0.001	0.212	2.17
		4	–0.138	0.325	0.001	0.212	2.17
		5 (urban only)	0.022	0.325	0.001	0.212	2.17
		6 (urban only)	0.182	0.325	0.001	0.212	2.17
Property damage only (*pdo*)	Rural or urban	2	–1.537	0.592	0.001	0.516	4.27
		3	–1.449	0.592	0.001	0.516	4.27
		4	–1.361	0.592	0.001	0.516	4.27
		5 (urban only)	–1.274	0.592	0.001	0.516	4.27
		6 (urban only)	–1.186	0.592	0.001	0.516	4.27

Table 19-13. SPF Coefficients for Crashes at Signalized Ramp Terminals—Three-Leg Terminal with Diagonal Exit Ramp or Four-Leg Terminal at Four-Quadrant Partial Cloverleaf A (*D3ex*, *A4*)

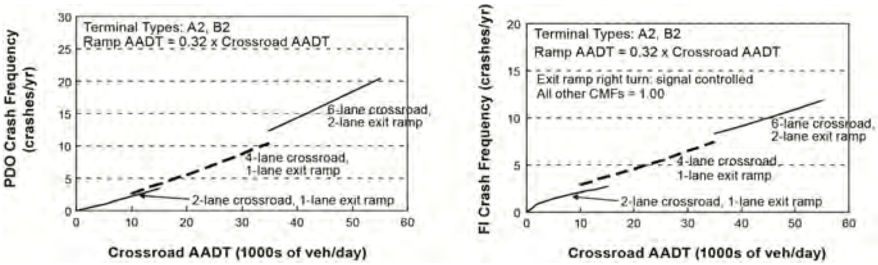
Crash Severity (*z*)	Area Type	Number of Crossroad Through Lanes (*n*)	SPF Coefficient *a*	*b*	*c*	*d*	Inverse Dispersion Parameter $K_{w, SGn, at, z}$
Fatal and injury (*fi*)	Rural or urban	2	–1.352	0.379	0.001	0.394	8.72
		3	–1.192	0.379	0.001	0.394	8.72
		4	–1.032	0.379	0.001	0.394	8.72
		5 (urban only)	–0.872	0.379	0.001	0.394	8.72
		6 (urban only)	–0.712	0.379	0.001	0.394	8.72
Property damage only (*pdo*)	Rural or urban	2	–2.247	0.797	0.001	0.384	4.05
		3	–2.159	0.797	0.001	0.384	4.05
		4	–2.071	0.797	0.001	0.384	4.05
		5 (urban only)	–1.984	0.797	0.001	0.384	4.05
		6 (urban only)	–1.896	0.797	0.001	0.384	4.05

Table 19-14. SPF Coefficients for Crashes at Signalized Ramp Terminals—Three-Leg Terminal with Diagonal Entrance Ramp or Four-Leg Terminal at Four-Quadrant Partial Cloverleaf B (*D3en*, *B4*)

Crash Severity (*z*)	Area Type	Number of Crossroad Through Lanes (*n*)	SPF Coefficient *a*	*b*	*c*	*d*	Inverse Dispersion Parameter $K_{Sw, SGn, at, z}$
Fatal and injury (*fi*)	Rural or urban	2	–2.068	0.265	0.001	0.905	5.37
		3	–1.908	0.265	0.001	0.905	5.37
		4	–1.748	0.265	0.001	0.905	5.37
		5 (urban only)	–1.588	0.265	0.001	0.905	5.37
		6 (urban only)	–1.428	0.265	0.001	0.905	5.37
Property damage only (*pdo*)	Rural or urban	2	–2.931	0.741	0.001	0.845	3.72
		3	–2.843	0.741	0.001	0.845	3.72
		4	–2.755	0.741	0.001	0.845	3.72
		5 (urban only)	–2.668	0.741	0.001	0.845	3.72
		6 (urban only)	–2.580	0.741	0.001	0.845	3.72

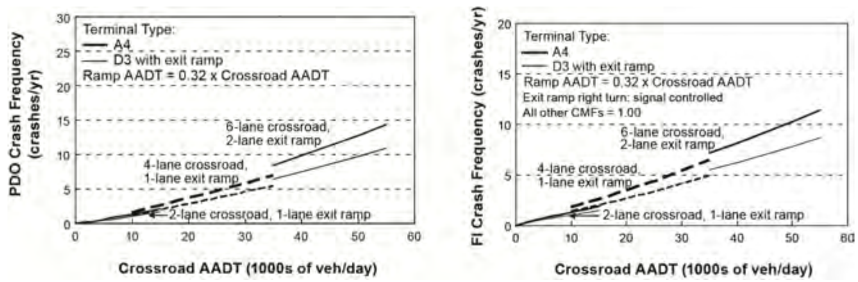
Table 19-15. SPF Coefficients for Crashes at Signalized Ramp Terminals—Four-Leg Terminal with Diagonal Ramps (*D4*)

Crash Severity (*z*)	Area Type	Number of Crossroad Through Lanes (*n*)	SPF Coefficient *a*	*b*	*c*	*d*	Inverse Dispersion Parameter $K_{w, SGn, at, z}$
Fatal and injury (*fi*)	Rural or urban	2	–2.655	1.191	0.001	0.131	11.5
		3	–2.495	1.191	0.001	0.131	11.5
		4	–2.335	1.191	0.001	0.131	11.5
		5 (urban only)	–2.175	1.191	0.001	0.131	11.5
		6 (urban only)	–2.015	1.191	0.001	0.131	11.5
Property damage only (*pdo*)	Rural or urban	2	–2.248	0.879	0.001	0.545	7.21
		3	–2.160	0.879	0.001	0.545	7.21
		4	–2.072	0.879	0.001	0.545	7.21
		5 (urban only)	–1.985	0.879	0.001	0.545	7.21
		6 (urban only)	–1.897	0.879	0.001	0.545	7.21



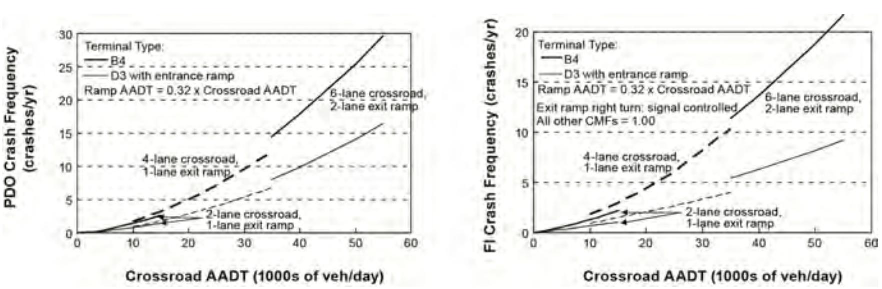
a. Fatal-and-Injury Crash Frequency b. Property-Damage-Only Crash Frequency

Figure 19-15. Graphical Form of the SPF for Crashes at Signalized Ramp Terminals—Three-Leg Terminal at Two-Quadrant Partial Cloverleaf A or B (*A2*, *B2*)



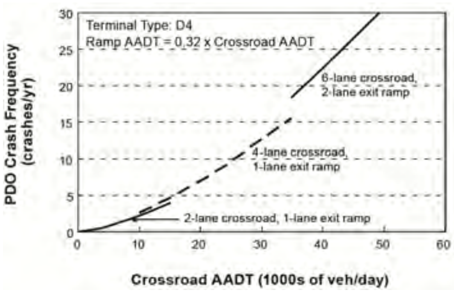
a. Fatal-and-Injury Crash Frequency b. Property-Damage-Only Crash Frequency

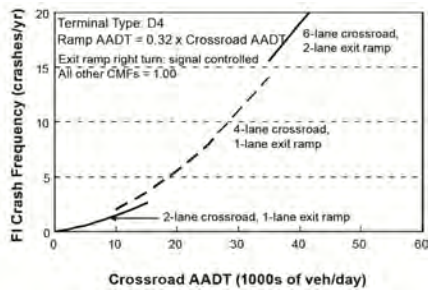
Figure 19-16. Graphical Form of the SPF for Crashes at Signalized Ramp Terminals—Three-Leg Terminal with Diagonal Exit Ramp or Four-Leg Terminal at Four-Quadrant Partial Cloverleaf A (*D3ex*, *A4*)



a. Fatal-and-Injury Crash Frequency b. Property-Damage-Only Crash Frequency

Figure 19-17. Graphical Form of the SPF for Crashes at Signalized Ramp Terminals—Three-Leg Terminal with Diagonal Entrance Ramp or Four-Leg Terminal at Four-Quadrant Partial Cloverleaf B (*D3en*, *B4*)





a. Fatal-and-Injury Crash Frequency b. Property-Damage-Only Crash Frequency

Figure 19-18. Graphical Form of the SPF for Crashes at Signalized Ramp Terminals—Four-Leg Terminal with Diagonal Ramps (*D4*)

The value of the overdispersion parameter associated with the SPFs for signalized crossroad ramp terminals is computed using Equation 19-30.

$$k_{w,SGn,at,z} = \frac{1.0}{K_{w,SGn,at,z}} \quad (19\text{-}30)$$

Where:

$k_{w,SGn,at,z}$ = overdispersion parameter for signal-controlled site of type *w*, when *n* crossroad lanes, all crash types *at*, and severity *z*; and

$K_{w,SGn,at,z}$ = inverse dispersion parameter for signal-controlled site of type *w*, when *n* crossroad lanes, all crash types *at*, and severity *z.*

The crash frequency obtained from Equation 19-28 can be multiplied by the proportions in Table 19-16 to estimate the predicted average signalized crossroad ramp terminal crash frequency by crash type or crash type category.

Table 19-16. Default Distribution of Signal-Controlled Ramp Terminal Crashes by Crash Type

Area Type	Crash Type	Crash Type Category	Proportion of Crashes by Severity	
			Fatal and Injury	Property Damage Only
Rural	Multiple vehicle	Head-on	0.000	0.006
		Right-angle	0.333	0.187
		Rear-end	0.552	0.466
		Sideswipe	0.000	0.219
		Other multiple-vehicle crash	0.014	0.013
	Single vehicle	Crash with animal	0.000	0.000
		Crash with fixed object	0.043	0.077
		Crash with other object	0.000	0.000
		Crash with parked vehicle	0.000	0.013
		Other single-vehicle crashes	0.058	0.019
Urban	Multiple vehicle	Head-on	0.011	0.007
		Right-angle	0.260	0.220
		Rear-end	0.625	0.543
		Sideswipe	0.042	0.149
		Other multiple-vehicle crash	0.009	0.020
	Single vehicle	Crash with animal	0.000	0.000
		Crash with fixed object	0.033	0.050
		Crash with other object	0.001	0.002
		Crash with parked vehicle	0.001	0.002
		Other single-vehicle crashes	0.018	0.007

One-Way Stop-Controlled Crossroad Ramp Terminals
The predictive models described in this section are calibrated to address one-way stop control, where the ramp is stop controlled. An interim predictive model is provided in Section 19.10 for all-way stop control.

The base conditions for the one-way stop-controlled crossroad ramp terminal SPFs are presented in the following list (the variables are defined in Section 19.4.2):

- Crossroad left-turn lane (or bay) Not present
- Crossroad right-turn lane (or bay) Not present
- Public street approach presence No public street approaches present
- Distance to adjacent intersection No adjacent ramp or public street intersection within 6 mi
- Median width (on crossroad) 12 ft
- Skew angle 0.0 degrees (i.e., no skew)

The SPF for crashes at one-way stop-controlled ramp terminals is applied as follows:

$$N_{spf,w,ST,at,z} = \exp\left(a + b' \ln[c' AADT_{xrd}] + d' \ln[c' AADT_{ex} + c' AADT_{en}]\right) \quad (19\text{-}31)$$

Where:

$N_{spf, w,ST, at, z}$ = predicted average crash frequency of a one-way stop-controlled crossroad ramp terminal of site type *w* ($w = D3ex, D3en, D4, A4, B4, A2, B2$) with base conditions, all crash types *at*, and severity *z* ($z = fi$: fatal and injury, *pdo*: property damage only) (crashes/yr).

The SPF coefficients and inverse dispersion parameter are provided in Table 19-17 to Table 19-20. The SPFs are illustrated in Figure 19-19 through Figure 19-22.

The exit ramp capacity CMF is combined with the SPF for fatal-and-injury crashes to create the trend lines shown in the figures for fatal-and-injury crashes. This CMF is a function of exit ramp volume, number of exit ramp lanes, and the traffic control for the exit ramp right turn. These variables in combination do not readily lend themselves to the specification of a representative base condition. For this reason, the CMF is combined with the SPF for the graphical presentation. The exit ramp capacity CMF is described in Section 19.7.2.

Table 19-17. SPF Coefficients for Crashes at One-Way Stop-Controlled Ramp Terminals—Three-Leg Terminal at Two-Quadrant Partial Cloverleaf A or B (*A2*, *B2*)

Crash Severity (*z*)	Area Type	Number of Crossroad Through Lanes (*n*)	SPF Coefficient				Inverse Dispersion Parameter $K_{w,ST,at,z}$
			a	*b*	*c*	*d*	
Fatal and injury (*fi*)	Rural	All lanes	–2.363	0.260	0.001	0.947	3.40
	Urban	All lanes	–2.687	0.260	0.001	0.947	3.40
Property damage only (*pdo*)	Rural	All lanes	–3.055	0.773	0.001	0.878	5.49
	Urban	All lanes	–3.055	0.773	0.001	0.878	5.49

Table 19-18. SPF Coefficients for Crashes at One-Way Stop-Controlled Ramp Terminals—Three-Leg Terminal with Diagonal Exit Ramp or Four-Leg Terminal at Four-Quadrant Partial Cloverleaf A (*D3ex*, *A4*)

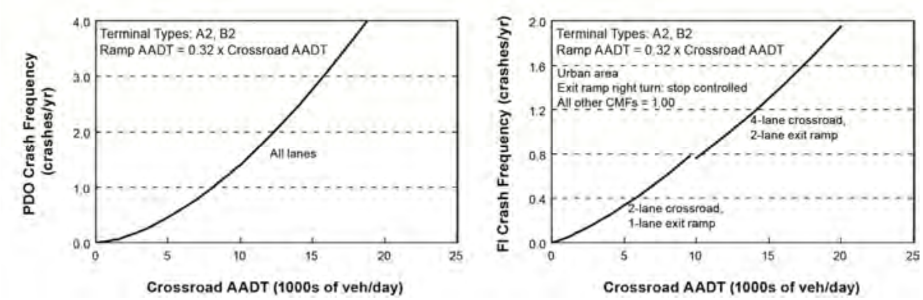
Crash Severity (*z*)	Area Type	Number of Crossroad Through Lanes (*n*)	SPF Coefficient				Inverse Dispersion Parameter $K_{w,ST,at,z}$
			a	*b*	*c*	*d*	
Fatal and injury (*fi*)	Rural	All lanes	–2.899	0.582	0.001	0.899	2.16
	Urban	All lanes	–3.223	0.582	0.001	0.899	2.16
Property damage only (*pdo*)	Rural	All lanes	–2.670	0.595	0.001	0.937	6.57
	Urban	All lanes	–2.670	0.595	0.001	0.937	6.57

Table 19-19. SPF Coefficients for Crashes at One-Way Stop-Controlled Ramp Terminals—Three-Leg Terminal with Diagonal Entrance Ramp or Four-Leg Terminal at Four-Quadrant Partial Cloverleaf B (*D3en*, *B4*)

Crash Severity (*z*)	Area Type	Number of Crossroad Through Lanes (*n*)	SPF Coefficient *a*	*b*	*c*	*d*	Inverse Dispersion Parameter $K_{w, ST, at, z}$
Fatal and injury (*fi*)	Rural	All lanes	–2.817	0.709	0.001	0.730	0.92
	Urban	All lanes	–3.141	0.709	0.001	0.730	0.92
Property damage only (*pdo*)	Rural	All lanes	–2.358	0.885	0.001	0.350	3.90
	Urban	All lanes	–2.358	0.885	0.001	0.350	3.90

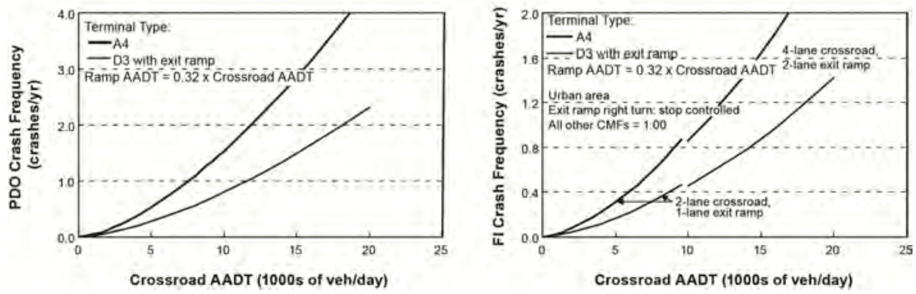
Table 19-20. SPF Coefficients for Crashes at One-Way Stop-Controlled Ramp Terminals—Four-Leg Terminal with Diagonal Ramps (*D4*)

Crash Severity (*z*)	Area Type	Number of Crossroad Through Lanes (*n*)	SPF Coefficient *a*	*b*	*c*	*d*	Inverse Dispersion Parameter $K_{w, ST, at, z}$
Fatal and injury (*fi*)	Rural	All lanes	–2.740	1.008	0.001	0.177	2.58
	Urban	All lanes	–3.064	1.008	0.001	0.177	2.58
Property damage only (*pdo*)	Rural	All lanes	–2.432	0.845	0.001	0.476	4.27
	Urban	All lanes	–2.432	0.845	0.001	0.476	4.27



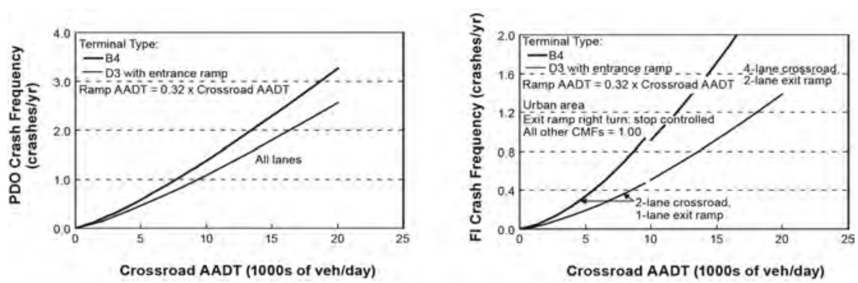
a. Fatal-and-Injury Crash Frequency b. Property-Damage-Only Crash Frequency

Figure 19-19. Graphical Form of the SPF Crashes at One-Way Stop-Controlled Ramp Terminals—Three-Leg Terminal at Two-Quadrant Partial Cloverleaf A or B (*A2*, *B2*)



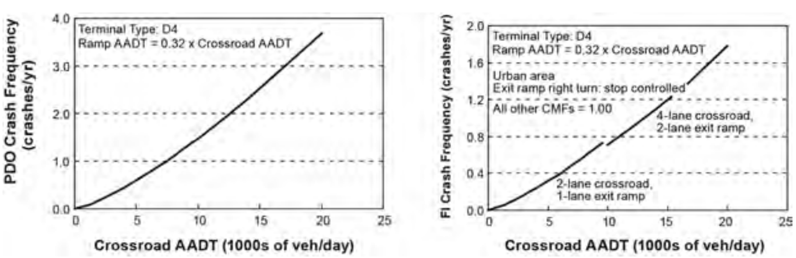
a. Fatal-and-Injury Crash Frequency b. Property-Damage-Only Crash Frequency

Figure 19-20. Graphical Form of the SPF Crashes at One-Way Stop-Controlled Ramp Terminals—Three-Leg Terminal with Diagonal Exit Ramp or Four-Leg Terminal at Four-Quadrant Partial Cloverleaf A (*D3ex*, *A4*)



a. Fatal-and-Injury Crash Frequency b. Property-Damage-Only Crash Frequency

Figure 19-21. Graphical Form of the SPF Crashes at One-Way Stop-Controlled Ramp Terminals—Three-Leg Terminal with Diagonal Entrance Ramp or Four-Leg Terminal at Four-Quadrant Partial Cloverleaf B (*D3en*, *B4*)



a. Fatal-and-Injury Crash Frequency b. Property-Damage-Only Crash Frequency

Figure 19-22. Graphical Form of the SPF Crashes at One-Way Stop-Controlled Ramp Terminals—Four-Leg Terminal with Diagonal Ramps (*D4*)

The value of the overdispersion parameter associated with the SPFs for one-way stop-controlled crossroad ramp terminals is computed using Equation 19-32.

$$k_{w,ST,at,z} = \frac{1.0}{K_{w,ST,at,z}} \qquad (19\text{-}32)$$

Where:

$k_{w, ST, at, z}$ = overdispersion parameter for a stop-controlled site of type *w*, with *n* crossroad lanes, and all crash types *at* and severity *z*; and

$K_{w, ST, at, z}$ = inverse dispersion parameter for a stop-controlled site of type *w*, with *n* crossroad lanes, and all crash types *at* and severity *z*.

The crash frequency obtained from Equation 19-31 can be multiplied by the proportions in Table 19-21 to estimate the predicted average stop-controlled crossroad ramp terminal crash frequency by crash type or crash type category.

Table 19-21. Default Distribution of One-Way Stop-Controlled Ramp Terminal Crashes by Crash Type

			Proportion of Crashes by Severity	
Area Type	Crash Type	Crash Type Category	Fatal and Injury	Property Damage Only
Rural	Multiple vehicle	Head-on	0.020	0.015
		Right-angle	0.522	0.372
		Rear-end	0.275	0.276
		Sideswipe	0.020	0.107
		Other multiple-vehicle crash	0.013	0.026
	Single vehicle	Crash with animal	0.000	0.000
		Crash with fixed object	0.078	0.158
		Crash with other object	0.000	0.005
		Crash with parked vehicle	0.007	0.015
		Other single-vehicle crashes	0.065	0.026
Urban	Multiple vehicle	Head-on	0.017	0.012
		Right-angle	0.458	0.378
		Rear-end	0.373	0.377
		Sideswipe	0.025	0.079
		Other multiple-vehicle crash	0.017	0.016
	Single vehicle	Crash with animal	0.000	0.000
		Crash with fixed object	0.085	0.110
		Crash with other object	0.000	0.000
		Crash with parked vehicle	0.000	0.008
		Other single-vehicle crashes	0.025	0.020

Crossroad Ramp Terminals at Single-Point Diamond Interchanges

Separate SPFs are presented for three configurations of crossroad ramp terminals at single-point diamond interchanges, based on the number of exit ramps with free-flow right turns to the crossroad (0, 1, or 2). There are no additional base conditions.

The SPFs for crashes at single-point diamond crossroad ramp terminals are presented using the following equation:

$$N_{spf,w,x,at,z} = \exp[a + b \times \ln(AADT_{xrd}) + c \times \ln(AADT_{ramp})] \quad (19\text{-}XA)$$

Where:

$N_{spf,w,x,at,z}$ = predicted average crash frequency of crossroad ramp terminal of site type *w* (*w* = *SP*), number of free-flow right turns from exit ramp to crossroad x (x = 0, 1, or 2), all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr);

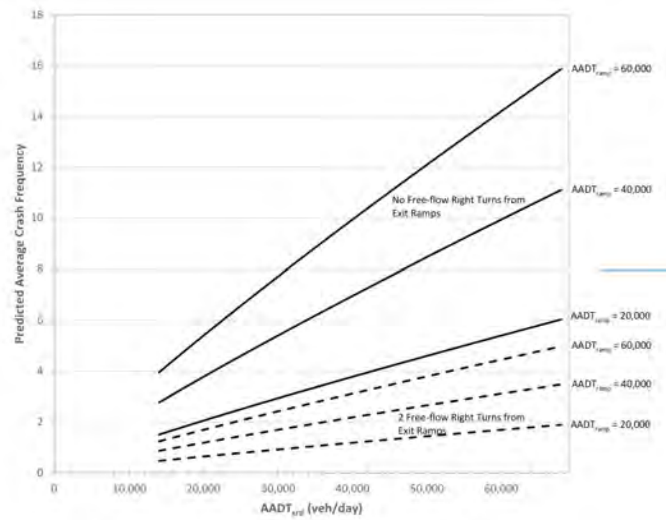
$AADT_{xrd}$ = AADT volume for the crossroad (veh/day);

$AADT_{ramp}$ = sum of AADT volumes for all four ramps (veh/day);

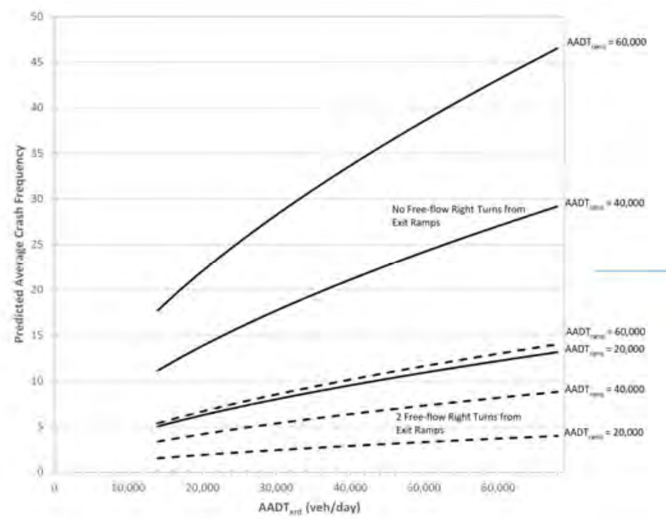
The SPF coefficients and dispersion parameter are provided in Table 19-XA. The SPFs are illustrated in Figure 19-XA.

Table 19-XA. SPF Coefficients for Crashes at Single-Point Diamond Interchange Crossroad Ramp Terminals

Crash Severity (*z*)	Number of Free-Flow Right Turns from Exit Ramp to Crossroad (*x*)	SPF Coefficient *a*	*b*	*c*	Dispersion Parameter $k_{SP,x,at,z}$
Fatal and injury (*fi*)	0	-16.71	0.88	0.88	0.11
	1	-17.29	0.88	0.88	0.11
	2	-17.87	0.88	0.88	0.11
Property damage only (*pdo*)	0	-15.60	0.61	1.15	0.10
	1	-16.20	0.61	1.15	0.10
	2	-16.80	0.61	1.15	0.10



a. Fatal-and-Injury Crash Frequency



b. Property-Damage-Only Crash Frequency

Figure 19-XA. Graphical Form of the SPF for Crashes at Single-Point Diamond Interchange Crossroad Ramp Terminals

The crash frequency obtained from Equation 19-XA can be multiplied by the proportions in Table 19-XB to estimate the predicted average crash frequency at single-point diamond crossroad ramp terminals by crash type or crash type category.

Table 19-XB. Default Distribution of Single-Point Diamond Interchange Crossroad Ramp Terminal Crashes by Crash Type

		Proportion of Crashes by Severity	
Crash Type	Crash Type Category	Fatal and Injury	Property Damage Only
Multiple vehicle	Head-on	0.034	0.006
	Angle	0.129	0.080
	Rear-end	0.662	0.744
	Sideswipe	0.040	0.112
	Other multiple-vehicle crash	0.011	0.006
Single vehicle	Crash with animal	0.000	0.000
	Crash with fixed object	0.046	0.046
	Crash with other object	0.002	0.001
	Crash with parked vehicle	0.000	0.000
	Other single-vehicle crashes	0.013	0.005
Non-motorized	Pedestrian	0.021	0.000
	Bicycle	0.042	0.000

Crossroad Ramp Terminals at Tight Diamond Interchanges

SPFs are presented for crossroad ramp terminals at tight diamond interchanges for different severity levels. The SPFs for crashes at tight diamond interchange crossroad ramp terminals are presented using the following equation:

$$N_{spf,w,x,at,z} = \exp[a + b \times \ln(AADT_{xrd}) + c \times \ln(AADT_{ramp})] \quad (19\text{-}XB)$$

Where:

$N_{spf,w,x,at,z}$ = predicted average crash frequency of crossroad ramp terminal of site type *w* (*w* = *TD*), cross section x (x = all cross sections of tight diamond crossroad ramp terminals), all crash types *at*, and severity *z* (*z* = *fi*: fatal and injury, *pdo*: property damage only) (crashes/yr);

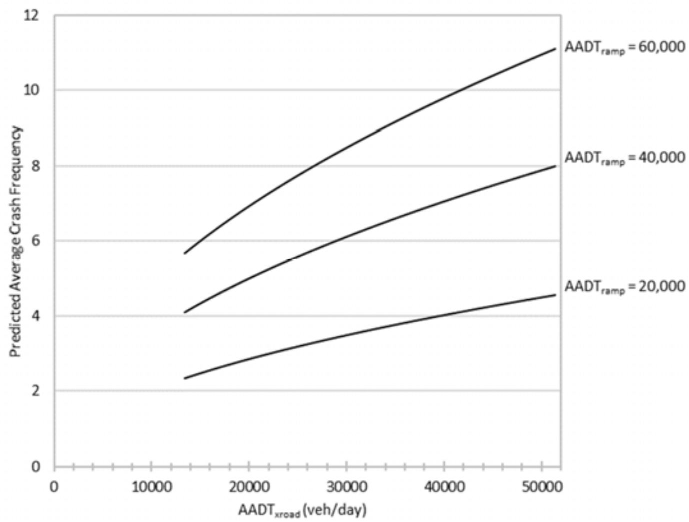
$AADT_{xrd}$ = AADT volume for the crossroad (veh/day);

$AADT_{ramp}$ = sum of AADT volumes for all four ramps (veh/day);

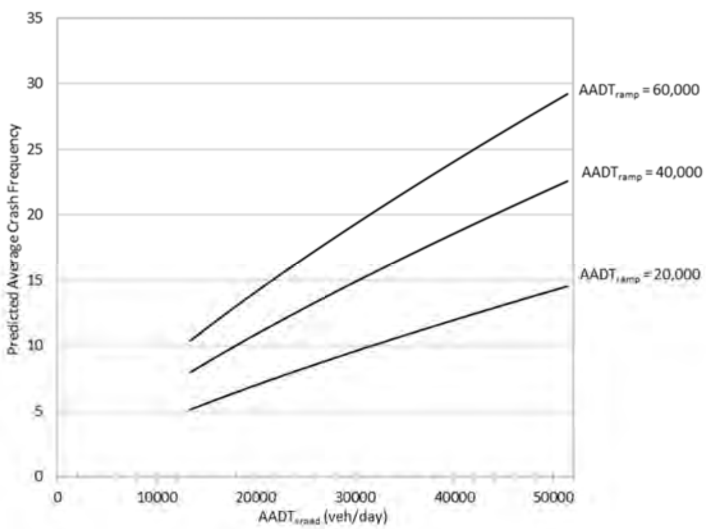
The SPF coefficients and dispersion parameter are provided in Table 19-XD. The SPFs are illustrated in Figure 19-XB.

Table 19-XD. SPF Coefficients for Crashes at Tight Diamond Interchange Crossroad Ramp Terminals

Crash Severity (*z*)	SPF Coefficient *a*	*b*	*c*	Dispersion Parameter $k_{TD, at, z}$
Fatal and injury (*fi*)	-11.90	0.50	0.81	0.23
Property damage only (*pdo*)	-11.99	0.77	0.63	0.29



a. Fatal-and-Injury Crash Frequency



b. Property-Damage-Only Crash Frequency

Figure 19-XB. Graphical Form of the SPF for Crashes at Tight Diamond Interchange Crossroad Ramp Terminals

The crash frequency obtained from Equation 19-XB can be multiplied by the proportions in Table 19-XE to estimate the predicted average crash frequency at tight diamond interchange crossroad ramp terminals by crash type or crash type category.

Table 19-XE. Default Distribution of Tight Diamond Crossroad Ramp Terminal Crashes by Crash Type

Crash Type	Crash Type Category	Proportion of Crashes by Severity	
		Fatal and Injury	Property Damage Only
Multiple vehicle	Head-on	0.010	0.005
	Angle	0.436	0.239
	Rear-end	0.444	0.579
	Sideswipe	0.028	0.124
	Other multiple-vehicle crash	0.012	0.014
Single vehicle	Crash with animal	0.000	0.000
	Crash with fixed object	0.013	0.032
	Crash with other object	0.000	0.001
	Crash with parked vehicle	0.000	0.000
	Other single-vehicle crashes	0.010	0.004
Non-motorized	Pedestrian	0.017	0.000
	Bicycle	0.030	0.002

19.7. CRASH MODIFICATION FACTORS

This section describes the CMFs applicable to the SPFs presented in Section 19.6. These CMFs were calibrated along with the SPFs. They are summarized in Table 19-22 and Table 19-23.

Table 19-22. Ramp Segment Crash Modification Factors and their Corresponding SPFs

Applicable SPF(s)	CMF Variable	CMF Description	CMF Equations
Ramp or C-D road segments	$CMF_{1,\,w,\,x,\,y,\,z}$	Horizontal curve	Equation 19-33
	$CMF_{2,\,w,\,x,\,y,\,fi}$	Lane width	Equation 19-34
	$CMF_{3,\,w,\,x,\,y,\,z}$	Right shoulder width	Equation 19-35
	$CMF_{4,\,w,\,x,\,y,\,z}$	Left shoulder width	Equation 19-36
	$CMF_{5,\,w,\,x,\,y,\,z}$	Right side barrier	Equation 19-37
	$CMF_{6,\,w,\,x,\,y,\,z}$	Left side barrier	Equation 19-38
	$CMF_{7,\,w,\,x,\,y,\,fi}$	Lane add or drop	Equation 19-39
Multiple-vehicle crashes on ramp or C-D Road segments	$CMF_{8,\,w,\,x,\,mv,\,fi}$	Ramp speed-change lane	Equation 19-40
C-D road segments	$CMF_{9,\,cds,\,ac,\,y,\,z}$	Weaving section	Equation 19-41

Note: Subscripts to the CMF variables use the following notation:

- Site type *w* ($w = rps$: ramp segment, *cds*: C-D road segment),
- Cross section *x* ($x = n$: *n*-lane C-D road, *nEN*: *n*-lane entrance ramp, *nEX*: *n*-lane exit ramp, *ac*: any cross section),
- Crash type *y* ($y = sv$: single vehicle, *mv*: multiple vehicle, *at*: all types), and
- Severity *z* ($z = fi$: fatal and injury, *pdo*: property damage only, *as*: all severities).

Many of the CMFs in Table 19-22 and Table 19-23 are developed for specific site types, cross sections, crash types, or crash severities. This approach was undertaken to make the predictive model sensitive to the geometric design and traffic control features of specific sites with specific cross sections, in terms of their influence on specific crash types and severities. The subscripts for each CMF variable indicate the sites, cross sections, crash types, and severities to which each CMF is applicable. The subscript definitions are provided in the table footnote. In some cases, a CMF is applicable to several site types, cross sections, crash types, or severities. In these cases, the subscript retains the generic letter w, x, y, or z, as appropriate. The discussion of these CMFs in Section 19.7.1 or 19.7.2 identifies the specific site types, cross sections, crash types, or severities to which they apply.

As indicated in Table 19-22, some of the CMFs apply to both ramp segments and C-D road segments. For some of the CMFs, supplemental calculations must be performed before the CMF value can be computed. For example, to apply the right side barrier CMF, the proportion of the segment length having barrier on the right side and the length-weighted average barrier offset (as measured from the edge of the outside shoulder) must be computed. Procedures for supplemental calculations are described in Section 19.7.3.

Table 19-23. Crossroad Ramp Terminal Crash Modification Factors and their Corresponding SPFs

Applicable SPF(s)	CMF Variable	CMF Description	CMF Equations
Signal-controlled or one-way stop-controlled ramp terminals	$CMF_{10,\,w,\,x,\,at,\,fi}$	Exit ramp capacity	Equation 19-42
	$CMF_{11,\,w,\,x,\,at,\,z}$	Crossroad left-turn lane	Equation 19-45
	$CMF_{12,\,w,\,x,\,at,\,z}$	Crossroad right-turn lane	Equation 19-48
	$CMF_{13,\,w,\,x,\,at,\,z}$	Access point frequency	Equation 19-49
	$CMF_{14,\,w,\,x,\,at,\,z}$	Segment length	Equation 19-50
	$CMF_{15,\,w,\,x,\,at,\,z}$	Median width	Equation 19-51
Signal-controlled crossroad ramp terminals	$CMF_{16,\,w,\,SGn,\,at,\,z}$	Protected left-turn operation	Equation 19-53
	$CMF_{17,\,w,\,SGn,\,at,\,z}$	Channelized right turn on crossroad	Equation 19-55
	$CMF_{18,\,w,\,SGn,\,at,\,z}$	Channelized right turn on exit ramp	Equation 19-56
	$CMF_{19,\,w,\,SGn,\,at,\,z}$	Non-ramp public street leg	Equation 19-57
One-way stop-controlled ramp terminals	$CMF_{20,\,w,\,ST,\,at,\,fi}$	Skew angle	Equation 19-58

Note: Subscripts to the CMF variables use the following notation:

- Site type *w* ($w = D3ex, D3en, D4, A4, B4, A2, B2$),
- Cross section *x* ($x = ST$: one-way stop control; *SGn*: signal control with *n*-lane crossroad; *ac*: any cross section),
- Crash type *y* ($y = sv$: single vehicle, *mv*: multiple vehicle, *at*: all types), and
- Severity *z* ($z = fi$: fatal and injury, *pdo*: property damage only, *as*: all severities).

19.7.1. Crash Modification Factors for Ramp Segments

The CMFs for geometric design and traffic control features of freeway segments are presented in this section.

$CMF_{1,\,w,\,x,\,y,\,z}$—Horizontal Curve

Four CMFs are used to describe the relationship between horizontal curve geometry and predicted crash frequency. The six fatal-and-injury SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane entrance ramp (*rps*, *nEN*, *mv*, *fi*);
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane entrance ramp (*rps*, *nEN*, *sv*, *fi*);
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane exit ramp (*rps*, *nEX*, *mv*, *fi*);

- SPF for fatal-and-injury single-vehicle crashes, *n*-lane exit ramp (*rps*, *nEX*, *sv*, *fi*);
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *mv*, *fi*); and
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *sv*, *fi*).

The six property-damage-only SPFs to which these CMFs apply are not shown in the previous list. However, the only difference is that the *fi* subscript (shown in parentheses in the previous list) is replaced by *pdo*.

The base condition is an uncurved (i.e., tangent) segment. The CMFs are described using the following equation:

$$CMF_{1,w,x,y,z} = 1.0 + a \times \left[\frac{1{,}000}{32.2}\sum_{i=1}^{m}\left(\frac{v_{ent,i}}{R_i}\right)^2 P_{c,i}\right] \qquad (19\text{-}33)$$

Where:

$CMF_{1,w,x,y,z}$ = crash modification factor for horizontal curvature on a site of type *w*, cross section *x*, crash type *y*, and severity *z*;

m = number of horizontal curves in the segment;

$v_{ent,i}$ = average entry speed for curve *i* (ft/s);

R_i = radius of curve *i* (ft); and

$P_{c,i}$ = proportion of segment length with curve *i*.

The coefficient for Equation 19-33 is provided in Table 19-24. Equation 19-33 is derived to recognize that more than one curve may exist in a segment and that a curve may be located only partially in the segment (and partially on an adjacent segment). The variable $P_{c,i}$ is computed as the ratio of the length of curve *i* in the segment to the length of the segment (i.e., L_r or L_{cd}). For example, consider a segment that is 0.5 mi long and a curve that is 0.2 mi long. If one-half of the curve is in the segment, then $P_{c,i} = 0.20\,(= 0.1/0.5)$. In fact, this proportion is the same regardless of the curve's length (provided that it is 0.1 mi or longer and 0.1 mi of this curve is located in the segment).

Table 19-24. Coefficients for Horizontal Curve CMF–Ramp and C-D Road Segments

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$CMF_{1,w,ac,mv,fi}$	0.779
		Property damage only (*pdo*)	$CMF_{1,w,ac,mv,pdo}$	0.545
	Single vehicle (*sv*)	Fatal and injury (*fi*)	$CMF_{1,w,ac,sv,fi}$	2.406
		Property damage only (*pdo*)	$CMF_{1,w,ac,sv,pdo}$	3.136

Details regarding the measurement of radius and curve length are provided in Section 19.4. A procedure for estimating the average curve entry speed is provided in Section 19.7.3. The CMF is applicable to curves with a radius of 100 ft or larger.

$CMF_{2,w,x,y,fi}$—Lane Width

Two CMFs are used to describe the relationship between average lane width and predicted crash frequency. The six SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane entrance ramp (*rps*, *nEN*, *mv*, *fi*);
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane entrance ramp (*rps*, *nEN*, *sv*, *fi*);
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane exit ramp (*rps*, *nEX*, *mv*, *fi*);
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane exit ramp (*rps*, *nEX*, *sv*, *fi*);
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *mv*, *fi*); and
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *sv*, *fi*).

The base condition is a 14-ft lane width. The CMFs are described using the following equation:

$$CMF_{2,w,x,y,fi} = \exp\left(a \times [W_l - 14]\right) \qquad (19\text{-}34)$$

Where:

$CMF_{2,w,x,y,fi}$ = crash modification factor for lane width on a site of type *w*, cross section *x*, crash type *y*, and fatal-and-injury crashes *fi*; and

W_l = lane width (ft).

The coefficient for Equation 19-34 is provided in Table 19-25. In fact, the coefficient value is the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs. The CMF is applicable to lane widths in the range of 10 to 20 ft.

Table 19-25. Coefficients for Lane Width CMF–Ramp and C-D Road Segments

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$CMF_{2,w,ac,mv,fi}$	–0.0458
	Single vehicle (*sv*)	Fatal and injury (*fi*)	$CMF_{2,w,ac,sv,fi}$	–0.0458

$CMF_{3,w,x,y,z}$—Right Shoulder Width

Four CMFs are used to describe the relationship between average right shoulder width and predicted crash frequency. The six fatal-and-injury SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane entrance ramp (*rps*, *nEN*, *mv*, *fi*);
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane entrance ramp (*rps*, *nEN*, *sv*, *fi*);
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane exit ramp (*rps*, *nEX*, *mv*, *fi*);
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane exit ramp (*rps*, *nEX*, *sv*, *fi*);
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *mv*, *fi*); and
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *sv*, *fi*).

The six property-damage-only SPFs to which these CMFs apply are not shown in the previous list. However, the only difference is that the *fi* subscript (shown in parentheses in the previous list) is replaced by *pdo*.

The base condition is an 8-ft shoulder width. The CMFs are described using the following equation:

$$CMF_{3,w,x,y,z} = \exp\left(a \times [W_{rs} - 8]\right) \qquad (19\text{-}35)$$

Where:

$CMF_{3,\,w,\,x,\,y,\,z}$ = crash modification factor for the right shoulder width on a site of type *w*, cross section *x*, crash type *y*, and severity *z*; and

W_{rs} = paved right shoulder width (ft).

The coefficient for Equation 19-35 is provided in Table 19-26. For a given severity, the coefficient values are the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs. The CMF is applicable to shoulder widths in the range of 2 to 12 ft.

Table 19-26. Coefficients for Right Shoulder Width CMF–Ramp and C-D Road Segments

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$CMF_{3,\,w,\,ac,\,mv,\,fi}$	–0.0539
		Property damage only (*pdo*)	$CMF_{3,\,w,\,ac,\,mv,\,pdo}$	–0.0259
	Single vehicle (*sv*)	Fatal and injury (*fi*)	$CMF_{3,\,w,\,ac,\,sv,\,fi}$	–0.0539
		Property damage only (*pdo*)	$CMF_{3,\,w,\,ac,\,sv,\,pdo}$	–0.0259

$CMF_{4,\,w,\,x,\,y,\,z}$—Left Shoulder Width

Four CMFs are used to describe the relationship between average left shoulder width and predicted crash frequency. The six fatal-and-injury SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane entrance ramp (*rps*, *nEN*, *mv*, *fi*);
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane entrance ramp (*rps*, *nEN*, *sv*, *fi*);
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane exit ramp (*rps*, *nEX*, *mv*, *fi*);
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane exit ramp (*rps*, *nEX*, *sv*, *fi*);
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *mv*, *fi*); and
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *sv*, *fi*).

The six property-damage-only SPFs to which these CMFs apply are not shown in the previous list. However, the only difference is that the *fi* subscript (shown in parentheses in the previous list) is replaced by *pdo*.

The base condition is a 4-ft shoulder width. The CMFs are described using the following equation:

$$CMF_{4,w,x,y,z} = \exp\left(a' \; [W_{ls} - 4]\right) \quad (19\text{-}36)$$

Where:

$CMF_{4,\,w,\,x,\,y,\,z}$ = crash modification factor for the left shoulder width on a site of type *w*, cross section *x*, crash type *y*, and severity *z*; and

W_{ls} = paved left shoulder width (ft).

The coefficient for Equation 19-36 is provided in Table 19-27. For a given severity, the coefficient values are the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs. The CMF is applicable to shoulder widths in the range of 2 to 10 ft.

Table 19-27. Coefficients for Left Shoulder Width CMF–Ramp and C-D Road Segments

Cross Section (x)	Crash Type (y)	Crash Severity (z)	CMF Variable	CMF Coefficient (a)
Any cross section (*ac*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$CMF_{4,\ w,\ ac,\ mv,\ fi}$	–0.0539
		Property damage only (*pdo*)	$CMF_{4,\ w,\ ac,\ mv,\ pdo}$	–0.0259
	Single vehicle (*sv*)	Fatal and injury (*fi*)	$CMF_{4,\ w,\ ac,\ sv,\ fi}$	–0.0539
		Property damage only (*pdo*)	$CMF_{4,\ w,\ ac,\ sv,\ pdo}$	–0.0259

$CMF_{5,\ w,\ x,\ y,\ z}$—Right Side Barrier

Four CMFs are used to describe the relationship between right side barrier presence and predicted crash frequency. The six fatal-and-injury SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane entrance ramp (*rps*, *nEN*, *mv*, *fi*);
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane entrance ramp (*rps*, *nEN*, *sv*, *fi*);
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane exit ramp (*rps*, *nEX*, *mv*, *fi*);
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane exit ramp (*rps*, *nEX*, *sv*, *fi*);
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *mv*, *fi*); and
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *sv*, *fi*).

The six property-damage-only SPFs to which these CMFs apply are not shown in the previous list. However, the only difference is that the *fi* subscript (shown in parentheses in the previous list) is replaced by *pdo*.

The base condition is no barrier present on the right side of the ramp. The CMFs are described using the following equation:

$$CMF_{5,\ w,x,y,z} = (1.0 - P_{rb}) \times 1.0 + P_{rb} \times \exp\left(\frac{a}{W_{rcb}}\right) \tag{19-37}$$

Where:

$CMF_{5,\ w,\ x,\ y,\ z}$ = crash modification factor for right side barrier on a site of type *w*, cross section *x*, crash type *y*, and severity *z*;

P_{rb} = proportion of segment length with a barrier present on the right side; and

W_{rcb} = distance from edge of right shoulder to barrier face (ft).

The coefficient for Equation 19-37 is provided in Table 19-28. For a given severity, the coefficient values are the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs. Guidance for computing the variables P_{rb} and W_{rcb} is provided in Section 19.7.3. The CMF is applicable to W_{rcb} values in the range of 0.75 to 25 ft. This CMF is applicable to cable barrier, concrete barrier, guardrail, and bridge rail.

Table 19-28. Coefficients for Right Side Barrier CMF–Ramp and C-D Road Segments

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$CMF_{5,\,w,\,ac,\,mv,\,fi}$	0.210
		Property damage only (*pdo*)	$CMF_{5,\,w,\,ac,\,mv,\,pdo}$	0.193
	Single vehicle (*sv*)	Fatal and injury (*fi*)	$CMF_{5,\,w,\,ac,\,sv,\,fi}$	0.210
		Property damage only (*pdo*)	$CMF_{5,\,w,\,ac,\,sv,\,pdo}$	0.193

$CMF_{6,\,w,\,x,\,y,\,z}$—Left Side Barrier

Four CMFs are used to describe the relationship between left side barrier presence and predicted crash frequency. The six fatal-and-injury SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane entrance ramp (*rps*, *nEN*, *mv*, *fi*);
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane entrance ramp (*rps*, *nEN*, *sv*, *fi*);
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane exit ramp (*rps*, *nEX*, *mv*, *fi*);
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane exit ramp (*rps*, *nEX*, *sv*, *fi*);
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *mv*, *fi*); and
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *sv*, *fi*).

The six property-damage-only SPFs to which these CMFs apply are not shown in the previous list. However, the only difference is that the *fi* subscript (shown in parentheses in the previous list) is replaced by *pdo*.

The base condition is no barrier present on the left side of the ramp. The CMFs are described using the following equation:

$$CMF_{6,\,w,\,x,\,y,\,z} = (1.0 - P_{lb}) \times 1.0 + P_{lb} \times \exp\left(\frac{a}{W_{lcb}}\right) \tag{19-38}$$

Where:

$CMF_{6,\,w,\,x,\,y,\,z}$ = crash modification factor for left side barrier on a site of type *w*, cross section *x*, crash type *y*, and severity *z*;

P_{lb} = proportion of segment length with a barrier present on the left side; and

W_{lcb} = distance from edge of left shoulder to barrier face (ft).

The coefficient for Equation 19-38 is provided in Table 19-29. For a given severity, the coefficient values are the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs. Guidance for computing the variables P_{lb} and W_{lcb} is provided in Section 19.7.3. The CMF is applicable to W_{lcb} values in the range of 0.75 to 24 ft. This CMF is applicable to cable barrier, concrete barrier, guardrail, and bridge rail.

Table 19-29. Coefficients for Left Side Barrier CMF–Ramp and C-D Road Segments

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$CMF_{6,\,w,\,ac,\,mv,\,fi}$	0.210
		Property damage only (*pdo*)	$CMF_{6,\,w,\,ac,\,mv,\,pdo}$	0.193
	Single vehicle (*sv*)	Fatal and injury (*fi*)	$CMF_{6,\,w,\,ac,\,sv,\,fi}$	0.210
		Property damage only (*pdo*)	$CMF_{6,\,w,\,ac,\,sv,\,pdo}$	0.193

$CMF_{7,\,w,\,x,\,y,\,fi}$—Lane Add or Drop

Two CMFs are used to describe the relationship between a change in lanes and predicted crash frequency. The six SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane entrance ramp (*rps*, *nEN*, *mv*, *fi*);
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane entrance ramp (*rps*, *nEN*, *sv*, *fi*);
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane exit ramp (*rps*, *nEX*, *mv*, *fi*);
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane exit ramp (*rps*, *nEX*, *sv*, *fi*);
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *mv*, *fi*); and
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *sv*, *fi*).

The base condition is no lane change (i.e., no lanes added or dropped). The CMFs are described using the following equation:

$$CMF_{7,\,w,x,y,\,fi} = (1.0 - P_{tpr}) \times 1.0 + P_{tpr} \times \exp(a \times [I_{add} - I_{drop}]) \tag{19-39}$$

Where:

$CMF_{7,\,w,\,x,\,y,\,fi}$ = crash modification factor for lane add or drop on a site of type *w*, cross section *x*, crash type *y*, and fatal-and-injury crashes *fi*;

P_{tpr} = proportion of segment length adjacent to the taper associated with a lane add or drop;

I_{add} = lane add indicator variable (= 1.0 if one or more lanes are added, 0.0 otherwise); and

I_{drop} = lane drop indicator variable (= 1.0 if one or more lanes are dropped, 0.0 otherwise).

The coefficient for Equation 19-39 is provided in Table 19-30. In fact, the coefficient value is the same for both crash types listed in the table, which indicates that the CMF value is the same for the corresponding SPFs. The variable P_{tpr} is computed as the ratio of the length of the lane add (or drop) taper in the segment to the length of the segment. If the segment is wholly located in the taper, then this variable is equal to 1.0.

Table 19-30. Coefficients for Lane Add or Drop CMF–Ramp and C-D Road Segments

Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Any cross section (*ac*)	Multiple vehicle (*mv*)	Fatal and injury (*fi*)	$CMF_{7,w,ac,mv,fi}$	–0.231
	Single vehicle (*sv*)	Fatal and injury (*fi*)	$CMF_{7,w,ac,sv,fi}$	–0.231

This CMF is not used with the weaving section CMF. If a C-D road segment is being evaluated, either the lane add or drop CMF is used for the subject segment or the weaving section CMF is used.

If a lane add occurs as a result of a ramp-to-ramp merge, then a taper does not exist and this CMF is not used. Similarly, if a lane drop occurs as a result of a ramp-to-ramp diverge, then a taper does not exist and this CMF is not used.

$CMF_{8,w,x,mv,fi}$—Ramp Speed-Change Lane

One CMF is used to describe the relationship between ramp speed-change lane presence and predicted crash frequency. The three SPFs to which it applies are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane entrance ramp (*rps*, *nEN*, *mv*, *fi*);
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane exit ramp (*rps*, *nEX*, *mv*, *fi*); and
- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *mv*, *fi*).

The base condition is no ramp speed-change lane present. The CMF is described using the following equation:

$$CMF_{8,w,x,mv,fi} = (1.0 - P_{en-ex}) \times 1.0 + P_{en-ex} \times \exp(0.310) \quad (19\text{-}40)$$

Where:

$CMF_{8,w,x,mv,fi}$ = crash modification factor for speed-change lane presence on a site of type *w*, cross section *x*, and with multiple-vehicle *mv* fatal-and-injury crashes *fi*; and

P_{en-ex} = proportion of segment length that is adjacent to the speed-change lane for a connecting ramp.

This CMF is used to evaluate a ramp or C-D road segment that is being joined by another ramp by way of a speed-change lane. The speed-change lane can be either an acceleration lane or a deceleration lane. This CMF is not used with the weaving section CMF because the ramps in the weaving section are joined by an auxiliary lane (i.e., they do not have a speed-change lane).

The variable P_{en-ex} in Equation 19-40 is computed as the ratio of the length of the ramp speed-change lane in the segment to the length of the segment. If the segment is wholly located in the speed-change lane, then this variable is equal to 1.0.

$CMF_{9,cds,ac,y,z}$—Weaving Section

Two CMFs are used to describe the relationship between weaving section presence and predicted crash frequency. The four SPFs to which they apply are identified in the following list:

- SPF for fatal-and-injury multiple-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *mv*, *fi*);
- SPF for property-damage-only multiple-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *mv*, *pdo*);
- SPF for fatal-and-injury single-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *sv*, *fi*); and
- SPF for property-damage-only single-vehicle crashes, *n*-lane C-D road (*cds*, *n*, *sv*, *pdo*).

The base condition is no weaving section on the C-D road segment. The CMFs are described using the following equation.

$$CMF_{9,cds,ac,y,z} = (1.0 - P_{wev}) \times 1.0 + P_{wev} \times \exp\left(\frac{a + b \times \ln[c \times AADT_c]}{L_{wev}}\right) \quad (19\text{-}41)$$

Where:

$CMF_{9,\,cds,\,ac,\,y,\,z}$ = crash modification factor for weaving section presence on a C-D road segment with any cross section *ac*, crash type *y*, and severity *z*;

$AADT_c$ = AADT volume of C-D road segment (veh/day);

P_{wev} = proportion of segment length within a weaving section; and

L_{wev} = weaving section length (may extend beyond segment boundaries) (mi).

The coefficients for Equation 19-41 are provided in Table 19-31. The variable P_{wev} in Equation 19-41 is computed as the ratio of the length of the weaving section in the segment to the length of the segment. If the segment is wholly located in the weaving section, then this variable is equal to 1.0.

Table 19-31. Coefficients for Weaving Section CMF—C-D Road Segments

				CMF Coefficients		
Cross Section (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	*a*	*b*	*c*
Any cross section (*ac*)	All types (*mv*)	Fatal and injury (*fi*)	$CMF_{9,\,cds,\,ac,\,mv,\,fi}$	0.191	–0.0715	0.001
		Property damage only (*pdo*)	$CMF_{9,\,cds,ac,\,mv,\,pdo}$	0.187	–0.0580	0.001
	All types (*sv*)	Fatal and injury (*fi*)	$CMF_{9,\,cds,\,ac,\,sv,\,fi}$	0.191	–0.0715	0.001
		Property damage only (*pdo*)	$CMF_{9,\,cds,ac,\,sv,\,pdo}$	0.187	–0.0580	0.001

This CMF is used to evaluate C-D road segments that have some or all of their length in a weaving section. This CMF is not used with the ramp speed-change lane CMF or the lane add or drop CMF.

The variable for weaving section length L_{wev} in Equation 19-41 is intended to reflect the degree to which the weaving activity is concentrated along the C-D road. The CMF is applicable to weaving section lengths in the range from 0.05 to 0.30 mi.

19.7.2. Crash Modification Factors for Ramp Terminals

The CMFs for geometric design and traffic control features of crossroad ramp terminals are presented in this section. There are no CMFs for use with the single-point ~~diamond~~ and tight diamond interchange crossroad ramp terminal SPFs.

$CMF_{10,\,w,\,x,\,at,\,fi}$—Exit Ramp Capacity

Excessively long queues on exit ramps are recognized as sometimes creating unsafe operating conditions. Crash risk tends to increase as the length of ramp available for deceleration to the back of queue is reduced due to long queues at the downstream ramp terminal. The exit ramp capacity CMF is derived to capture this influence.

Two CMFs are used to describe the relationship between exit ramp capacity and predicted crash frequency. The two SPFs applicable to three-leg terminals with a diagonal exit ramp (*D3ex*) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, stop control, *n* lanes (*D3ex*, *ST*, *at*, *fi*); and
- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *fi*).

There are two more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the *D3ex* subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (*D3en*, *D4*, *A4*, *B4*, *A2*, *B2*).

The CMFs are described using the following equation:

$$CMF_{10,w,x,at,fi} = (1.0 - P_{ex}) \times 1.0 + P_{ex} \times \exp\left(a \times \frac{c \times AADT_{ex}}{n_{ex,eff}}\right) \quad (19\text{-}42)$$

with

$$n_{ex,eff} = \begin{cases} 0.5 \times (n_{ex} - 1.0) + 1.0 & : \text{merge or free-flow right turn} \\ 0.5 \times n_{ex} & : \text{signal, stop, or yield-controlled right turn} \end{cases} \quad (19\text{-}43)$$

$$P_{ex} = \frac{AADT_{ex}}{AADT_{in} + AADT_{out} + AADT_{en} + AADT_{ex}} \quad (19\text{-}44)$$

Where:

$CMF_{10,w,x,at,fi}$ = crash modification factor for exit ramp capacity at a site of type *w*, control type *x*, and all types *at* of fatal-and-injury crashes;

P_{ex} = proportion of total leg AADT on exit ramp leg;

$AADT_{ex}$ = AADT volume for the exit ramp (veh/day);

$n_{ex,eff}$ = effective number of lanes serving exit ramp traffic (lanes);

n_{ex} = number of lanes serving exit ramp traffic (lanes).

$AADT_{in}$ = AADT volume for the crossroad leg between ramps (veh/day);

$AADT_{out}$ = AADT volume for the crossroad leg outside of interchange (veh/day); and

$AADT_{en}$ = AADT volume for the entrance ramp (veh/day).

The coefficients for Equation 19-42 are provided in Table 19-32. When computing P_{ex}, the AADT volume of the loop exit ramp at a *B4* terminal configuration is not included in $AADT_{ex}$. Similarly, the AADT volume of the loop entrance ramp at an *A4* configuration is not included in $AADT_{en}$.

Table 19-32. Coefficients for Exit Ramp Capacity CMF—Crossroad Ramp Terminals

				CMF Coefficients	
Control Type (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	*a*	*c*
One-way stop control (*ST*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{10,\,w,\,ST,\,at,\,fi}$	0.151	0.001
Signal control, *n* lanes (*SGn*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{10,\,w,\,SGn,\,at,\,fi}$	0.0668	0.001

The effective number of lanes is based on the number of lanes on the exit ramp at the terminal, and the type of control used for the exit ramp right-turn movement. The constant "0.5" in Equation 19-43 approximately represents the ratio of capacity for a signal-, stop-, or yield-controlled lane to the capacity of a free-flow lane.

Figure 19-23 illustrates the use of Equation 19-43 to calculate the effective number of lanes for various exit ramp configurations. This figure also indicates that all lanes counted need to be fully developed for 100 ft or more upstream from the point at which their respective movement intersects with the crossroad (as discussed in Section 19.4.2).

Figure 19-23 shows eight exit ramps in plan view. The four ramps on the left side of the figure have two lanes serving exit ramp traffic. The four ramps on the right side of the figure have one lane serving exit ramp traffic (because the lane development is less than 100 ft). The two ramps at the bottom of the figure have merge or free-flow operation for the ramp right-turn movement. The other ramps have signal, stop, or yield control for the right-turn movement. The computed number of effective lanes is typically less than the actual lanes (i.e., $n_{ex,\,eff} \leq n_{ex}$) due to the control used for the ramp movement.

This CMF is applicable to stop-controlled terminals with one or two lanes serving exit ramp traffic. It is applicable to signal-controlled terminals with one, two, three, or four lanes serving exit ramp traffic.

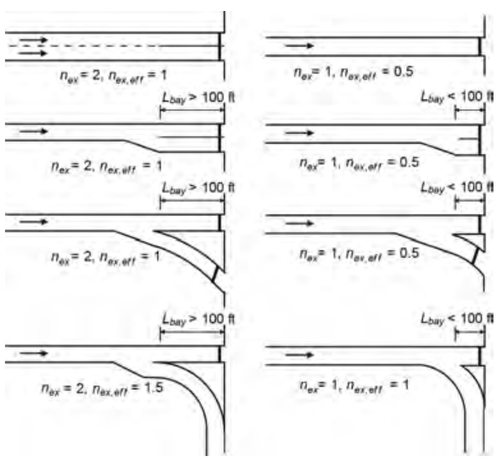


Figure 19-23. Effective Number of Lanes for Various Exit Ramp Configurations

$CMF_{11,\,w,\,x,\,at,\,z}$—Crossroad Left-Turn Lane

Eight CMFs are used to describe the relationship between left-turn lane (or bay) presence and predicted crash frequency. The four SPFs applicable to three-leg terminals with a diagonal exit ramp (*D3ex*) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, stop control, *n* lanes (*D3ex*, *ST*, *at*, *fi*);
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, stop control, *n* lanes (*D3ex*, *ST*, *at*, *pdo*);
- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *fi*); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *pdo*).

There are four more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the *D3ex* subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (*D3en*, *D4*, *A4*, *B4*, *A2*, *B2*).

The base condition is no left-turn lane (or bay) present. The CMFs are described using the following equation:

$$CMF_{11,\,w,x,at,z} = \left[(1.0 - P_{in}) \times 1.0 + P_{in} \times a^{I_{bay,lt,in}}\right] \times \left[(1.0 - P_{out}) \times 1.0 + P_{out} \times a^{I_{bay,lt,out}}\right] \quad (19\text{-}45)$$

with

$$P_{in} = \frac{AADT_{in}}{AADT_{in} + AADT_{out} + AADT_{en} + AADT_{ex}} \quad (19\text{-}46)$$

$$P_{out} = \frac{AADT_{out}}{AADT_{in} + AADT_{out} + AADT_{en} + AADT_{ex}} \quad (19\text{-}47)$$

Where:

$CMF_{11,\,w,\,x,\,at,\,z}$ = crash modification factor for left-turn lane (or bay) presence at a site of type *w*, control type *x*, all crash types *at*, and severity *z*;

P_{in} = proportion of total leg AADT on crossroad leg between ramps;

$I_{bay,\,lt,\,k}$ = left-turn lane (or bay) indicator variable for crossroad leg *k* (*k* = in or out) (= 1.0 if left-turn lane [or bay] is present, 0.0 otherwise); and

P_{out} = proportion of total leg AADT on crossroad leg outside of interchange.

The coefficient for Equation 19-45 is provided in Table 19-33. When computing P_{in} and P_{out}, the AADT volume of the loop exit ramp at a B4 terminal configuration is not included in $AADT_{ex}$. Similarly, the AADT volume of the loop entrance ramp at an A4 configuration is not included in $AADT_{en}$.

Table 19-33. Coefficients for Crossroad Left-Turn Lane CMF—Crossroad Ramp Terminals

Control Type (*x*)	Area Type	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
One-way stop control (*ST*)	Rural	All types (*at*)	Fatal and injury (*fi*)	$CMF_{11,\,w,\,ST,\,at,\,fi}$	0.36
			Property damage only (*pdo*)	$CMF_{11,\,w,\,ST,\,at,\,pdo}$	0.55
	Urban	All types (*at*)	Fatal and injury (*fi*)	$CMF_{11,\,w,\,ST,\,at,\,fi}$	0.59
			Property damage only (*pdo*)	$CMF_{11,\,w,\,ST,\,at,\,pdo}$	0.58
Signal control, *n* lanes (*SGn*)	Rural	All types (*at*)	Fatal and injury (*fi*)	$CMF_{11,\,w,\,SGn,\,at,\,fi}$	0.44
			Property damage only (*pdo*)	$CMF_{11,\,w,\,SGn,\,at,\,pdo}$	0.66
	Urban	All types (*at*)	Fatal and injury (*fi*)	$CMF_{11,\,w,\,SGn,\,at,\,fi}$	0.65
			Property damage only (*pdo*)	$CMF_{11,\,w,\,SGn,\,at,\,pdo}$	0.68

This CMF is applicable to any crossroad approach that is either signalized or uncontrolled. It is not applicable to a stop-controlled approach. The CMF value is applicable to turn bays that have a design that is consistent with agency policy such that their length adequately provides for vehicle storage or deceleration, as appropriate.

$CMF_{12,\,w,\,x,\,at,\,z}$—Crossroad Right-Turn Lane

Eight CMFs are used to describe the relationship between right-turn lane (or bay) presence and predicted crash frequency. The four SPFs applicable to three-leg terminals with a diagonal exit ramp (*D3ex*) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, stop control, *n* lanes (*D3ex*, *ST*, *at*, *fi*);
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, stop control, *n* lanes (*D3ex*, *ST*, *at*, *pdo*);
- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *fi*); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex, SGn, at, pdo*).

There are four more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the *D3ex* subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (*D3en*, *D4*, *A4*, *B4*, *A2*, *B2*).

The base condition is no right-turn lane (or bay) present. The CMFs are described using the following equation:

$$CMF_{12,\,w,\,x,\,at,\,z} = \left[(1.0 - P_{in}) \times 1.0 + P_{in} \times a^{I_{bay,rt,in}}\right] \times \left[(1.0 - P_{out}) \times 1.0 + P_{out} \times a^{I_{bay,rt,out}}\right] \qquad (19\text{-}48)$$

Where:

$CMF_{12,\,w,\,x,\,at,\,z}$ = crash modification factor for right-turn lane (or bay) presence at a site of type *w*, control type *x*, all crash types *at*, and severity *z*; and

$I_{bay,\,rt,\,k}$ = right-turn lane (or bay) indicator variable for crossroad leg *k* (*k* = in or out) (= 1.0 if right-turn lane [or bay] is present, 0.0 otherwise).

The coefficient for Equation 19-48 is provided in Table 19-34. The variable P_{in} is computed using Equation 19-46. The variable P_{out} is computed using Equation 19-47.

This CMF is applicable to any crossroad approach that is either signalized or uncontrolled. It is not applicable to a stop-controlled approach. The CMF value is applicable to turn bays that have a design that is consistent with agency policy such that their length adequately provides for vehicle storage or deceleration, as appropriate.

Table 19-34. Coefficients for Crossroad Right-Turn Lane CMF—Crossroad Ramp Terminals

Control Type (*x*)	Area Type	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
One-way stop control (*ST*)	Rural	All types (*at*)	Fatal and injury (*fi*)	$CMF_{12,\,w,\,ST,\,at,\,fi}$	0.76
			Property damage only (*pdo*)	$CMF_{12,\,w,\,ST,\,at,\,pdo}$	0.63
	Urban	All types (*at*)	Fatal and injury (*fi*)	$CMF_{12,\,w,\,ST,\,at,\,fi}$	0.87
			Property damage only (*pdo*)	$CMF_{12,\,w,\,ST,\,at,\,pdo}$	0.69
Signal control, *n* lanes (*SGn*)	Rural	All types (*at*)	Fatal and injury (*fi*)	$CMF_{12,\,w,\,SGn,\,at,\,fi}$	0.59
			Property damage only (*pdo*)	$CMF_{12,\,w,\,SGn,\,at,\,pdo}$	0.97
	Urban	All types (*at*)	Fatal and injury (*fi*)	$CMF_{12,\,w,\,SGn,\,at,\,fi}$	0.76
			Property damage only (*pdo*)	$CMF_{12,\,w,\,SGn,\,at,\,pdo}$	0.94

$CMF_{13,\,w,\,x,\,at,\,z}$—Access Point Frequency

Three CMFs are used to describe the relationship between unsignalized access point presence and predicted crash frequency. The three SPFs applicable to three-leg terminals with a diagonal exit ramp (*D3ex*) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, stop control, *n* lanes (*D3ex*, *ST*, *at*, *fi*);
- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *fi*); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *pdo*).

There are three more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the *D3ex* subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (*D3en*, *D4*, *A4*, *B4*, *A2*, *B2*).

The base condition is no unsignalized driveways and no unsignalized public street approaches present on the outside leg of the crossroad ramp terminal. The CMFs are described using the following equation:

$$CMF_{13,\,w,x,at,z} = (1.0 - P_{out}) \times 1.0 + P_{out} \times \exp(a \times n_{dw} + b \times n_{ps}) \qquad (19\text{-}49)$$

Where:

$CMF_{13,\,w,\,x,\,at,\,z}$ = crash modification factor for access point frequency at a site of type *w*, control type *x*, all crash types *at*, and severity *z*;

n_{dw} = number of unsignalized driveways on the crossroad leg outside of the interchange and within 250 ft of the ramp terminal; and

n_{ps} = number of unsignalized public street approaches to the crossroad leg outside of the interchange and within 250 ft of the ramp terminal.

The coefficients for Equation 19-49 are provided in Table 19-35. The variable P_{out} is computed using Equation 19-47. This CMF applies to any ramp terminal with unsignalized driveways or unsignalized public street approaches on the crossroad leg that is outside of the interchange.

Table 19-35. Coefficients for Access Point Frequency CMF—Crossroad Ramp Terminals

Control Type (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficients *a*	CMF Coefficients *b*
One-way stop control (*ST*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{13,\,w,\,ST,\,at,\,fi}$	0.00	0.522
Signal control, *n* lanes (*SGn*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{13,\,w,\,SGn,\,at,\,fi}$	0.158	0.158
		Property damage only (*pdo*)	$CMF_{13,\,w,\,SGn,\,at,\,pdo}$	0.203	0.203

This CMF is applicable when there are four or fewer driveways and two or fewer unsignalized public street approaches on the crossroad leg outside of the interchange.

$CMF_{14,\,w,\,x,\,at,\,z}$—Segment Length

The distance between the subject ramp terminal and adjacent intersections (or terminals) along the crossroad is logically correlated with crossroad operating speed. This speed is likely to increase as distance increases, and an increase in speed may increase the risk of a crash.

Three CMFs are used to describe the relationship between intersection spacing and predicted crash frequency. The three SPFs applicable to three-leg terminals with a diagonal exit ramp (*D3ex*) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, stop control, *n* lanes (*D3ex*, *ST*, *at*, *fi*);
- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *fi*); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *pdo*).

There are three more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the *D3ex* subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (*D3en*, *D4*, *A4*, *B4*, *A2*, *B2*).

The base condition is no adjacent ramp or public street intersection within 6 mi. The CMFs are described using the following equation:

$$CMF_{14,\,w,\,x,\,at,\,z} = \exp\left(a \times \left[\frac{1.0}{L_{rmp}} + \frac{1.0}{L_{str}} - 0.333\right]\right) \quad (19\text{-}50)$$

Where:

$CMF_{14,\,w,\,x,\,at,\,z}$ = crash modification factor for segment length at a site of type *w*, control type *x*, all crash types *at*, and severity *z*;

L_{rmp} = distance between subject ramp terminal and adjacent ramp terminal (measured along the crossroad from terminal center to terminal center) (mi); and

L_{str} = distance between subject ramp terminal and nearest public road intersection in a direction away from the freeway (measured along the crossroad from terminal center to intersection center) (mi).

The coefficient for Equation 19-50 is provided in Table 19-36.

Table 19-36. Coefficients for Segment Length CMF—Crossroad Ramp Terminals

Control Type (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
One-way stop control (*ST*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{14,\,w,\,ST,\,at,\,fi}$	–0.0141
Signal control, *n* lanes (*SGn*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{14,\,w,\,SGn,\,at,\,fi}$	–0.0185
		Property damage only (*pdo*)	$CMF_{14,\,w,\,SGn,\,at,\,pdo}$	–0.0186

This CMF describes the relationship between ramp terminal crash frequency and the distance to the adjacent ramp or nearest public street intersection. The adjacent ramp or intersection can be signalized or unsignalized. The CMF is applicable to distances of 0.02 mi or more.

$CMF_{15,\,w,\,x,\,at,\,z}$—Median Width

Research indicates that median width at an intersection can influence crash frequency, provided that this width is 14 ft or more (2). At rural unsignalized intersections, an increase in median width is associated with a decrease in crash frequency. In contrast, at urban intersections (unsignalized and signalized), an increase in median width is associated with an increase in crash frequency. This latter trend is contrary to segment-based safety research that shows crash frequency decreases with an increase in median width. Conflict studies have confirmed a tendency for improper use of wide median areas within intersections that, when complicated by high traffic volume, results in an increased propensity for multiple-vehicle crashes (2).

Three CMFs are used to describe the relationship between crossroad median width and predicted crash frequency. The three SPFs applicable to three-leg terminals with a diagonal exit ramp (*D3ex*) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, stop control, *n* lanes (*D3ex*, *ST*, *at*, *fi*);
- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *fi*); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *pdo*).

There are three more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the *D3ex* subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (*D3en*, *D4*, *A4*, *B4*, *A2*, *B2*).

The base condition is a 12-ft median width. The CMFs are described using the following equation:

$$CMF_{15,\,w,x,at,z} = \left[(1.0 - P_{in}) \times 1.0 + P_{in} \times \exp\left([a + b \times c \times AADT_{in}] \times W_{me,in}\right)\right] \times \left[(1.0 - P_{out}) \times 1.0 + P_{out} \times \exp\left([a + b \times c \times AADT_{out}] \times W_{me,out}\right)\right] \quad (19\text{-}51)$$

with

$$W_{me,k} = Max\left\{\begin{array}{l} 0.0 \\ W_m - Max\left\{\begin{array}{l} 12 \\ W_{b,k} \end{array}\right. \end{array}\right. \quad (19\text{-}52)$$

Where:

$CMF_{15,\,w,\,x,\,at,\,z}$ = crash modification factor for median width at a site of type *w*, control type *x*, all crash types *at*, and severity *z*;

$W_{me,\,k}$ = width of median adjacent to turn lane (or bay) for crossroad leg *k* (*k* = *in* or *out*) (ft);

W_m = median width (ft); and

$W_{b,\,k}$ = left-turn lane (or bay) width for crossroad leg *k* (*k* = *in* or *out*) (= 0.0 if no lane present on leg) (ft).

The coefficients for Equation 19-51 are provided in Table 19-37. The variable P_{in} is computed using Equation 19-46. The variable P_{out} is computed using Equation 19-47.

Table 19-37. Coefficients for Median Width CMF—Crossroad Ramp Terminals

				CMF Coefficients		
Control Type (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	*a*	*b*	*c*
One-way stop control (*ST*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{15,\,w,\,ST,\,at,\,fi}$	–0.0322	0.00354	0.001
Signal control, *n* lanes (*SGn*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{15,\,w,\,SGn,\,at,\,fi}$	0.0287	–0.00074	0.001
		Property damage only (*pdo*)	$CMF_{15,\,w,SGn,\,at,\,pdo}$	0.0610	–0.00246	0.001

For signalized ramp terminals, the applicable values for $AADT_{in}$ and $AADT_{out}$ range from 14,000 to 60,000 veh/day. AADT volumes smaller than 14,000 should be set to 14,000 in Equation 19-51.

For unsignalized ramp terminals, the applicable values for $AADT_{in}$ and $AADT_{out}$ range from 0 to 14,000 veh/day. AADT volumes larger than 14,000 should be set to 14,000 in Equation 19-51.

The CMF is applicable to W_m values in the range of 0 to 50 ft. Similarly, it is applicable to $W_{b,\,k}$ values in the range of 0 to 26 ft.

$CMF_{16,\,w,\,SGn,\,at,\,z}$—Protected Left-Turn Operation

Two CMFs are used to describe the relationship between protected-only left-turn operation and predicted crash frequency. The two SPFs applicable to three-leg terminals with a diagonal exit ramp (*D3ex*) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *fi*); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *pdo*).

There are two more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the *D3ex* subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (*D3en*, *D4*, *A4*, *B4*, *A2*, *B2*).

The base condition is permissive or protected-permissive left-turn operation (i.e., not protected-only operation). The CMFs are described using the following equation:

$$CMF_{16,w,SGn,at,z} = \left[(1.0 - P_{xrd}) + 1.0 + P_{xrd} \times \exp(a \times n_{o,in})\right]^{I_{p,lt,in}} \times \left[(1.0 - P_{xrd}) + 1.0 + P_{xrd} \times \exp(a \times n_{o,out})\right]^{I_{p,lt,out}} \quad (19\text{-}53)$$

with

$$P_{xrd} = \frac{AADT_{in} + AADT_{out}}{AADT_{in} + AADT_{out} + AADT_{en} + AADT_{ex}} \quad (19\text{-}54)$$

Where:

$CMF_{16,\,w,\,SGn,\,at,\,z}$ = crash modification factor for protected left-turn operation at a signal-controlled site of type *w*, with *n* crossroad lanes, all crash types *at*, and severity *z*;

P_{xrd} = proportion of total leg AADT on crossroad;

$n_{o,\,k}$ = number of through traffic lanes that oppose the left-turn movement on crossroad leg *k* (*k* = in or out) (lanes); and

$I_{p,\,lt,\,k}$ = protected left-turn operation indicator variable for crossroad leg *k* (*k* = in or out) (= 1.0 if protected operation exists, 0.0 otherwise).

The coefficient for Equation 19-53 is provided in Table 19-38. When computing P_{xrd}, the AADT volume of the loop exit ramp at a B4 terminal configuration is not included in $AADT_{ex}$. Similarly, the AADT volume of the loop entrance ramp at an A4 configuration is not included in $AADT_{en}$.

Table 19-38. Coefficients for Protected Left-Turn Operation CMF—Crossroad Ramp Terminals

Control Type (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Signal control, *n* lanes (*SGn*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{16,\,w,\,SGn,\,at,\,fi}$	–0.363
		Property damage only (*pdo*)	$CMF_{16,\,w,\,SGn,\,at,\,pdo}$	–0.223

The CMF is applicable to $n_{o,\,k}$ values in the range of 1 to 3 lanes.

$CMF_{17,\,w,\,SGn,\,at,\,z}$—Channelized Right Turn on Crossroad

Two CMFs are used to describe the relationship between crossroad right-turn channelization and predicted crash frequency. The two SPFs applicable to three-leg terminals with a diagonal exit ramp (*D3ex*) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *fi*); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *pdo*).

There are two more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the *D3ex* subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (*D3en*, *D4*, *A4*, *B4*, *A2*, *B2*).

The base condition is no crossroad right-turn channelization. The CMFs are described using the following equation:

$$CMF_{17,w,SGn,at,z} = \left[(1.0 - P_{in}) \times 1.0 + P_{in} \times \exp(a)\right]^{I_{ch,in}} \times \left[(1.0 - P_{out}) \times 1.0 + P_{out} \times \exp(a)\right]^{I_{ch,out}} \quad (19\text{-}55)$$

Where:

$CMF_{17,\,w,\,SGn,\,at,\,z}$ = crash modification factor for crossroad right-turn channelization at a signal-controlled site of type *w*, with *n* crossroad lanes, all crash types *at*, and severity *z*; and

$I_{ch,\,k}$ = right-turn channelization indicator variable for crossroad leg *k* (*k* = in or out) (= 1.0 if right-turn channelization exists, 0.0 otherwise).

The coefficient for Equation 19-55 is provided in Table 19-39. The variable P_{in} is computed using Equation 19-46. The variable P_{out} is computed using Equation 19-47.

Table 19-39. Coefficients for Channelized Right Turn on Crossroad CMF—Crossroad Ramp Terminals

Control Type (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Signal control, *n* lanes (*SGn*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{17,\,w,\,SGn,\,at,\,fi}$	0.466
		Property damage only (*pdo*)	$CMF_{17,\,w,\,SGn,\,at,\,pdo}$	0.465

This CMF is applicable to any ramp terminal with right-turn channelization on one or both crossroad legs, where the associated right-turn movement is turning from the crossroad. This CMF can be applied to channelization associated with the loop entrance ramp of the *A4* configuration.

$CMF_{18,\,w,\,SGn,\,at,\,z}$—Channelized Right Turn on Exit Ramp

Two CMFs are used to describe the relationship between exit ramp right-turn channelization and predicted crash frequency. The two SPFs applicable to three-leg terminals with a diagonal exit ramp (*D3ex*) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *fi*); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *pdo*).

There are two more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the *D3ex* subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (*D3en*, *D4*, *A4*, *B4*, *A2*, *B2*).

The base condition is no exit ramp right-turn channelization. The CMFs are described using the following equation:

$$CMF_{18,w,SGn,at,z} = \left[(1.0 - P_{ex}) \times 1.0 + P_{ex} \times \exp(a)\right]^{I_{ch,ex}} \quad (19\text{-}56)$$

Where:

$CMF_{18,w,SGn,at,z}$ = crash modification factor for exit ramp right-turn channelization at a signal-controlled site of type *w*, with *n* crossroad lanes, all crash types *at*, and severity *z*; and

$I_{ch,ex}$ = right-turn channelization indicator variable for exit ramp (= 1.0 if right-turn channelization exists, 0.0 otherwise).

The coefficient for Equation 19-56 is provided in Table 19-40. The variable P_{ex} is computed using Equation 19-44.

Table 19-40. Coefficients for Channelized Right Turn on Exit Ramp CMF—Crossroad Ramp Terminals

Control Type (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Signal control, *n* lanes (*SGn*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{18,w,SGn,at,fi}$	0.992
		Property damage only (*pdo*)	$CMF_{18,w,SGn,at,pdo}$	1.429

This CMF is applicable to any ramp terminal with an exit ramp that has left-turn and right-turn movements and right-turn channelization. This CMF is not applicable to the loop exit ramp of the *B4* configuration.

$CMF_{19,w,SGn,at,z}$—Non-Ramp Public Street Leg

Two CMFs are used to describe the relationship between public-street leg presence and predicted crash frequency. The two SPFs applicable to three-leg terminals with a diagonal exit ramp (*D3ex*) are identified in the following list:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *fi*); and
- SPF for property-damage-only crashes, three-legs with diagonal exit ramp, signal control, *n* lanes (*D3ex*, *SGn*, *at*, *pdo*).

There are two more SPFs for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the *D3ex* subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (*D3en*, *D4*, *A4*, *B4*, *A2*, *B2*).

The base condition is no public-street leg present. The CMFs are described using the following equation:

$$CMF_{19,w,SGn,at,z} = \exp(a \times I_{ps}) \quad (19\text{-}57)$$

Where:

$CMF_{19,w,SGn,at,z}$ = crash modification factor for non-ramp public street leg presence at a signal-controlled site of type *w*, with *n* crossroad lanes, all crash types *at*, and severity *z*; and

I_{ps} = non-ramp public street leg indicator variable (= 1.0 if leg is present, 0.0 otherwise).

The coefficient for Equation 19-57 is provided in Table 19-41. The variable P_{ex} is computed using Equation 19-44.

This CMF is applicable to any ramp terminal that has a fourth leg that (a) is a public street serving two-way traffic and (b) intersects with the crossroad at the terminal. This situation occurs occasionally. When it does, the public street leg is opposite from one ramp and the other ramp either does not exist or is located at some distance from the subject ramp terminal such that it is not part of the terminal.

Table 19-41. Coefficients for Non-Ramp Public Street Leg CMF—Crossroad Ramp Terminals

Control Type (*x*)	Crash Type (*y*)	Crash Severity (*z*)	CMF Variable	CMF Coefficient (*a*)
Signal control, *n* lanes (*SGn*)	All types (*at*)	Fatal and injury (*fi*)	$CMF_{19,\,w,\,SGn,\,at,\,fi}$	0.592
		Property damage only (*pdo*)	$CMF_{19,\,w,\,SGn,\,at,\,pdo}$	0.520

$CMF_{20,\,w,\,ST,\,at,\,fi}$—Skew Angle

One CMF is used to describe the relationship between the exit ramp skew angle and predicted crash frequency. The SPF applicable to three-leg terminals with a diagonal exit ramp (*D3ex*) is identified as follows:

- SPF for fatal-and-injury crashes, three-legs with diagonal exit ramp, stop control, *n* lanes (*D3ex*, *ST*, *at*, *fi*).

There is one more SPF for each of six terminal configurations (i.e., site types) to which these CMFs apply. They are not shown in the previous list. However, the only difference is that the *D3ex* subscript (shown in parentheses in the previous list) is replaced by the other configuration subscripts (*D3en*, *D4*, *A4*, *B4*, *A2*, *B2*).

The base condition is no skew in the intersecting alignments (i.e., a skew angle of 0.0 degrees). The CMFs are described using the following equation:

$$CMF_{20,w,ST,at,fi} = (1.0 - P_{ex}) \times 1.0 + P_{ex} \times \exp(0.341 \times \sin[I_{sk}] \times 0.001 \times AADT_{ex}) \quad (19\text{-}58)$$

Where:

$CMF_{20,\,w,\,ST,\,at,\,fi}$ = crash modification factor for skew angle at a stop-controlled site of type *w*, with *n* crossroad lanes, and all types *at* of fatal-and-injury crashes *fi*; and

I_{sk} = skew angle between exit ramp and crossroad (degrees).

The variable P_{ex} is computed using Equation 19-44.

This CMF is applicable to any one-way stop-controlled ramp terminal with an exit ramp that has stop or yield control for the "reference" exit ramp movement. The reference movement is the left-turn movement for all terminal configurations except the *B4* configuration. At a *B4* ramp terminal, the reference movement is the right-turn movement on the diagonal exit ramp (not the loop exit ramp). This CMF is applicable to skew angles in the range of 0 to 70 degrees.

19.7.3. Supplemental Calculations to Apply Crash Modification Factors

Some of the CMFs in Section 19.7.1 require the completion of supplemental calculations before they can be applied to the SPFs in Section 19.6. These CMFs are: horizontal curve, right side barrier, and left side barrier.

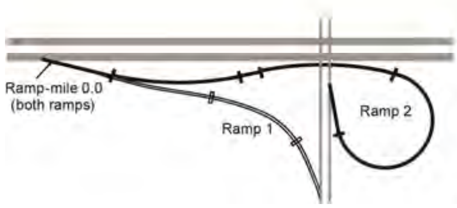
This section consists of two subsections. The first section describes the procedure for calculating the curve entry speed needed for the horizontal curve CMF. The second section describes the procedure for calculating the barrier-related variables for the right side barrier CMF and the left side barrier CMF.

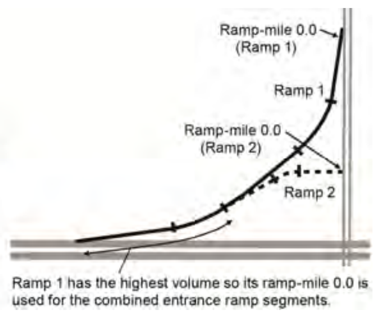
Calculation of Curve Entry Speed

This subsection describes a procedure for predicting the average curve entry speed for each curve on a ramp or C-D road. This procedure is developed for use with the horizontal curve CMF, as described in Section 19.7.1. It is not intended to be used with other applications, or to predict vehicle speed at other points along a ramp or C-D road.

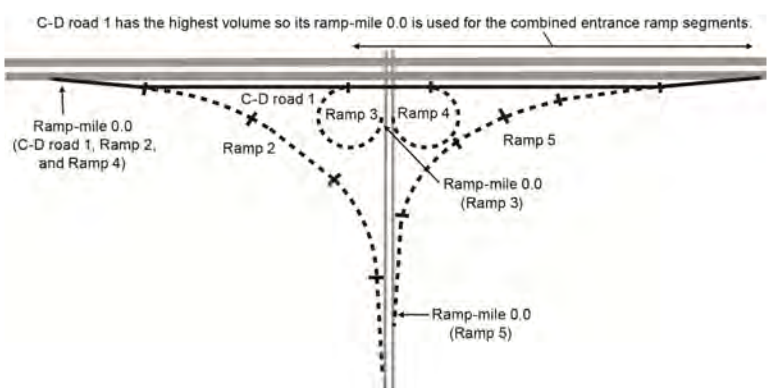
The speed prediction procedure consists of a sequence of steps that lead to a prediction of average entry speed for each horizontal curve on the subject ramp or C-D road. Each curve is addressed by the procedure in the same sequence as they are encountered when traveling along the ramp or C-D road. In this manner, the speed for all previous curves encountered must be calculated first, before the speed on the subject curve can be calculated. The steps used will vary depending on whether the segment is part of an entrance ramp, exit ramp, connector ramp, or C-D road.

The horizontal curves are located along the ramp or C-D road using a linear referencing system. For exit ramps, ramp-mile 0.0 is located at the gore point. For entrance ramps that intersect the crossroad, ramp-mile 0.0 is located at the point where the ramp reference line intersects with the near edge of traveled way of the crossroad. The location of ramp-mile 0.0 is shown in Figure 19-4 for simple situations. It is shown in Figure 19-24 for more complex ramp and C-D road combinations. When a specific entrance ramp or C-D road segment serves traffic from two or more sources combined, ramp-mile 0.0 for this segment should be that of the one ramp that is the source of the highest daily traffic volume.





a. Exit Ramp b. Entrance Ramp



c. Entrance and Exit Ramps with C-D Road

Figure 19-24. Starting Location for Ramp and C-D Road Combinations

The input data needed for this procedure are identified in Table 19-42. The first three variables listed represent required input data. Default values are provided for the remaining variables.

Table 19-42. Input Data for Ramp Curve Speed Prediction

Variable	Description	Default Value	Applicable Site Type
X_i	Ramp-mile of the point of change from tangent to curve (PC) for curve *i* (mi) [a]	None	All
R_i	Radius of curve *i* (ft) [b]	None	All
$L_{c,i}$	Length of horizontal curve *i* (mi)	None	All
V_{frwy}	Average traffic speed on the freeway during off-peak periods of the typical day (mi/h)	Estimate as equal to the speed limit	All
V_{xroad}	Average speed at the point where the ramp connects to the crossroad (mi/h)	15 – ramps with stop-, yield-, or signal-controlled crossroad ramp terminals 30 – all other ramps at service interchanges	Entrance ramp, exit ramp, connector ramp at service interchange
V_{cdroad}	Average speed on C-D road or connector ramp (measured at the mid-point of the C-D road or ramp) (mi/h)	40	C-D road, connector ramp at system interchange

[a] If the curve is preceded by a spiral transition, then X_i is computed as equal to the average of the TS and SC ramp-mile locations, where TS is the point of change from tangent to spiral and SC is the point of change from spiral to curve.
[b] If the curve has spiral transitions, then R_i is equal to the radius of the central circular portion of the curve.

The curve entry speeds need to be calculated for all curves from milepost 0.0 to the end of the analysis segment. This may include segments of an adjacent ramp that are not included in the current analysis segment. For each curve, record the entry speed, the total length of the curve, and the length of the current analysis segment. Once the procedure on the following pages is completed, return to equation 19-33 (Page 19-47). In this equation, the summation term only includes entry speeds and radii that have a length in the current analysis segment. All other curves analyzed should be ignored if they are not part of the current analysis segment.

Entrance Ramp Procedure
This procedure is applicable to entrance ramps and connector ramps at service interchanges that serve motorists traveling from the crossroad to the freeway.

Step 1—Gather Input Data.
The input data needed for this procedure are identified in Table 19-42.

Step 2—Compute Limiting Curve Speed.
The limiting curve speed is computed for each curve on the ramp using the following equation:

$$v_{\max,i} = 3.24 \times (32.2 \times R_i)^{0.30} \tag{19-59}$$

where $v_{max,\,i}$ is the limiting speed for curve *i* (ft/s).

The analysis proceeds in the direction of travel. The first curve encountered is curve 1 (*i* =1). The value of v_{max} is computed for all curves prior to, and including, the curve of interest. The value obtained from Equation 19-59 represents an upper limit on the curve speed. The vehicle may reach this speed if the distance between curves is lengthy or the crossroad speed is high.

Step 3—Calculate Curve 1 Entry Speed.
The average entry speed at curve 1 is computed using the following equation:

$$v_{ent,1} = Min\begin{cases} \left([1.47 \times V_{xroad}]^3 + 495 \times 5,280 \times X_1\right)^{1/3} \\ 1.47 \times V_{frwy} \end{cases} \qquad (19\text{-}60)$$

where $v_{ent,\,1}$ is the average entry speed for curve 1 (ft/s).

The boundary condition on the right side of the equation indicates that the value computed cannot exceed the average freeway speed.

Step 4—Calculate Curve 1 Exit Speed.
The average exit speed at curve 1 is equal to the value obtained from the following equation:

$$v_{ext,1} = Min\begin{cases} \min\begin{cases} \left(v_{ent,1}^3 + 495 \times 5,280 \times L_{c,1}\right)^{1/3} \\ v_{\max,1} \end{cases} \\ 1.47 \times V_{frwy} \end{cases} \qquad (19\text{-}61)$$

where $v_{ext,\,1}$ is the average exit speed for curve 1 (ft/s).

The boundary condition indicates that the value computed should not exceed the limiting curve speed or the average freeway speed.

Step 5—Calculate Curve *i* Entry Speed.
The average entry speed at curve 2 (and all subsequent curves) is computed using the following equation:

$$v_{ent,i} = Min\begin{cases} \left(v_{ext,i-1}^3 + 495 \times 5,280 \times [X_i - X_{i-1} - L_{c,i-1}]\right)^{1/3} \\ 1.47 \times V_{frwy} \end{cases} \qquad (19\text{-}62)$$

where, $v_{ent,\,i}$ equals the average entry speed for curve i ($i = 2, 3, \ldots$) (ft/s) and $v_{ext,\,i}$ equals the average exit speed for curve i (ft/s).

Step 6—Calculate Curve *i* Exit Speed.
The average exit speed at curve 2 (and all subsequent curves) is computed using the following equation:

$$v_{ext,i} = Min\begin{cases} \min\begin{cases} \left(v_{ent,i}^3 + 495 \times 5,280 \times L_{c,i}\right)^{1/3} \\ v_{\max,i} \end{cases} \\ 1.47 \times V_{frwy} \end{cases} \qquad (19\text{-}63)$$

Step 7—Calculate Speed on Successive Curves.
The entry and exit speeds for curve 3 and higher are computed by applying Steps 5 and 6 for each curve. Step 6 does not need to be applied for the last curve because only the entry speed is used in the safety evaluation.

Exit Ramp Procedure
This procedure is applicable to exit ramps and connector ramps at service interchanges that serve motorists traveling from the freeway to the crossroad.

Step 1—Gather Input Data.
The input data needed for this procedure are identified in Table 19-42.

Step 2—Compute Limiting Curve Speed.
This step is the same as Step 2 for the entrance ramp procedure. A lower curve speed than that obtained from Equation 19-59 is possible due to the deceleration that occurs as the driver transitions from the freeway speed to the crossroad speed.

Step 3—Calculate Curve 1 Entry Speed.
The average entry speed at curve 1 is computed using the following equation:

$$v_{ent,1} = Max\left\{\begin{array}{l} 1.47 \times V_{frwy} - 0.034 \times 5,280 \times X_1 \\ 1.47 \times V_{xroad} \end{array}\right. \quad (19\text{-}64)$$

The boundary condition on the right side of the equation indicates that the value computed cannot be less than the average speed at the point where the ramp connects to the crossroad.

Step 4—Calculate Curve 1 Exit Speed.
This step is the same as Step 4 for the entrance ramp procedure.

$$v_{ext,1} = Max\left\{\begin{array}{l} \min\left\{\begin{array}{l} v_{ent,1} - 0.034 \times 5,280 \times L_{c,1} \\ v_{\max,1} \end{array}\right. \\ 1.47 \times V_{xroad} \end{array}\right. \quad (19\text{-}65)$$

The boundary condition indicates that the value computed should not exceed the limiting curve speed and should not be less than the average speed at the point where the ramp connects to the crossroad.

Step 5—Calculate Curve *i* Entry Speed.
The average entry speed at curve 2 (and all subsequent curves) is computed using the following equation:

$$v_{ent,i} = Max\left\{\begin{array}{l} v_{ext,i-1} - 0.034 \times 5,280 \times (X_i - X_{i-1} - L_{c,i-1}) \\ 1.47 \times V_{xroad} \end{array}\right. \quad (19\text{-}66)$$

Step 6—Calculate Curve *i* Exit Speed.
The average exit speed at curve 2 (and all subsequent curves) is computed using the following equation:

$$v_{ext,i} = Max\left\{\begin{array}{l} \min\left\{\begin{array}{l} v_{ent,i} - 0.034 \times 5,280 \times L_{c,i} \\ v_{\max,i} \end{array}\right. \\ 1.47 \times V_{xroad} \end{array}\right. \quad (19\text{-}67)$$

Step 7—Calculate Speed on Successive Curves.
This step is the same as Step 7 for the entrance ramp procedure.

C-D Road Procedure
This procedure is applicable to C-D roads and connector ramps at system interchanges.

Step 1—Gather Input Data.
The input data needed for this procedure are identified in Table 19-42.

Step 2—Compute Limiting Curve Speed.
This step is the same as Step 2 for the entrance ramp procedure.

Step 3—Calculate Curve 1 Entry Speed.
The average entry speed at curve 1 is computed using Equation 19-68 or Equation 19-69, depending on the following two conditions.

If $1.47 \times V_{frwy} \le v_{max,1}$ then:

$$v_{ent,1} = 1.47 \times V_{frwy} \tag{19-68}$$

If $1.47 \times V_{frwy} > v_{max,1}$ then:

$$v_{ent,1} = Max\begin{cases} 1.47 \times V_{frwy} - 0.034 \times 5,280 \times X_1 \\ 1.47 \times V_{cdroad} \end{cases} \tag{19-69}$$

The boundary condition for Equation 19-69 indicates that the value computed cannot be less than the average speed on the C-D road.

Step 4—Calculate Curve 1 Exit Speed.
The average exit speed at curve 1 is equal to the entrance speed, provided that it does not exceed the limiting curve speed. The following rule is used to make this determination.

$$v_{ext,1} = v_{ent,1} \quad \le \; v_{\max,1} \tag{19-70}$$

Step 5—Calculate Curve *i* Entry Speed.
The average entry speed at curve 2 (and all subsequent curves) is computed using Equation 19-71 or Equation 19-72, depending on the following conditions.

If $v_{ext,\,i\text{-}1} \le v_{max,\,i}$ then:

$$v_{ent,i} = Min\begin{cases} \left(v_{ext,i-1}^3 + 495 \times 5,280 \times [X_i - X_{i-1} - L_{c,i-1}]\right)^{1/3} \\ 1.47 \times V_{frwy} \end{cases} \tag{19-71}$$

If $v_{ext,\,i\text{-}1} > v_{max,\,i}$ then:

$$v_{ent,i} = Max\begin{cases} v_{ext,i-1} - 0.034 \times 5,280 \times (X_i - X_{i-1} - L_{c,i-1}) \\ 1.47 \times V_{cdroad} \end{cases} \tag{19-72}$$

Step 6—Calculate Curve *i* Exit Speed.
The average exit speed at curve 2 (and all subsequent curves) is computed using the following equation:

$$v_{ext,i} = v_{ent,i} \quad \le \; v_{\max,i} \tag{19-73}$$

Step 7—Calculate Speed on Successive Curves.
This step is the same as Step 7 for the entrance ramp procedure.

Calculation of Barrier-Related Variables
The two barrier CMFs include variables that describe the presence of barrier on the left or right side of the ramp or C-D road. These variables include barrier offset and length.

Barrier offset represents a lateral distance measured from the near edge of the shoulder to the face of the barrier (i.e., it does not include the width of the shoulder). Barrier length represents the length of lane paralleled by a barrier; it is a total for both travel directions. For example, if the left side barrier extends for the length of the ramp segment, then the left side barrier length equals the segment length.

Two key variables that are needed for the evaluation of barrier presence are the right side barrier offset distance W_{rcb} and the left side barrier offset distance W_{lcb}. As indicated in Equation 19-37 and Equation 19-38, this distance is included as a divisor in the exponential term. This relationship implies that the correlation between distance and crash frequency is an inverse one (i.e., crash frequency decreases with increasing distance to the barrier). When multiple sections of barrier exist along the segment, a length-weighted average of the reciprocal of the individual distances is needed to properly reflect this inverse relationship. The length used to weight the average is the barrier length.

Additional key variables include the proportion of segment length with a barrier present on the right side P_{rb} and the proportion of segment length with a barrier present on the left side P_{lb}. Equations for calculating these proportions and the aforementioned distances are described in the following paragraphs.

The length of segment L used in the following equations is equal to that of the ramp segment L_r or C-D road segment L_{cd}, as appropriate for the CMF to which the calculated value will be applied.

The following equations should be used to estimate W_{rcb} and P_{rb}.

$$W_{rcb} = \frac{\sum L_{rb,i}}{\sum \frac{L_{rb,i}}{W_{off,r,i} - W_{rs}}} \tag{19-74}$$

$$P_{rb} = \frac{\sum L_{rb,i}}{L} \tag{19-75}$$

Where:

W_{rcb} = distance from edge of right shoulder to barrier face (ft);

$L_{rb,i}$ = length of right side lane paralleled by barrier *i* (mi);

$W_{off,r,i}$ = horizontal clearance from the edge of the traveled way to the face of right side barrier *i* (ft);

W_{rs} = paved right shoulder width (ft);

P_{rb} = proportion of segment length with a barrier present on the right side; and

L = length of segment (mi).

Any clearance distance ($= W_{off,r,i} - W_{rs}$) that is less than 0.75 ft should be set to 0.75 ft.

The following equations should be used to estimate W_{lcb} and P_{lb}:

$$W_{lcb} = \frac{\sum L_{lb,i}}{\sum \frac{L_{lb,i}}{W_{off,l,i} - W_{ls}}} \tag{19-76}$$

$$P_{lb} = \frac{\sum L_{lb,i}}{L} \tag{19-77}$$

Where:

W_{lcb} = distance from edge of left shoulder to barrier face (ft);

$L_{lb,i}$ = length of left side lane paralleled by barrier i (mi);

$W_{off,l,i}$ = horizontal clearance from the edge of the traveled way to the face of left side barrier i (ft);.

W_{ls} = paved left shoulder width (ft);

P_{lb} = proportion of segment length with a barrier present on the left side; and

L = length of segment (mi).

Any clearance distance ($= W_{off,l,i} - W_{ls}$) that is less than 0.75 ft should be set to 0.75 ft.

19.8. SEVERITY DISTRIBUTION FUNCTIONS

The severity distribution functions (SDFs) are presented in this section. They are used in the predictive model to estimate the expected average crash frequency for the following severity levels: fatal *K*, incapacitating injury *A*, non-incapacitating injury *B*, and possible injury *C*. Each SDF was developed as a regression model using observed crash data for a set of similar sites as the dependent variable. The SDF, like all regression models, estimates the value of the dependent variable as a function of a set of independent variables. The independent variables include various geometric features, traffic control features, and area type (i.e., rural or urban). Separate SDFs described in this section for ramp segments and crossroad ramp terminals.

The general model form for the severity distribution prediction is shown in the following equation:

$$N_{e,w,x,y,i} = N_{e,w,x,y,fi} \times P_{w,ac,at,j} \qquad (19\text{-}78)$$

Where:

$N_{e,w,x,y,j}$ = expected average crash frequency for site type w, cross section or control type x, crash type y, and severity level j ($j = K$: fatal, *A*: incapacitating injury, *B*: non-incapacitating injury, *C*: possible injury) (crashes/yr);

$N_{e,w,x,y,fi}$ = expected average crash frequency for site type w, cross section or control type x, crash type y, and fatal-and-injury crashes *fi* (crashes/yr); and

$P_{w,x,at,j}$ = probability of the occurrence of severity level j ($j = K$: fatal, *A*: incapacitating injury, *B*: non-incapacitating injury, *C*: possible injury) for all crash types *at* at site type w with cross section or control type x.

There is one SDF associated with each probability level j in the predictive model. An SDF predicts the probability of occurrence of severity level j for a crash based on various geometric design and traffic control features at the subject site. Each SDF also contains a calibration factor that is used to calibrate it to local conditions.

19.8.1. Severity Distribution Functions for Ramp Segments

The SDFs for ramp and C-D road segments are described by the following equations:

$$P_{rps+cds,ac,at,K} = \frac{\exp(V_{K+A})}{\frac{1.0}{C_{sdf,rps+cds}} + \exp(V_{K+A}) + \exp(V_B)} \times P_{K|K+A,rps+cds,ac,at} \quad (19\text{-}79)$$

$$P_{rps+cds,ac,at,A} = \frac{\exp(V_{K+A})}{\frac{1.0}{C_{sdf,rps+cds}} + \exp(V_{K+A}) + \exp(V_B)} \times (1.0 - P_{K|K+A,rps+cds,ac,at}) \quad (19\text{-}80)$$

$$P_{rps+cds,ac,at,B} = \frac{\exp(V_B)}{\frac{1.0}{C_{sdf,rps+cds}} + \exp(V_{K+A}) + \exp(V_B)} \quad (19\text{-}81)$$

$$P_{rps+cds,ac,at,C} = 1.0 - (P_K + P_A + P_B) \quad (19\text{-}82)$$

Where:

V_j = systematic component of crash severity likelihood for severity level *j*;

$P_{K|K+A,\ rps+cds,\ ac,\ at}$ = probability of a fatal *K* crash given that the crash has a severity of either fatal or incapacitating injury *A* on a ramp or C-D road segment based on all crash types *at* and any cross section *ac*; and

$C_{sdf,\ rps+cds}$ = calibration factor to adjust SDF for local conditions for ramp and C-D road segments.

The first term Equation 19-79 estimates the probability of a fatal or incapacitating injury crash. The second term (i.e., $P_{K|K+A}$) is used to convert the estimate into the probability of a fatal crash. A value of 0.248 is used for $P_{K|K+A}$ based on an analysis of fatal and incapacitating injury crashes on ramps and C-D road segments.

A model for estimating the systematic component of crash severity V_j for ramp and C-D road segments is described by the following equation:

$$V_j = a + \left(b \times \frac{P_{lb} + P_{rb}}{2}\right) + (c \times n) + (d \times I_{rural}) + (e \times I_{exr}) \quad (19\text{-}83)$$

Where:

a, b, c, d, e = regression coefficients;

P_{lb} = proportion of segment length with a barrier present on the left side;

P_{rb} = proportion of segment length with a barrier present on the right side;

n = number of through lanes in the segment (lanes);

I_{rural} = area type indicator variable (= 1.0 if area is rural, 0.0 if it is urban); and

I_{exr} = exit ramp indicator variable (= 1.0 if segment is an exit ramp, 0.0 otherwise.

The SDF coefficients in Equation 19-83 are provided in Table 19-43. Guidance for computing the variables P_{lb} and P_{rb} is provided in Section 19.7.3.

Table 19-43. SDF Coefficients for Ramp Segments

Severity Level (*j*)	Variable	SDF Coefficients				
		a	***b***	***c***	***d***	***e***
Fatal or incapacitating injury (*K+A*)	V_{K+A}	–1.537	–0.481	–0.228	0.668	0.426
Non-incapacitating injury (*B*)	V_B	0.236	–0.431	–0.435	0.696	0.00

The SDF is applicable to rural ramps and C-D roads with one lane (i.e., n = 1), and to urban ramps and C-D roads with one or two lanes (i.e., n = 1 or 2).

The sign of a coefficient in Table 19-43 indicates the change in the proportion of crashes associated with a change in the corresponding variable. For example, the negative coefficient associated with barrier presence indicates that the proportion of fatal *K* and incapacitating injury *A* crashes decreases with an increase in the proportion of barrier present in the segment. A similar trend is indicated for barrier presence on non-incapacitating injury *B* crashes. By inference, the proportion of possible injury *C* crashes *increases* with an increase in the proportion of barrier present.

19.8.2. Severity Distribution Functions for Ramp Terminals

The SDFs for crossroad ramp terminals are described by the following equations:

$$P_{aS,x,at,K} = \frac{\exp(V_{K+A})}{\frac{1.0}{C_{sdf,aS,x}} + \exp(V_{K+A}) + \exp(V_B)} \times P_{K|K+A,aS,x,at} \quad (19\text{-}84)$$

$$P_{aS,x,at,A} = \frac{\exp(V_{K+A})}{\frac{1.0}{C_{sdf,aS,x}} + \exp(V_{K+A}) + \exp(V_B)} \times (1.0 - P_{K|K+A,aS,x,at}) \quad (19\text{-}85)$$

$$P_{aS,x,at,B} = \frac{\exp(V_B)}{\frac{1.0}{C_{sdf,aS,x}} + \exp(V_{K+A}) + \exp(V_B)} \quad (19\text{-}86)$$

$$P_{aS,x,at,C} = 1.0 - (P_K + P_A + P_B) \quad (19\text{-}87)$$

Where:

V_j = systematic component of crash severity likelihood for severity level j;

$P_{K|K+A,\ aS,\ x,\ at}$ = probability of a fatal *K* crash given that the crash has a severity of either fatal or incapacitating injury *A* for all ramp terminal sites *aS* based on all crash types *at* and control type *x* ($x = ST$: one-way stop control; *SGn*: signal control, *n*-lane crossroad); and

$C_{sdf,\ aS,\ x}$ = calibration factor to adjust SDF for local conditions for all ramp terminal sites *aS* with control type *x* (x = *ST*: stop control, *SGn*: signal control, *n*-lane crossroad).

The first term Equation 19-84 estimates the probability of a fatal or incapacitating injury crash. The second term (i.e., $P_{K|K+A}$) is used to convert the estimate into the probability of a fatal crash. For signal-controlled ramp terminals, a value of 0.0385 is used for $P_{K|K+A}$ based on an analysis of fatal and incapacitating injury crashes at signalized ramp terminals. For one-way stop-controlled ramp terminals, a value of 0.160 is used for $P_{K|K+A}$ based on a similar analysis.

A model for estimating the systematic component of crash severity V_j for crossroad ramp terminals is described by the following equation:

$$V_j = a + (b' \; I_{p,lt}) + (c' \; [n_{dw} + n_{ps}]) + (d' \; I_{ps}) + (e' \; I_{rural}) \tag{19-88}$$

Where:

$I_{p,\,lt}$ = protected left-turn operation indicator variable for crossroad (= 1.0 if protected operation exists, 0.0 otherwise);

n_{dw} = number of unsignalized driveways on the crossroad leg outside of the interchange and within 250 ft of the ramp terminal;

n_{ps} = number of unsignalized public street approaches to the crossroad leg outside of the interchange and within 250 ft of the ramp terminal; and

I_{ps} = non-ramp public street leg indicator variable (= 1.0 if leg is present, 0.0 otherwise).

The SDF coefficients in Equation 19-88 are provided in Table 19-44.

Table 19-44. SDF Coefficients for Crossroad Ramp Terminals

Control Type (*x*)	Severity Level (*j*)	Variable	SDF Coefficients				
			a	***b***	***c***	***d***	***e***
One-way stop control (*ST*)	Fatal or incapacitating injury (*K+A*)	V_{K+A}	–3.168	0.00	0.00	0.00	0.891
	Non-incapacitating injury (*B*)	V_B	–1.476	0.00	0.00	0.00	0.221
Signal control, *n* lanes (*SGn*)	Fatal or incapacitating inj. (*K+A*)	V_{K+A}	–3.257	–0.288	0.0991	1.171	0.619
	Non-incapacitating injury (*B*)	V_B	–1.511	–0.193	0.149	0.741	0.416

This SDF is applicable when there are four or fewer driveways and two or fewer unsignalized public street approaches on the crossroad leg outside of the interchange.

The variable $I_{p,\,lt}$ is equal to 1.0 if protected-only left-turn operation is provided on each crossroad leg with a left-turn movement. If permissive or protected-permissive operation is provided on either leg, then the variable equals 0.0.

The variable I_{ps} is equal to 1.0 if the ramp terminal has a fourth leg that (a) is a public street serving two-way traffic and (b) intersects with the crossroad at the terminal. This situation occurs occasionally. When it does, the public street leg is opposite from one ramp and the other ramp either does not exist or is located at some distance from the subject ramp terminal so that it is not part of the terminal.

The sign of a coefficient in Table 19-44 indicates the change in the proportion of crashes associated with a change in the corresponding variable. For example, the negative coefficient associated with protected left-turn operation indicates that the proportion of fatal *K* and incapacitating injury *A* crashes decreases when protected-only left-turn operation is provided. A similar trend is indicated for protected-only left-turn operation on non-incapacitating injury *B* crashes. By inference, the proportion of possible injury *C* crashes *increases* when protected-only left-turn operation is provided.

SDFs were not developed for crossroad ramp terminals at single-point diamond interchanges. The fatal and injury crash frequency obtained from Equation 19-XA can be multiplied by the proportions in Table 19-XC to estimate the predicted average fatal and injury crash frequency at single-point diamond crossroad ramp terminals by crash severity.

Table 19-XC. Default Distribution of Single-Point Diamond Interchange Crossroad Ramp Terminal Crashes by Crash Severity

Collision Severity	Fatal and Injury
Fatal	0.006
Incapacitating injury	0.047
Nonincapacitating injury	0.278
Possible injury	0.669

SDFs were also not developed for crossroad ramp terminals at tight diamond interchanges. The fatal-and-injury crash frequency obtained from Equation 19-XB can be multiplied by the proportions in Table 19-XF to estimate the predicted average fatal-and-injury crash frequency at tight diamond crossroad ramp terminals by crash severity.

Table 19-XF. Default Distribution of Tight Diamond Interchange Crossroad Ramp Terminal Crashes by Crash Severity

Collision Severity	Fatal and Injury
Fatal	0.003
Incapacitating injury	0.062
Nonincapacitating injury	0.329
Possible injury	0.607

19.9. CALIBRATION OF THE SPFS AND SDFS TO LOCAL CONDITIONS

Crash frequencies, even for nominally similar ramp segments or ramp terminals, can vary widely from one jurisdiction to another. Geographic regions differ markedly in climate, animal population, driver populations, crash-reporting threshold, and crash-reporting practices. These variations may result in some jurisdictions experiencing a different number of traffic crashes on ramps than others. Calibration factors are included in the methodology to allow transportation agencies to adjust the SPFs and SDFs to match actual local conditions.

The SPF calibration factors will have values greater than 1.0 for segments or terminals that, on average, experience more crashes than those used in the development of the SPFs. Similarly, the calibration factors for segments or terminals that experience fewer crashes on average than those used in the development of the SPFs will have values less than 1.0. The calibration procedures for SPFs are presented in Section B.1.1 of Appendix B.

The SDF calibration factors will have values greater than 1.0 for segments or terminals that, on average, experience more severe crashes than those used in the development of the SDFs. Similarly, the calibration factors for segments or terminals that experience fewer severe crashes on average than those used in the development of the SDFs will have values less than 1.0. The calibration procedures for SDFs are presented in Section B.1.4 of Appendix B.

Default values are also provided for the crash type distributions used in the methodology. These values can also be replaced with locally derived values. The derivation of these values is addressed in Section B.1.3 of Appendix B.

19.10. INTERIM PREDICTIVE METHOD FOR ALL-WAY STOP CONTROL

Sufficient research has not yet been conducted to form the basis for development of a predictive method for crossroad ramp terminals with all-way stop control. An interim method is presented in this section. It consists of the same steps as described previously in Section 19.4. The discussion below highlights the modifications to these steps when they are applied to an all-way stop-controlled ramp terminal.

Steps 1 to 18—Evaluate the Crossroad Ramp Terminal as One-Way Stop Control.
Apply the predictive method described in Section 19.4 to the subject crossroad ramp terminal. The subject crossroad ramp terminal has all-way stop control but it is evaluated using the predictive method for one-way stop control.

Step 10—The following list identifies the CMFs that can be used in Step 10 of the predictive method to evaluate all-way stop-controlled ramp terminals:

- Exit ramp capacity.
- Access point frequency.
- Segment length.
- Median width.

The crossroad left-turn lane CMF, crossroad right-turn lane CMF, and skew angle CMF cannot be used to evaluate all-way stop-controlled ramp terminals.

In addition, the all-way stop control CMF is used in Step 10 of the predictive method. This CMF has a value of 0.686 when applied to fatal-and-injury crashes. Research has not established a value for this CMF when applied to property-damage-only crashes, so the unadjusted estimate from the predictive method is considered to be equally applicable to all-way stop-controlled ramp terminals.

Step 13—The crash-type distribution Table 19-45 can be used in Step 13 of the predictive method, if desired, to compute the expected average crash frequency for each of ten crash types (e.g., head-on, fixed object).

Table 19-45. Default Distribution of All-Way Stop-Controlled Ramp Terminal Crashes by Crash Type

			Proportion of Crashes by Severity	
Area Type	Crash Type	Crash Type Category	Fatal and Injury	Property Damage Only
Rural	Multiple vehicle	Head-on	0.000	0.000
		Right-angle	0.500	0.375
		Rear-end	0.500	0.405
		Sideswipe	0.000	0.094
		Other multiple-vehicle crash	0.000	0.000
	Single vehicle	Crash with animal	0.000	0.000
		Crash with fixed object	0.000	0.063
		Crash with other object	0.000	0.000
		Crash with parked vehicle	0.000	0.000
		Other single-vehicle crashes	0.000	0.063
Urban	Multiple vehicle	Head-on	0.000	0.000
		Right-angle	0.182	0.333
		Rear-end	0.727	0.500
		Sideswipe	0.000	0.000
		Other multiple-vehicle crash	0.000	0.000
	Single vehicle	Crash with animal	0.000	0.000
		Crash with fixed object	0.000	0.167
		Crash with other object	0.000	0.000
		Crash with parked vehicle	0.000	0.000
		Other single-vehicle crashes	0.091	0.000

19.11. LIMITATIONS OF PREDICTIVE METHOD

The limitations of the predictive method that apply generally across all of the Part C chapters are discussed in Section C.8 of the *Highway Safety Manual*. This section discusses limitations of the predictive models described in this chapter.

The predictive method described in this chapter does not account for the influence of the following conditions on ramp safety:

- ramp or C-D road segments in rural areas with 2 or more lanes,
- ramp or C-D road segments in urban areas with 3 or more lanes,
- ramps and C-D roads providing two-way travel,

- ramp metering,
- a high-occupancy vehicle (HOV) bypass lane on a ramp or C-D road,
- a frontage-road segment,
- a frontage-road ramp terminal,
- a frontage-road crossroad terminal,
- a crossroad speed-change lane,
- a crossroad ramp terminal with 3 or more left-turn lanes on a crossroad approach,
- a crossroad ramp terminal where the crossroad provides one-way travel, or
- the crossroad ramp terminal formed by a single-point urban interchange or roundabout.

The predictive method does not distinguish between barrier types (i.e., cable barrier, concrete barrier, guardrail, and bridge rail) in terms of their possible different influence on crash severity.

19.12. APPLICATION OF PREDICTIVE METHOD

The predictive method presented in this chapter is applied to a ramp by following the 18 steps presented in Section 19.4. Worksheets are provided in Appendix 19A for applying calculations in the predictive method. All computations of crash frequencies within these worksheets are conducted with values expressed to three decimal places. This level of precision is needed only for consistency in computations. In the last stage of computations, rounding the final estimates of expected average crash frequency to one decimal place is appropriate.

19.13. SUMMARY

The predictive method for ramps is applied by following the 18 steps of the predictive method presented in Section 19.4. It is used to estimate the expected average crash frequency for a series of contiguous sites, or a single individual site. If a ramp is being evaluated, then it is divided into a series of sites in Step 5 of the predictive method.

Predictive models are applied in Steps 9, 10, and 11 of the method. Each predictive model consists of a safety performance function (SPF), crash modification factors (CMFs), a severity distribution function (SDF), and calibration factors. The SPF is selected in Step 9. It is used to estimate the predicted average crash frequency for a site with base conditions. CMFs are selected in Step 10. They are combined with the estimate from the SPF to produce the predicted average crash frequency.

When observed crash data are available, the EB Method is applied in Step 13 or 15 of the predictive method to estimate the expected average crash frequency. The EB Method can be applied at the site-specific level in Step 13, or at the project level in Step 15. The choice of level will depend on (a) the required reliability of the estimate and (b) the accuracy with which each observed crash can be associated with an individual site. The EB Method is described in Section B.2 of Appendix B.

Optionally, SDFs are selected in Step 13. They can be used to estimate the average crash frequency for one or more crash severity levels (i.e., fatal, incapacitating injury, non-incapacitating injury, or possible injury crash). Optionally, the crash type distribution can be used in Step 13 to estimate the average crash frequency for one or more crash types (e.g., head-on, fixed object).

The SPF should be calibrated to the specific state or geographic region in which the project is located. Calibration accounts for differences in state or regional crash frequencies, relative to the states and regions represented in the data used to define the predictive models described in this chapter. The process for determining calibration factors for the predictive models is described in Section B.1 of Appendix B.

Section 19.14 presents several sample problems that detail the application of the predictive method. A series of worksheets are used to guide the method application and document the calculations. The use of these worksheets is illustrated in the sample problems. Appendix 19A contains blank worksheets that can be photocopied to document future applications of the method.

19.14. SAMPLE PROBLEMS

In this section, eight~~six~~ sample problems are presented using the predictive method steps for ramp facilities. Sample Problems 1 through 3 illustrate how to calculate the predicted average crash frequency for ramp segments. Sample Problems 4 through 8~~6~~ illustrate how to calculate the predicted average crash frequency for ramp terminals.

Note: In the following sample problems, the tables show results of calculations copied from a spreadsheet used to obtain these results. Calculations shown in the text were determined using a calculator. In many cases, there are small differences between the results of the calculations because those shown in the text were rounded to the third decimal whereas the values from the spreadsheet were not rounded.

Table 19-46. List of Sample Problems

Problem No.	Description
1	Predicted average crash frequency for a one-lane urban exit ramp segment
2	Predicted average crash frequency for a two-lane urban C-D road segment
3	Predicted average crash frequency for a one-lane urban entrance ramp segment
4	Predicted average crash frequency for a D4 ramp terminal on an urban arterial with signal control
5	Predicted average crash frequency for a A4 ramp terminal on an urban arterial with one-way stop control
6	Predicted average crash frequency for a B2 ramp terminal on an urban arterial with all-way stop control
7	Predicted average crash frequency for a crossroad ramp terminal at a single-point diamond interchange (SP)
8	Predicted average crash frequency for a crossroad ramp terminal at a tight diamond interchange (TD)

19.14.1. Sample Problem 1

The Site/Facility
A one-lane urban exit ramp segment.

The Question
What is the predicted average crash frequency of the ramp segment for a one-year period?

The Facts
The study year is 2011. The conditions present during this year are provided in the following list:

- 0.15-mi length
- 6,750 veh/day
- 65-mi/h average speed on freeway mainline
- Signal control at crossroad ramp terminal
- One off-segment horizontal curve

  - 400-ft radius
  - 0.025-mi length
  - Beginning at ramp-mile 0.07
- One in-segment horizontal curve
  - 400-ft radius
  - 0.07-mi length, entirely in the segment
  - Beginning at ramp-mile 0.19
- 14-ft lane width
- 8-ft right shoulder width (paved)
- 4-ft left shoulder width (paved)
- No lane adds or lane drops
- No barrier on the right or left sides of the roadway
- No ramp entrances or exits in the segment
- No weaving section

Assumptions

- Crash type distributions used are the default values presented in Table 19-6 and Table 19-9.
- The calibration factor is 1.00.

Results

Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the ramp segment in Sample Problem 1 is determined to be 0.2 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 0.2 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8

To determine the predicted average crash frequency of the ramp segment in Sample Problem 1, only Steps 9 through 13 are conducted. No other steps are necessary because only one ramp segment is analyzed for a one-year period and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate SPF.

For a one-lane urban exit ramp segment, SPF values for multiple-vehicle and single-vehicle crashes are determined.

Multiple-Vehicle Crashes

The SPF for multiple-vehicle fatal-and-injury crashes is calculated from Equation 19-20 and Table 19-5 as follows:

$$\begin{aligned} N_{spf,\ rps,1EX,\ mv,\ fi} &= L_r \times \exp\left(a + b \times \ln\left[c \times AADT_r\right] + d\left[c \times AADT_r\right]\right) \\ &= 0.15 \times \exp\left(-4.971 + 0.524 \times \ln\left[0.001 \times 6{,}750\right] + 0.0699\left[0.001 \times 6{,}750\right]\right) \\ &= 0.005 \text{ crashes/year} \end{aligned}$$

Similarly, the SPF for multiple-vehicle property-damage-only crashes is calculated from Equation 19-20 and Table 19-5 to yield the following result:

$$N_{spf,\ rps,1EX,\ mv,\ pdo} = 0.013 \text{ crashes/year}$$

Single-Vehicle Crashes

The SPF for single-vehicle fatal-and-injury crashes is calculated from Equation 19-24 and Table 19-8 as follows:

$$\begin{aligned} N_{spf,\ rps,1EX,sv,\ fi} &= L_r \times \exp\left(a + b \times \ln\left[c \times AADT_r\right]\right) \\ &= 0.15 \times \exp\left(-1.645 + 0.718 \times \ln\left[0.001 \times 6{,}750\right]\right) \\ &= 0.114 \text{ crashes/year} \end{aligned}$$

Similarly, the SPF for single-vehicle property-damage-only crashes is calculated from Equation 19-24 and Table 19-8 to yield the following result:

$$N_{spf,\ rps,1EX,sv,\ pdo} = 0.124 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs.

Each CMF used in the calculation of the predicted average crash frequency of the ramp segment is calculated in this step.

Horizontal Curve (*$CMF_{1,rps,1EX,y,z}$*)

The limited curve speed for the off-segment horizontal curve (curve 1) is computed using Equation 19-59 as follows:

$$\begin{aligned} v_{\max,1} &= 3.24 \times \left(32.2 \times R_1\right)^{0.30} \\ &= 3.24 \times \left(32.2 \times 400\right)^{0.30} \\ &= 55.4 \text{ ft/s} \end{aligned}$$

The in-segment horizontal curve (curve 2) has the same radius as curve 1. Hence, its limited speed $v_{\max,\,2}$ is also equal to 55.4 ft/s.

The average entry speed at curve 1 is computed using Equation 19-64 and the default values in Table 19-42 as follows:

$$\begin{aligned} v_{ent,1} &= Max\begin{cases} 1.47 \times V_{frwy} - 0.034 \times 5{,}280 \times X_1 \\ 1.47 \times V_{xroad} \end{cases} \\ &= Max\begin{cases} 1.47 \times 65 - 0.034 \times 5{,}280 \times 0.07 \\ 1.47 \times 15 \end{cases} \\ &= Max\begin{cases} 83.0 \\ 22.05 \end{cases} \\ &= 83.0 \text{ ft/s} \end{aligned}$$

The average exit speed at curve 1 is computed using Equation 19-65 as follows:

$$v_{ext,1} = Max\begin{cases} \min\begin{cases} v_{ent,1} - 0.034 \times 5,280 \times L_{c,1} \\ v_{max,1} \end{cases} \\ 1.47 \times V_{xroad} \end{cases}$$
$$= Max\begin{cases} \min\begin{cases} 83.0 - 0.034 \times 5,280 \times 0.025 \\ 55.4 \end{cases} \\ 1.47 \times 15 \end{cases}$$
$$= Max\begin{cases} \min\begin{cases} 78.5 \\ 55.4 \end{cases} \\ 22.05 \end{cases}$$
$$= Max\begin{cases} 55.4 \\ 22.05 \end{cases}$$
$$= 55.4 \text{ ft/s}$$

The average entry speed at curve 2 is computed using Equation 19-66 and the default values in Table 19-42 as follows:

$$v_{ent,i} = Max\begin{cases} v_{ext,i-1} - 0.034 \times 5,280 \times (X_i - X_{i-1} - L_{c,i-1}) \\ 1.47 \times V_{xroad} \end{cases}$$
$$= Max\begin{cases} 55.4 - 0.034 \times 5,280 \times (0.19 - 0.07 - 0.025) \\ 1.47 \times 15 \end{cases}$$
$$= Max\begin{cases} 38.3 \\ 22.05 \end{cases}$$
$$= 38.3 \text{ ft/s}$$

$CMF_{1,rps,1EX,y,fi}$ is calculated using Equation 19-33 as follows:

$$CMF_{1,rps,1EX,y,fi} = 1.0 + a \times \frac{1,000}{32.2}\left[\sum_{i=1}^{m}\left(\frac{v_{ent,i}}{R_i}\right)^2 \times P_{c,i}\right]$$

Only curve 2 is included in the summation term. Curve 1 is not in the segment, but its presence upstream of the segment affects vehicle speeds in curve 2. From Table 19-24, $a = 0.779$ for multiple-vehicle fatal-and-injury crashes. $CMF_{1,rps,1EX,mv,fi}$ is calculated as follows:

$$CMF_{1,rps,1EX,mv,fi} = 1.0 + 0.779 \times \frac{1,000}{32.2}\left(\frac{38.3}{400}\right)^2 \times \frac{0.07}{0.15}$$
$$= 1.104$$

Calculations using the other coefficients from Table 19-24 yield the following results:

$$CMF_{1,rps,1EX,sv,fi} = 1.320$$

$$CMF_{1,rps,1EX,mv,pdo} = 1.073$$

$$CMF_{1,rps,1EX,sv,pdo} = 1.418$$

Lane Width ($CMF_{2,rps,1EX,y,z}$)

The segment has 14-ft lanes, which is the base condition for the lane width CMF. Hence, $CMF_{2,rps,1EX,y,fi}$ and $CMF_{2,rps,1EX,y,pdo}$ are equal to 1.000.

Right Shoulder Width ($CMF_{3,\,rps,\,1EX,\,y,\,z}$)
The segment has 8-ft right shoulders, which is the base condition for the right shoulder width CMF. Hence, $CMF_{3,rps,1EX,y,fi}$ and $CMF_{3,rps,1EX,y,pdo}$ are equal to 1.000.

Left Shoulder Width ($CMF_{4,\,rps,\,1EX,\,y,\,z}$)
The segment has 4-ft left shoulders, which is the base condition for the left shoulder width CMF. Hence, $CMF_{4,rps,1EX,y,fi}$ and $CMF_{4,rps,1EX,y,pdo}$ are equal to 1.000.

Right Side Barrier ($CMF_{5,\,rps,\,1EX,\,y,\,z}$)
The segment does not have right side barrier. Hence, $CMF_{5,\,rps,\,1EX,\,y,\,fi}$ and $CMF_{5,\,rps,\,1EX,\,y,\,pdo}$ are equal to 1.000.

Left Side Barrier ($CMF_{6,\,rps,\,1EX,\,y,\,z}$)
The segment does not have left side barrier. Hence, $CMF_{6,\,rps,\,1EX,\,y,\,fi}$ and $CMF_{6,\,rps,\,1EX,\,y,\,pdo}$ are equal to 1.000.

Lane Add or Drop ($CMF_{7,\,rps,\,1EX,\,y,\,fi}$)
The segment does not have a lane add or a lane drop. Hence, $CMF_{7,\,rps,\,1EX,\,y,\,fi}$ is equal to 1.000.

Ramp Speed-Change Lane ($CMF_{8,\,rps,\,1EX,\,mv,\,fi}$)
The segment does not have a speed-change lane. Hence, $CMF_{8,\,rps,\,1EX,\,mv,\,fi}$ is equal to 1.000.

Multiple-Vehicle Crashes
The CMFs are applied to the multiple-vehicle fatal-and-injury SPF as follows:

$$\begin{aligned} N_{p*,\,rps,1EX,\,mv,\,fi} &= N_{spf,\,rps,1EX,\,mv,\,fi} \times \left(CMF_{1,rps,1EX,mv,fi} \times \ldots \times CMF_{8,rps,1EX,mv,fi}\right) \\ &= 0.005 \times (1.104 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000) \\ &= 0.005 \times 1.104 \\ &= 0.005 \text{ crashes/year} \end{aligned}$$

The CMFs are applied to the multiple-vehicle property-damage-only SPF as follows:

$$\begin{aligned} N_{p*,\,rps,1EX,\,mv,\,pdo} &= N_{spf,\,rps,1EX,\,mv,\,pdo} \times \left(CMF_{1,rps,1EX,mv,pdo} \times \ldots \times CMF_{8,rps,1EX,mv,pdo}\right) \\ &= 0.013 \times (1.073 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000) \\ &= 0.013 \times 1.073 \\ &= 0.014 \text{ crashes/year} \end{aligned}$$

Single-Vehicle Crashes
The CMFs are applied to the single-vehicle fatal-and-injury SPF as follows:

$$\begin{aligned} N_{p*,\,rps,1EX,\,sv,\,fi} &= N_{spf,\,rps,1EX,\,sv,\,fi} \times \left(CMF_{1,rps,1EX,sv,fi} \times \ldots \times CMF_{8,rps,1EX,sv,fi}\right) \\ &= 0.114 \times (1.320 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000) \\ &= 0.114 \times 1.320 \\ &= 0.151 \text{ crashes/year} \end{aligned}$$

The CMFs are applied to the single-vehicle property-damage-only SPF as follows:

$$
\begin{aligned}
N_{p*,\,rps,1EX,\,sv,\,pdo} &= N_{spf,\,rps,1EX,\,sv,\,pdo} \times \left(CMF_{1,rps,1EX,sv,pdo} \times \ldots \times CMF_{8,rps,1EX,sv,pdo}\right) \\
&= 0.124 \times (1.418 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000) \\
&= 0.124 \times 1.418 \\
&= 0.175 \text{ crashes/year}
\end{aligned}
$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor of 1.00 has been determined for local conditions. As a result, $N_{p,rps,1EX,y,z} = N_{p*,\,rps,\,1EX,\,y,\,z}$ for both crash types *y* ($y=mv$: multiple-vehicle, *sv*: single-vehicle) and both crash severities *z* ($z = fi$: fatal-and-injury, *pdo*: property-damage-only). See Section B.1 of Appendix B for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 19-1 based on the results obtained in Steps 9 through 11 as follows.

Fatal-and-injury crashes:

$$
\begin{aligned}
N_{p,\,rps,1EX,\,at,\,fi} &= N_{p,\,rps,1EX,\,mv,\,fi} + N_{p,\,rps,1EX,\,sv,\,fi} \\
&= 0.005 + 0.151 \\
&= 0.156 \text{ crashes/year}
\end{aligned}
$$

Property-damage-only crashes:

$$
\begin{aligned}
N_{p,\,rps,1EX,\,at,\,pdo} &= N_{p,\,rps,1EX,\,mv,\,pdo} + N_{p,\,rps,1EX,\,sv,\,pdo} \\
&= 0.014 + 0.176 \\
&= 0.189 \text{ crashes/year}
\end{aligned}
$$

Step 12—If there is another year to be evaluated in the evaluation period for the selected site, return to Step 8. Otherwise, proceed to Step 13.
The study period is one year (2011), so steps 8 through 11 need not be repeated.

Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.
This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

Apply the site-specific EB Method to a future time period, if appropriate.
The site-specific EB Method is not applied in this sample problem because crash data are not available.

Apply the severity distribution functions (SDFs), if desired.
To apply the SDFs, the systematic component of crash severity likelihood V_j is computed for each severity level *j* using Equation 19-83 as follows:

$$
V_j = a + \left(b \times \frac{P_{lb} + P_{rb}}{2}\right) + (c \times n) + (d \times I_{rural}) + (e \times I_{exr})
$$

The coefficients *a*, *b*, *c*, *d*, and *e* are obtained from Table 19-43 for each severity level *j*. The segment does not have barrier, so P_{lb} and P_{rb} are equal to 0.0. V_j is computed for fatal and incapacitating injury crashes as follows:

$$V_{K+A} = -1.537 + \left(0.481 \times \frac{0.0+0.0}{2}\right) + (-0.228 \times 1.0) + (0.668 \times 0.0) + (0.426 \times 1.0)$$
$$= -1.339$$

Similar calculations using the coefficients from Table 19-43 for non-incapacitating injury crashes yield the following results:

$$V_B = -0.199$$

Using these computed V_{K+A} and V_B values, and assuming a calibration factor $C_{sdf,\ rps+cds}$ of 1.0, the probability of occurrence of a fatal crash is computed using Equation 19-79 as follows:

$$P_{rps+cds,ac,at,K} = \frac{\exp(V_{K+A})}{\frac{1.0}{C_{sdf,rps+cds}} + \exp(V_{K+A}) + \exp(V_B)} \times P_{K|K+A,rps+cds,ac,at}$$
$$= \frac{\exp(-1.339)}{\frac{1.0}{1.0} + \exp(-1.339) + \exp(-0.199)} \times 0.248$$
$$= 0.032$$

Similar calculations using Equations 19-80 and 19-81 yield the following results:

$$P_{rps+cds,ac,at,A} = 0.096$$

$$P_{rps+cds,ac,at,B} = 0.391$$

The probability of occurrence of a possible-injury crash is computed using Equation 19-82 as follows:

$$P_{rps+cds,ac,at,C} = 1.0 - (P_{rps+cds,ac,at,K} + P_{rps+cds,ac,at,A} + P_{rps+cds,ac,at,B})$$
$$= 1.0 - (0.032 + 0.096 + 0.391)$$
$$= 0.481$$

The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 19-78 as follows:

$$N_{e,rps,1EX,at,K} = N_{e,rps,1EX,at,fi} \times P_{rps+cds,ac,at,K}$$
$$= 0.156 \times 0.032$$
$$= 0.005 \text{ crashes/year}$$

Similar calculations using Equation 19-78 and the probabilities of occurrences of the other crash severities yield the following results:

$$N_{e,rps,1EX,at,A} = 0.015 \text{ crashes/year}$$

$$N_{e,rps,1EX,at,B} = 0.061 \text{ crashes/year}$$

$$N_{e,rps,1EX,at,C} = 0.075 \text{ crashes/year}$$

Apply the crash type distribution, if desired.
The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 19-6

and Table 19-9 by the predicted average crash frequencies obtained in Step 11.

WORKSHEETS

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

- Table 19-47. Ramp Segment Worksheet (1 of 4)—Sample Problem 1
- Table 19-48. Ramp Segment Worksheet (2 of 4)—Sample Problem 1
- Table 19-49. Ramp Segment Worksheet (3 of 4)—Sample Problem 1
- Table 19-50. Ramp Segment Worksheet (4 of 4)—Sample Problem 1

Filled versions of these worksheets are provided below. A blank version of the corresponding worksheets used in all Sample Problems is provided in Appendix 19A.

Table 19-47 is a summary of general information about the ramp segment, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 1. The input data include area type, crash data, basic roadway data, and alignment data.

Table 19-48 is a summary of general information about the ramp segment, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 1. The input data include cross section data, roadside data, ramp access data, and traffic data.

Table 19-49 is a tabulation of the CMF and SPF computations for Sample Problem 1.

Table 19-50 is a tabulation of the crash severity and crash type distributions for Sample Problem 1.

Table 19-47. Ramp Segment Worksheet (1 of 4)—Sample Problem 1

General Information						Location Information	
Analyst						Roadway	
Agency or company						Roadway section	
Date performed						Study year	
Area type	X	Urban		Rural			

Input Data

Crash Data		Crash Period	Study Year	Complete the study year column. Complete the crash period column if the EB Method is used.				
Crash data time period				First year	--	Last year	--	
Count of multiple-vehicle FI crashes $N^*_{o,w,n,mv,fi}$		--						
Count of single-vehicle FI crashes $N^*_{o,w,n,sv,fi}$		--						
Count of multiple-vehicle PDO crashes $N^*_{o,w,n,mv,pdo}$		--						
Count of single-vehicle PDO crashes $N^*_{o,w,n,sv,pdo}$		--						
Basic Roadway Data								
Number of through lanes n		1		Same value for crash period and study year.				
Segment length L (mi)		--	0.15					
Average traffic speed on the freeway V_{frwy} (mi/h)		--	65					
Segment type		Exit		Choices: Entrance, Exit, C-D road, Connector				
Type of control at crossroad ramp terminal		--	Signal	Choices: Stop, Yield, Signal, None				
Alignment Data								
Horizontal Curve Data								
1	Presence of horizontal curve 1	--	Off Seg.	Choices: No, In segment, Off segment.				
	Curve radius R_1 (ft)	--	400	If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.				
	Length of curve L_{c1} (mi)	--	0.025					
	Length of curve in segment $L_{c1,seg}$ (mi)	--	--					
	Ramp-mile of beginning of curve in dir. of travel X_1 (mi)	--	0.07					
2	Presence of horizontal curve 2	--	In Seg.	Choices: No, In segment, Off segment				
	Curve radius R_2 (ft)	--	400	If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.				
	Length of curve L_{c2} (mi)	--	0.07					
	Length of curve in segment $L_{c2,seg}$ (mi)	--	0.07					
	Ramp-mile of beginning of curve in dir. of travel X_2 (mi)	--	0.19					
3	Presence of horizontal curve 3	--	No	Choices: No, In segment, Off segment				
	Curve radius R_3 (ft)	--	--	If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.				
	Length of curve L_{c3} (mi)	--	--					
	Length of curve in segment $L_{c3,seg}$ (mi)	--	--					
	Ramp-mile of beginning of curve in dir. of travel X_3 (mi)	--	--					
4	Presence of horizontal curve 4	--	No	Choices: No, In segment, Off segment				
	Curve radius R_4 (ft)	--	--	If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.				
	Length of curve L_{c4} (mi)	--	--					
	Length of curve in segment $L_{c4,seg}$ (mi)	--	--					
	Ramp-mile of beginning of curve in dir. of travel X_4 (mi)	--	--					

Table 19-48. Ramp Segment Worksheet (2 of 4)—Sample Problem 1

Input Data						
Cross Section Data		Crash Period		Study Year		Complete the study year column. Complete the crash period column if the EB Method is used.
Lane width W_l (ft)		--		14		
Right shoulder width W_{rs} (ft)		--		8		
Left shoulder width W_{ls} (ft)		--		4		
Presence of lane add or lane drop		--		No		Choices: No, Lane add, Lane drop
Length of taper in segment $L_{add,\,seg}$ or $L_{drop,\,seg}$ (mi)		--		--		If “Lane add” or “Lane drop”, enter length.
Roadside Data						
Presence of barrier on right side of roadway		--	Y/N	N	Y/N	If Yes, then use the ramp barrier worksheet.
Presence of barrier on left side of roadway		--	Y/N	N	Y/N	If Yes, then use the ramp barrier worksheet.
Ramp Access Data						
Ramp Entrance						
Ent. ramp	Presence of speed-change lane in segment	--	Y/N	N	Y/N	If Yes, then enter data in the next row.
	Length of s-c lane in segment $L_{en,seg}$ (mi)	--		--		
Exit ramp	Presence of speed-change lane in segment	--	Y/N	N	Y/N	If Yes, then enter data in the next row.
	Length of s-c lane in segment $L_{ex,seg}$ (mi)	--		--		
Weave	Presence of a weaving section in segment	--	Y/N	N	Y/N	If Yes, then enter data in the next two rows.
	Length of weaving section L_{wev} (mi)	--		--		
	Length of weaving section in seg. $L_{wev,\,seg}$ (mi)	--		--		
Traffic Data						
Segment AADT $AADT_r$ or $AADT_c$ (veh/day)		--		6,750		

Table 19-49. Ramp Segment Worksheet (3 of 4)—Sample Problem 1

Crash Modification Factors

Complete the study year column. Complete the crash period column if the EB Method is used.	Equation	Fatal and Injury				Property Damage Only			
		Multiple Vehicle		Single Vehicle		Multiple Vehicle		Single Vehicle	
		Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year
Horizontal curve $CMF_{1, w, x, y, z}$	19-33	--	1.104	--	1.320	--	1.073	--	1.418
Lane width $CMF_{2, w, x, y, fi}$	19-34	--	1.000	--	1.000				
Right shoulder width $CMF_{3, w, x, y, z}$	19-35	--	1.000	--	1.000	--	1.000	--	1.000
Left shoulder width $CMF_{4, w, x, y, z}$	19-36	--	1.000	--	1.000	--	1.000	--	1.000
Right side barrier $CMF_{5, w, x, y, z}$	19-37	--	1.000	--	1.000	--	1.000	--	1.000
Left side barrier $CMF_{6, w, x, y, z}$	19-38	--	1.000	--	1.000	--	1.000	--	1.000
Lane add or drop $CMF_{7, w, x, y, fi}$	19-39	--	1.000	--	1.000				
Ramp speed-change lane $CMF_{8, w, x, mv, fi}$	19-40	--	1.000						
Weaving section $CMF_{9, cds, ac, y, z}$	19-41	--	1.000	--	1.000	--	1.000	--	1.000
Combined CMF (multiply all CMFs evaluated)		--	1.104	--	1.320	--	1.073	--	1.418

Expected Average Crash Frequency [a]

Complete the study year column. Complete the crash period column if the ***site-specific*** EB Method is used.	Fatal and Injury				Property Damage Only			
	Multiple Vehicle		Single Vehicle		Multiple Vehicle		Single Vehicle	
	Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year
Calibration factor $C_{w, x, y, z}$	1.00		1.00		1.00		1.00	
Overdispersion parameter $k_{w, x, y, z}$	--		--		--		--	
Observed crash count $N^{*}_{o, w, x, y, z}$ (cr)	--		--		--		--	
Reference year r	--		--		--		--	
Predicted average crash freq. for reference year $N_{p, w, x, y, z, r}$ (cr/yr)	--		--		--		--	
Predicted number of crashes for crash period (sum all years) $N^{*}_{p, w, x, y, z}$ (cr)	--		--		--		--	
Equivalent years associated with crash count $C_{b, w, x, y, z, r}$ (yr)	--		--		--		--	
Adjusted average crash freq. for ref. year given N^{*}_{o}, $N_{a, w, x, y, z, r}$ (cr/yr)	--		--		--		--	
Study year s		2011		2011		2011		2011
Predicted average crash freq. for study year $N_{p, w, x, y, z, s}$ (cr/yr)		0.005		0.151		0.014		0.175
Expected average crash freq. for study year $N_{e, w, x, y, z, s}$ (cr/yr)		0.005		0.151		0.014		0.175
Expected average crash freq. for study year (all crash types) $N_{e, w, x, at, z, s}$ (cr/yr)		0.156				0.189		

[a] If the EB Method is not used, then substitute the word "predicted" for the word "expected" and substitute the subscript "p" for the subscript "e".

Table 19-50. Ramp Segment Worksheet (4 of 4)—Sample Problem 1

Expected Average Crash Frequency [a]

Crash Severity Distribution

	K	A	B	C	Total FI	PDO	Total FI + PDO
Proportion by injury level	0.032	0.096	0.391	0.481	1.000		
Expected average crash freq. for study year (all crash types) $N_{e, w, x, at, z, s}$ (cr/yr)	0.005	0.015	0.061	0.075	0.156	0.189	0.345

Crash Type Distribution

Crash Type Category	Table	Fatal and Injury		Property Damage Only		Total
		Proportion	Expected Average Crash Frequency for Study Year $N_{e, w, x, y, fi, s}$ (cr/yr)	Proportion	Expected Average Crash Frequency for Study Year $N_{e, w, x, y, pdo, s}$ (cr/yr)	Expected Average Crash Frequency for Study Year $N_{e, w, x, y, as, s}$ (cr/yr)
Multiple-Vehicle Crashes	19-6					
Head-on		0.015	0.000	0.009	0.000	0.000
Right-angle		0.010	0.000	0.005	0.000	0.000
Rear-end		0.707	0.003	0.550	0.008	0.011
Sideswipe		0.129	0.001	0.335	0.005	0.005
Other multiple-vehicle crashes		0.139	0.001	0.101	0.001	0.002
Total		1.000	0.005	1.000	0.014	0.019
Single-Vehicle Crashes	19-9					
Crash with animal		0.003	0.000	0.005	0.001	0.001
Crash with fixed object		0.718	0.108	0.834	0.146	0.254
Crash with other object		0.015	0.002	0.023	0.004	0.006
Crash with parked vehicle		0.012	0.002	0.012	0.002	0.004
Other single-vehicle crashes		0.252	0.038	0.126	0.022	0.060
Total		1.000	0.151	1.000	0.175	0.326

[a] If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e”.

19.14.2. Sample Problem 2

The Site/Facility
A two-lane urban C-D road segment.

The Question
What is the predicted average crash frequency of the C-D road segment for a one-year period?

The Facts
The study year is 2011. The conditions present during this year are provided in the following list:

- 0.08-mi length
- 5,500 veh/day
- 60-mi/h average speed on freeway mainline
- One off-segment horizontal curve
  - 1,100-ft radius
  - 0.08-mi length
  - Beginning at ramp-mile 0.09
- 14-ft lane width
- 8-ft right shoulder width (paved)
- 4-ft left shoulder width (paved)
- No lane adds or lane drops
- No barrier on the right or left sides of the roadway
- No ramp entrances or exits in the segment
- 0.08-mi weaving section along entire length of segment

Assumptions

- Crash type distributions used are the default values presented in Table 19-6 and Table 19-9.
- The calibration factor is 1.00.

Results
Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the C-D road segment in Sample Problem 2 is determined to be 0.1 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 0.2 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the C-D road segment in Sample Problem 2, only Steps 9 through 13 are conducted. No other steps are necessary because only one C-D road segment is analyzed for a one-year period and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate SPF.
For a two-lane urban C-D road segment, SPF values for multiple-vehicle and single-vehicle crashes are determined.

Multiple-Vehicle Crashes
The SPF for multiple-vehicle fatal-and-injury crashes is calculated from Equation 19-22 and Table 19-7 as follows:

$$
\begin{aligned}
N_{spf,\,cds,\,2,\,mv,\,fi} &= L_{cd} \times \exp\left(a + b \times \ln\left[c \times AADT_c\right] + d\left[c \times AADT_c\right]\right) \\
&= 0.08 \times \exp\left(-2.515 + 0.524 \times \ln\left[0.001 \times 5{,}500\right] + 0.0699\left[0.001 \times 5{,}500\right]\right) \\
&= 0.023 \text{ crashes/year}
\end{aligned}
$$

Similarly, the SPF for multiple-vehicle property-damage-only crashes is calculated from Equation 19-22 and Table 19-7 to yield the following result:

$$N_{spf,\ cds,\ 2,\ mv,\ pdo} = 0.057 \text{ crashes/year}$$

Single-Vehicle Crashes

The SPF for single-vehicle fatal-and-injury crashes is calculated from Equation 19-26 and Table 19-10 as follows:

$$\begin{aligned} N_{spf,\ cds,\ 2,\ sv,\ fi} &= L_{cd} \times \exp\left(a + b \times \ln\left[c \times AADT_c\right]\right) \\ &= 0.08 \times \exp\left(-2.881 + 0.718 \times \ln\left[0.001 \times 5{,}500\right]\right) \\ &= 0.015 \text{ crashes/year} \end{aligned}$$

Similarly, the SPF for single-vehicle property-damage-only crashes is calculated from Equation 19-26 and Table 19-10 to yield the following result:

$$N_{spf,\ cds,\ 2,\ sv,\ pdo} = 0.025 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs.

Each CMF used in the calculation of the predicted average crash frequency of the ramp segment is calculated in this step.

Horizontal Curve (*CMF*$_{1,\ cds,\ 2,\ y,\ z}$)

CMF$_{1,\ cds,\ 2,\ y,\ z}$ is calculated using Equation 19-33 as follows:

$$CMF_{1,\ cds,\ 2,\ y,\ z} = 1.0 + a \times \left[\frac{1{,}000}{32.2}\sum_{i=1}^{m}\left(\frac{v_{ent,i}}{R_i}\right)^2 \times P_{c,i}\right]$$

Only in-segment curves are included in the summation term. The C-D road has a curve upstream of the segment being analyzed, but there are no curves in the segment. Hence, *CMF*$_{1,\ cds,\ 2,\ y,\ z}$ is equal to 1.000.

Lane Width (*CMF*$_{2,\ cds,\ 2,\ y,\ z}$)

The segment has 14-ft lanes, which is the base condition for the lane width CMF. Hence, CMF$_{2,\ cds,\ 2,\ y,\ fi}$ and CMF$_{2,\ cds,\ 2,\ y,\ pdo}$ are equal to 1.000.

Right Shoulder Width (*CMF*3, *cds*, 2, *y*, *z*)

The segment has 8-ft right shoulders, which is the base condition for the right shoulder width CMF. Hence, CMF$_{3,\ cds,\ 2,\ y,\ fi}$ and CMF$_{3,\ cds,\ 2,\ y,\ pdo}$ are equal to 1.000.

Left Shoulder Width (*CMF*$_{4,\ cds,\ 2,\ y,\ z}$)

The segment has 4-ft left shoulders, which is the base condition for the left shoulder width CMF. Hence, CMF$_{4,\ cds,\ 2,\ y,\ fi}$ and CMF$_{4,\ cds,\ 2,\ y,\ pdo}$ are equal to 1.000.

Right Side Barrier (*CMF*$_{5,\ cds,\ 2,\ y,\ z}$)

The segment does not have right side barrier. Hence, *CMF*$_{5,\ rps,\ 1EX,\ y,\ fi}$ and *CMF*$_{5,\ rps,\ 1EX,\ y,\ pdo}$ are equal to 1.000.

Left Side Barrier (*CMF*$_{6,\ rps,\ 1EX,\ y,\ z}$)

The segment does not have left side barrier. Hence, *CMF*$_{6,\ cds,\ 2,\ y,\ fi}$ and *CMF*$_{6,\ cds,\ 2,\ y,\ pdo}$ are equal to 1.000.

Lane Add or Drop (*CMF*$_{7,\ cds,\ 2,\ y,\ fi}$)

The segment does not have a lane add or a lane drop. Hence, *CMF*$_{7,\ rps,\ 1EX,\ y,\ fi}$ is equal to 1.000.

Ramp Speed-Change Lane (*CMF*$_{8,\ cds,\ 2,\ mv,\ fi}$)

The segment does not have a speed-change lane. Hence, *CMF*$_{8,\ cds,\ 2,\ mv,\ fi}$ is equal to 1.000.

Weaving Section (*$CMF_{9,\ cds,\ 2,\ at,\ z}$*)

$CMF_{9,\ cds,\ 2,\ at,\ z}$ is calculated using Equation 19-41 as follows:

$$CMF_{9,cds,2,at,z} = (1.0 - P_{wev}) \times 1.0 + P_{wev} \times \exp\left(\frac{a + b \times \ln[c \times AADT_c]}{L_{wev}}\right)$$

From Table 19-31, $a = 0.191$, $b = -0.0715$, and $c = 0.001$ for multiple-vehicle fatal-and-injury crashes. $CMF_{9,\ cds,\ 2,\ at,\ z}$ is calculated as follows:

$$\begin{aligned} CMF_{9,cds,2,at,fi} &= (1.0 - 1.0) \times 1.0 + 1.0 \times \exp\left(\frac{0.191 - 0.0715 \times \ln[0.001 \times 5{,}500]}{0.08}\right) \\ &= 2.372 \end{aligned}$$

Similar calculations using the property-damage-only coefficients from Table 19-31 yield the following results:

$$CMF_{9,cds,2,at,pdo} = 3.009$$

Multiple-Vehicle Crashes

The CMFs are applied to the multiple-vehicle fatal-and-injury SPF as follows:

$$\begin{aligned} N_{p*,\ cds,\ 2,\ mv,\ fi} &= N_{spf,\ cds,\ 2,\ mv,\ fi} \times (CMF_{1,cds,2,mv,fi} \times \ldots \times CMF_{9,cds,2,mv,fi}) \\ &= 0.023 \times (1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 2.372) \\ &= 0.023 \times 2.372 \\ &= 0.055 \text{ crashes/year} \end{aligned}$$

The CMFs are applied to the multiple-vehicle property-damage-only SPF as follows:

$$\begin{aligned} N_{p*,\ cds,\ 2,\ mv,\ pdo} &= N_{spf,\ cds,\ 2,\ mv,\ pdo} \times (CMF_{1,cds,2,mv,pdo} \times \ldots \times CMF_{9,cds,2,mv,pdo}) \\ &= 0.057 \times (1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 3.009) \\ &= 0.057 \times 3.009 \\ &= 0.172 \text{ crashes/year} \end{aligned}$$

Single-Vehicle Crashes

The CMFs are applied to the single-vehicle fatal-and-injury SPF as follows:

$$\begin{aligned} N_{p*,\ cds,\ 2,\ sv,\ fi} &= N_{spf,\ cds,\ 2,\ sv,\ fi} \times (CMF_{1,cds,2,sv,fi} \times \ldots \times CMF_{7,cds,2,sv,fi} \times CMF_{9,cds,2,sv,fi}) \\ &= 0.015 \times (1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 2.372) \\ &= 0.015 \times 2.372 \\ &= 0.036 \text{ crashes/year} \end{aligned}$$

The CMFs are applied to the single-vehicle property-damage-only SPF as follows:

$$\begin{aligned} N_{p*,\ cds,\ 2,\ sv,\ pdo} &= N_{spf,\ cds,\ 2,\ sv,\ pdo} \times (CMF_{1,cds,2,sv,pdo} \times \ldots \times CMF_{7,cds,2,sv,pdo} \times CMF_{9,cds,2,sv,pdo}) \\ &= 0.025 \times (1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 1.000 \times 3.009) \\ &= 0.025 \times 3.009 \\ &= 0.075 \text{ crashes/year} \end{aligned}$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor of 1.00 has been determined for local conditions. As a result, $N_{p,\text{cds},2,y,z} = N_{p*,\,cds,\,2,\,y,\,z}$ for both crash types y ($y=mv$: multiple-vehicle, sv: single-vehicle) and both crash severities z ($z=fi$: fatal-and-injury, pdo: property-damage-only). See Section B.1 of Appendix B for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 19-1 based on the results obtained in Steps 9 through 11 as follows.

Fatal-and-injury crashes:

$$
\begin{aligned}
N_{p,\,cds,\,2,\,at,\,fi} &= N_{p,\,cds,\,2,\,mv,\,fi} + N_{p,\,cds,\,2,\,sv,\,fi} \\
&= 0.055 + 0.036 \\
&= 0.091 \text{ crashes/year}
\end{aligned}
$$

Property-damage-only crashes:

$$
\begin{aligned}
N_{p,\,cds,\,2,\,at,\,pdo} &= N_{p,\,cds,\,2,\,mv,\,pdo} + N_{p,\,cds,\,2,\,sv,\,pdo} \\
&= 0.172 + 0.075 \\
&= 0.247 \text{ crashes/year}
\end{aligned}
$$

Step 12—If there is another year to be evaluated in the evaluation period for the selected site, return to Step 8. Otherwise, proceed to Step 13.
The study period is one year (2011), so steps 8 through 11 need not be repeated.

Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.
This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

Apply the site-specific EB Method to a future time period, if appropriate.
The site-specific EB Method is not applied in this sample problem because crash data are not available.

Apply the severity distribution functions (SDFs), if desired.
To apply the SDFs, the systematic component of crash severity likelihood V_j is computed for each severity level j using Equation 19-83 as follows:

$$
V_j = a + \left(b \times \frac{P_{lb} + P_{rb}}{2}\right) + (c \times n) + (d \times I_{rural}) + (e \times I_{exr})
$$

The coefficients a, b, c, d, and e are obtained from Table 19-43 for each severity level j. The segment does not have barrier, so P_{lb} and P_{rb} are equal to 0.0. V_j is computed for fatal and incapacitating injury crashes as follows:

$$
\begin{aligned}
V_{K+A} &= -1.537 + \left(0.481 \times \frac{0.0 + 0.0}{2}\right) + (-0.228 \times 2.0) + (0.668 \times 0.0) + (0.426 \times 0.0) \\
&= -1.993
\end{aligned}
$$

Similar calculations using the coefficients from Table 19-43 for non-incapacitating injury crashes yield the following results:

$$V_B = -0.634$$

Using these computed V_{K+A} and V_B values, and assuming a calibration factor $C_{sdf,\,rps+cds}$ of 1.0, the probability of occurrence of a fatal crash is computed using Equation 19-79 as follows:

$$\begin{aligned} P_{rps+cds,ac,at,K} &= \frac{\exp(V_{K+A})}{\frac{1.0}{C_{sdf,rps+cds}} + \exp(V_{K+A}) + \exp(V_B)} \times P_{K|K+A,rps+cds,ac,at} \\ &= \frac{\exp(-1.993)}{\frac{1.0}{1.0} + \exp(-1.993) + \exp(-0.634)} \times 0.248 \\ &= 0.022 \end{aligned}$$

Similar calculations using Equations 19-80 and 19-81 yield the following results:

$$P_{rps+cds,ac,at,A} = 0.065$$

$$P_{rps+cds,ac,at,B} = 0.315$$

The probability of occurrence of a possible-injury crash is computed using Equation 19-82 as follows:

$$\begin{aligned} P_{rps+cds,ac,at,C} &= 1.0 - (P_{rps+cds,ac,at,K} + P_{rps+cds,ac,at,A} + P_{rps+cds,ac,at,B}) \\ &= 1.0 - (0.022 + 0.065 + 0.315) \\ &= 0.598 \end{aligned}$$

The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 19-78 as follows:

$$\begin{aligned} N_{e,cds,2,at,K} &= N_{e,cds,2,at,fi} \times P_{rps+cds,ac,at,K} \\ &= 0.091 \times 0.022 \\ &= 0.002 \text{ crashes/year} \end{aligned}$$

Similar calculations using Equation 19-78 and the probabilities of occurrences of the other crash severities yield the following results:

$$N_{e,cds,2,at,A} = 0.006 \text{ crashes/year}$$

$$N_{e,cds,2,at,B} = 0.029 \text{ crashes/year}$$

$$N_{e,cds,2,at,C} = 0.055 \text{ crashes/year}$$

Apply the crash type distribution, if desired.

The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 19-6 and Table 19-9 by the predicted average crash frequencies obtained in Step 11.

WORKSHEETS

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

- Table 19-51. Ramp Segment Worksheet (1 of 4)—Sample Problem 2
- Table 19-52. Ramp Segment Worksheet (2 of 4)—Sample Problem 2
- Table 19-53. Ramp Segment Worksheet (3 of 4)—Sample Problem 2
- Table 19-54. Ramp Segment Worksheet (4 of 4)—Sample Problem 2

Filled versions of these worksheets are provided below. A blank version of the corresponding worksheets used in all Sample Problems is provided in Appendix 19A.

Table 19-51 is a summary of general information about the ramp segment, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 2. The input data include area type, crash data, basic roadway data, and alignment data.

Table 19-52 is a summary of general information about the ramp segment, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 2. The input data include cross section data, roadside data, ramp access data, and traffic data.

Table 19-53 is a tabulation of the CMF and SPF computations for Sample Problem 2.

Table 19-54 is a tabulation of the crash severity and crash type distributions for Sample Problem 2.

Table 19-51. Ramp Segment Worksheet (1 of 4)—Sample Problem 2

General Information						Location Information	
Analyst						Roadway	
Agency or company						Roadway section	
Date performed						Study year	
Area type	X	Urban		Rural			

Input Data

Crash Data		Crash Period	Study Year	Complete the study year column. Complete the crash period column if the EB Method is used.				
Crash data time period				First year	--	Last year	--	
Count of multiple-vehicle FI crashes N*o, w, n, mv, fi								
Count of single-vehicle FI crashes N*o, w, n, sv, fi								
Count of multiple-vehicle PDO crashes N*o, w, n, mv, pdo								
Count of single-vehicle PDO crashes N*o, w, n, sv, pdo								
Basic Roadway Data								
Number of through lanes n		2		Same value for crash period and study year.				
Segment length L (mi)			0.08					
Average traffic speed on the freeway Vfrwy (mi/h)			60					
Segment type		C-D Road		Choices: Entrance, Exit, C-D road, Connector				
Type of control at crossroad ramp terminal			--	Choices: Stop, Yield, Signal, None				
Alignment Data								
Horizontal Curve Data								
1	Presence of horizontal curve 1		Off Seg.	Choices: No, In segment, Off segment.				
	Curve radius R1 (ft)		1,100	If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.				
	Length of curve Lc1 (mi)		0.08					
	Length of curve in segment Lc1, seg (mi)		--					
	Ramp-mile of beginning of curve in dir. of travel X1 (mi)		0.09					
2	Presence of horizontal curve 2		No	Choices: No, In segment, Off segment				
	Curve radius R2 (ft)		--	If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.				
	Length of curve Lc2 (mi)		--					
	Length of curve in segment Lc2, seg (mi)		--					
	Ramp-mile of beginning of curve in dir. of travel X2 (mi)		--					
3	Presence of horizontal curve 3		No	Choices: No, In segment, Off segment				
	Curve radius R3 (ft)		--	If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.				
	Length of curve Lc3 (mi)		--					
	Length of curve in segment Lc3, seg (mi)		--					
	Ramp-mile of beginning of curve in dir. of travel X3 (mi)		--					
4	Presence of horizontal curve 4		No	Choices: No, In segment, Off segment				
	Curve radius R4 (ft)		--	If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.				
	Length of curve Lc4 (mi)		--					
	Length of curve in segment Lc4, seg (mi)		--					
	Ramp-mile of beginning of curve in dir. of travel X4 (mi)		--					

Table 19-52. Ramp Segment Worksheet (2 of 4)—Sample Problem 2

Input Data						
Cross Section Data		Crash Period		Study Year		Complete the study year column. Complete the crash period column if the EB Method is used.
Lane width W_l (ft)		--		14		
Right shoulder width W_{rs} (ft)		--		8		
Left shoulder width W_{ls} (ft)		--		4		
Presence of lane add or lane drop		--		No		Choices: No, Lane add, Lane drop
Length of taper in segment $L_{add, seg}$ or $L_{drop, seg}$ (mi)		--		--		If “Lane add” or “Lane drop”, enter length.
Roadside Data						
Presence of barrier on right side of roadway		--	Y/N	N	Y/N	If Yes, then use the ramp barrier worksheet.
Presence of barrier on left side of roadway		--	Y/N	N	Y/N	If Yes, then use the ramp barrier worksheet.
Ramp Access Data						
Ramp Entrance						
Ent. ramp	Presence of speed-change lane in segment	--	Y/N	N	Y/N	If Yes, then enter data in the next row.
	Length of s-c lane in segment $L_{en,seg}$ (mi)	--		--		
Exit ramp	Presence of speed-change lane in segment	--	Y/N	N	Y/N	If Yes, then enter data in the next row.
	Length of s-c lane in segment $L_{ex,seg}$ (mi)	--		--		
Weave	Presence of a weaving section in segment	--	Y/N	Y	Y/N	If Yes, then enter data in the next two rows.
	Length of weaving section L_{wev} (mi)	--		0.08		
	Length of weaving section in seg. $L_{wev, seg}$ (mi)	--		0.08		
Traffic Data						
Segment AADT $AADT_r$ or $AADT_c$ (veh/day)		--		5,500		

Table 19-53. Ramp Segment Worksheet (3 of 4)—Sample Problem 2

Crash Modification Factors

Complete the study year column. Complete the crash period column if the EB Method is used.	Equation	Fatal and Injury				Property Damage Only			
		Multiple Vehicle		Single Vehicle		Multiple Vehicle		Single Vehicle	
		Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year
Horizontal curve $CMF_{1, w, x, y, z}$	19-33	--	1.000	--	1.000	--	1.000	--	1.000
Lane width $CMF_{2, w, x, y, fi}$	19-34	--	1.000	--	1.000				
Right shoulder width $CMF_{3, w, x, y, z}$	19-35	--	1.000	--	1.000	--	1.000	--	1.000
Left shoulder width $CMF_{4, w, x, y, z}$	19-36	--	1.000	--	1.000	--	1.000	--	1.000
Right side barrier $CMF_{5, w, x, y, z}$	19-37	--	1.000	--	1.000	--	1.000	--	1.000
Left side barrier $CMF_{6, w, x, y, z}$	19-38	--	1.000	--	1.000	--	1.000	--	1.000
Lane add or drop $CMF_{7, w, x, y, fi}$	19-39	--	1.000	--	1.000				
Ramp speed-change lane $CMF_{8, w, x, mv, fi}$	19-40	--	1.000						
Weaving section $CMF_{9, cds, ac, y, z}$	19-41	--	2.372	--	2.372	--	3.009	--	3.009
Combined CMF (multiply all CMFs evaluated)		--	2.372	--	2.372	--	3.009	--	3.009

Expected Average Crash Frequency [a]

Complete the study year column. Complete the crash period column if the ***site-specific*** EB Method is used.	Fatal and Injury				Property Damage Only			
	Multiple Vehicle		Single Vehicle		Multiple Vehicle		Single Vehicle	
	Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year
Calibration factor $C_{w, x, y, z}$	1.00		1.00		1.00		1.00	
Overdispersion parameter $k_{w, x, y, z}$	--		--		--		--	
Observed crash count $N^*_{o, w, x, y, z}$ (cr)	--		--		--		--	
Reference year r	--		--		--		--	
Predicted average crash freq. for reference year $N_{p, w, x, y, z, r}$ (cr/yr)	--		--		--		--	
Predicted number of crashes for crash period (sum all years) $N^*_{p, w, x, y, z}$ (cr)	--		--		--		--	
Equivalent years associated with crash count $C_{b, w, x, y, z, r}$ (yr)	--		--		--		--	
Adjusted average crash freq. for ref. year given N^*_o, $N_{a, w, x, y, z, r}$ (cr/yr)	--		--		--		--	
Study year s		2011		2011		2011		2011
Predicted average crash freq. for study year $N_{p, w, x, y, z, s}$ (cr/yr)		0.055		0.036		0.172		0.075
Expected average crash freq. for study year $N_{e, w, x, y, z, s}$ (cr/yr)		0.055		0.036		0.172		0.075
Expected average crash freq. for study year (all crash types) $N_{e, w, x, at, z, s}$ (cr/yr)			0.091				0.247	

[a] If the EB Method is not used, then substitute the word "predicted" for the word "expected" and substitute the subscript "p" for the subscript "e".

Table 19-54. Ramp Segment Worksheet (4 of 4)—Sample Problem 2

Expected Average Crash Frequency [a]							
Crash Severity Distribution							
	K	A	B	C	Total FI	PDO	Total FI + PDO
Proportion by injury level	0.022	0.065	0.315	0.598	1.000		
Expected average crash freq. for study year (all crash types) $N_{e,\,w,\,x,\,at,\,z,\,s}$ (cr/yr)	0.002	0.006	0.029	0.055	0.091	0.247	0.338

Crash Type Distribution

Crash Type Category	Table	Fatal and Injury		Property Damage Only		Total
		Proportion	Expected Average Crash Frequency for Study Year $N_{e,\,w,\,x,\,y,\,fi,\,s}$ (cr/yr)	Proportion	Expected Average Crash Frequency for Study Year $N_{e,\,w,\,x,\,y,\,pdo,\,s}$ (cr/yr)	Expected Average Crash Frequency for Study Year $N_{e,\,w,\,x,\,y,\,as,\,s}$ (cr/yr)
Multiple-Vehicle Crashes	19-6					
Head-on		0.015	0.001	0.009	0.002	0.002
Right-angle		0.010	0.001	0.005	0.001	0.001
Rear-end		0.707	0.039	0.550	0.095	0.134
Sideswipe		0.129	0.007	0.335	0.058	0.065
Other multiple-vehicle crashes		0.139	0.008	0.101	0.017	0.025
Total		1.000	0.055	1.000	0.172	0.227
Single-Vehicle Crashes	19-9					
Crash with animal		0.003	0.000	0.005	0.000	0.000
Crash with fixed object		0.718	0.026	0.834	0.062	0.088
Crash with other object		0.015	0.001	0.023	0.002	0.002
Crash with parked vehicle		0.012	0.000	0.012	0.001	0.001
Other single-vehicle crashes		0.252	0.009	0.126	0.009	0.019
Total		1.000	0.036	1.000	0.075	0.111

[a] If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e”.

19.14.3. Sample Problem 3

The Site/Facility
A one-lane urban entrance ramp segment.

The Question
What is the predicted average crash frequency of the ramp segment for a one-year period?

The Facts
The study year is 2011. The conditions present during this year are provided in the following list:

- 0.3-mi length
- 7,250 veh/day
- 65-mi/h average speed on freeway mainline
- Yield control at crossroad ramp terminal
- One in-segment horizontal curve
  - 475-ft radius
  - 0.08-mi length, entirely in the segment
  - Beginning at ramp-mile 0.07
- 14-ft lane width
- 8-ft right shoulder width (paved)
- 4-ft left shoulder width (paved)
- No lane adds or lane drops
- Barrier on both sides of the roadway
  - Right-side barrier length: 0.15 mi
  - Right-side barrier offset: 9 ft
  - Left-side barrier length: 0.15 mi
  - Left-side barrier offset: 5 ft
- No ramp entrances or exits in the segment
- No weaving section

Assumptions

- Crash type distributions used are the default values presented in Table 19-6 and Table 19-9.
- The calibration factor is 1.00.

Results
Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the ramp segment in Sample Problem 3 is determined to be 0.3 crashes per year, and the predicted average property-damage-only crash frequency 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 ramp segment in Sample Problem 3, only Steps 9 through 13 are conducted. No other steps are necessary because only one ramp segment is analyzed for a one-year period and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate SPF.
For a one-lane urban exit ramp segment, SPF values for multiple-vehicle and single-vehicle crashes are determined.

Multiple-Vehicle Crashes

The SPF for multiple-vehicle fatal-and-injury crashes is calculated from Equation 19-20 and Table 19-5 as follows:

$$\begin{aligned} N_{spf,\ rps,1EN,\ mv,\ fi} &= L_r \times \exp\left(a + b \times \ln\left[c \times AADT_r\right] + d\left[c \times AADT_r\right]\right) \\ &= 0.3 \times \exp\left(-3.505 + 0.524 \times \ln\left[0.001 \times 7{,}250\right] + 0.0699\left[0.001 \times 7{,}250\right]\right) \\ &= 0.042 \text{ crashes/year} \end{aligned}$$

Similarly, the SPF for multiple-vehicle property-damage-only crashes is calculated from Equation 19-20 and Table 19-5 to yield the following result:

$$N_{spf,\ rps,1EN,\ mv,\ pdo} = 0.079 \text{ crashes/year}$$

Single-Vehicle Crashes

The SPF for single-vehicle fatal-and-injury crashes is calculated from Equation 19-24 and Table 19-8 as follows:

$$\begin{aligned} N_{spf,\ rps,1EN,\ sv,\ fi} &= L_r \times \exp\left(a + b \times \ln\left[c \times AADT_r\right]\right) \\ &= 0.3 \times \exp\left(-1.966 + 0.718 \times \ln\left[0.001 \times 7{,}250\right]\right) \\ &= 0.174 \text{ crashes/year} \end{aligned}$$

Similarly, the SPF for single-vehicle property-damage-only crashes is calculated from Equation 19-24 and Table 19-8 to yield the following result:

$$N_{spf,\ rps,1EN,\ sv,\ pdo} = 0.211 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs.

Each CMF used in the calculation of the predicted average crash frequency of the ramp segment is calculated in this step.

Horizontal Curve ($CMF_{1,\ rps,\ 1EN,\ y,\ z}$)

The limited curve speed for the in-segment horizontal curve is computed using Equation 19-59 as follows:

$$\begin{aligned} v_{\max,1} &= 3.24 \times \left(32.2 \times R_1\right)^{0.30} \\ &= 3.24 \times \left(32.2 \times 475\right)^{0.30} \\ &= 58.3 \text{ ft/s} \end{aligned}$$

The average entry speed at the curve is computed using Equation 19-60 and the default values in Table 19-42 as follows:

$$\begin{aligned} v_{ent,1} &= Min\begin{cases} \left(\left[1.47 \times V_{xroad}\right]^3 + 495 \times 5{,}280 \times X_1\right)^{1/3} \\ 1.47 \times V_{frwy} \end{cases} \\ &= Min\begin{cases} \left(\left[1.47 \times 15\right]^3 + 495 \times 5{,}280 \times 0.07\right)^{1/3} \\ 1.47 \times 65 \end{cases} \\ &= Min\begin{cases} 57.9 \\ 95.55 \end{cases} \\ &= 57.9 \text{ ft/s} \end{aligned}$$

The average exit speed at curve 1 is computed using Equation 19-61 as follows:

$$v_{ext,1} = Min\begin{cases}\min\begin{cases}\left(v_{ent,1}^3 + 495 \times 5,280 \times L_{c,1}\right)^{1/3} \\ v_{\max,1}\end{cases} \\ 1.47 \times V_{frwy}\end{cases}$$

$$= Min\begin{cases}\min\begin{cases}\left(57.9^3 + 495 \times 5,280 \times 0.3\right)^{1/3} \\ 58.3\end{cases} \\ 1.47 \times 65\end{cases}$$

$$= Min\begin{cases}58.3 \\ 95.55\end{cases}$$

$$= 58.3 \text{ ft/s}$$

$CMF_{1,\,rps,\,1EN,\,y,\,fi}$ is calculated using Equation 19-33 as follows:

$$CMF_{1,\,rps,\,1EN,\,y,\,fi} = 1.0 + a \times \left[\frac{1,000}{32.2}\sum_{i=1}^{m}\left(\frac{v_{ent,i}}{R_i}\right)^2 \times P_{c,i}\right]$$

From Table 19-24, $a = 0.779$ for multiple-vehicle fatal-and-injury crashes and 2.406 for single-vehicle fatal-and-injury crashes. $CMF_{1,\,rps,\,1EN,\,mv,\,fi}$ is calculated as follows:

$$CMF_{1,\,rps,\,1EN,\,mv,\,fi} = 1.0 + 0.779 \times \frac{1,000}{32.2}\left(\frac{57.9}{475}\right)^2 \times \frac{0.08}{0.3}$$

$$= 1.096$$

Calculations using the other coefficients from Table 19-24 yield the following results:

$$CMF_{1,\,rps,\,1EN,\,sv,\,fi} = 1.296$$

$$CMF_{1,\,rps,\,1EN,\,mv,\,pdo} = 1.067$$

$$CMF_{1,\,rps,\,1EN,\,sv,\,pdo} = 1.385$$

Lane Width (**$CMF_{2,\,rps,\,1EN,\,y,\,z}$**)

The segment has 14-ft lanes, which is the base condition for the lane width CMF. Hence, $CMF_{2,\,rps,\,1EN,\,y,\,fi}$ and $CMF_{2,\,rps,\,1EN,\,y,\,pdo}$ are equal to 1.000.

Right Shoulder Width ($CMF_{3,\,rps,\,1EN,\,y,\,z}$)

The segment has 8-ft right shoulders, which is the base condition for the right shoulder width CMF. Hence, $CMF_{3,\,rps,\,1EN,\,y,\,fi}$ and $CMF_{3,\,rps,\,1EN,\,y,\,pdo}$ are equal to 1.000.

Left Shoulder Width ($CMF_{4,\,rps,\,1EN,\,y,\,z}$)

The segment has 4-ft left shoulders, which is the base condition for the left shoulder width CMF. Hence, $CMF_{4,\,rps,\,1EN,\,y,\,fi}$ and $CMF_{4,\,rps,\,1EN,\,y,\,pdo}$ are equal to 1.000.

Right Side Barrier ($CMF_{5,\,rps,\,1EN,\,y,\,z}$)

$CMF_{5,\,rps,\,1EN,\,y,\,fi}$ is calculated using Equation 19-37 as follows:

$$CMF_{5,\,rps,\,1EN,\,y,\,fi} = (1.0 - P_{rb}) \times 1.0 + P_{rb} \times \exp\left(\frac{a}{W_{rcb}}\right)$$

The distance from the edge of the right shoulder to the barrier face W_{rcb} is computed using Equation 19-74 as follows:

$$\begin{aligned} W_{rcb} &= \frac{\sum L_{rb,\,i}}{\sum \dfrac{L_{rb,\,i}}{W_{off,\,r,\,i} - W_{rs}}} \\ &= \frac{0.15}{\left(\dfrac{0.15}{9 - 8}\right)} \\ &= 1.0 \end{aligned}$$

From Table 19-28, $a = 0.210$ for multiple-vehicle crashes. $CMF_{5,\,rps,\,1EN,\,y,\,fi}$ is calculated as follows:

$$\begin{aligned} CMF_{5,\,rps,\,1EN,\,y,\,fi} &= \left(1.0 - \frac{0.15}{0.3}\right) \times 1.0 + \frac{0.15}{0.3} \times \exp\left(\frac{0.210}{1.0}\right) \\ &= 1.117 \end{aligned}$$

Similar calculations using the property-damage-only coefficients from Table 19-28 yield the following results:

$$CMF_{5,\,rps,\,1EN,\,y,\,pdo} = 1.106$$

Left Side Barrier ($CMF_{6,\,rps,\,1EN,\,y,\,z}$)

$CMF_{6,\,rps,\,1EN,\,y,\,fi}$ is calculated using Equation 19-38 as follows:

$$CMF_{6,\,rps,\,1EN,\,y,\,fi} = (1.0 - P_{lb}) \times 1.0 + P_{lb} \times \exp\left(\frac{a}{W_{lcb}}\right)$$

The distance from the edge of the right shoulder to the barrier face W_{rcb} is computed using Equation 19-76 as follows:

$$\begin{aligned} W_{lcb} &= \frac{\sum L_{lb,\,i}}{\sum \dfrac{L_{lb,\,i}}{W_{off,\,l,\,i} - W_{ls}}} \\ &= \frac{0.15}{\left(\dfrac{0.15}{5 - 4}\right)} \\ &= 1.0 \end{aligned}$$

From Table 19-29, $a = 0.210$ for multiple-vehicle crashes. $CMF_{6,\,rps,\,1EN,\,y,\,fi}$ is calculated as follows:

$$
\begin{aligned}
CMF_{6,\,rps,\,1EN,\,y,\,fi} &= \left(1.0-\frac{0.15}{0.3}\right) 1.0+\frac{0.15}{0.3}\times\exp\left(\frac{0.210}{1.0}\right)\\
&= 1.117
\end{aligned}
$$

Similar calculations using the property-damage-only coefficients from Table 19-29 yield the following results:

$$CMF_{6,\,rps,1EN,\,y,\,pdo} = 1.106$$

Lane Add or Drop ($CMF_{7,\,rps,\,1EN,\,y,\,fi}$)

The segment does not have a lane add or a lane drop. Hence, $CMF_{7,\,rps,\,1EN,\,y,\,fi}$ is equal to 1.000.

Ramp Speed-Change Lane ($CMF_{8,\,rps,\,1EN,\,mv,\,fi}$)

The segment does not have a speed-change lane. Hence, $CMF_{8,\,rps,\,1EN,\,mv,\,fi}$ is equal to 1.000.

Multiple-Vehicle Crashes

The CMFs are applied to the multiple-vehicle fatal-and-injury SPF as follows:

$$
\begin{aligned}
N_{p*,\,rps,1EN,\,mv,\,fi} &= N_{spf,\,rps,1EN,\,mv,\,fi}\times\left(CMF_{1,rps,1EN,mv,\,fi}\times\ldots\times CMF_{8,rps,1EN,mv,\,fi}\right)\\
&= 0.042\times(1.096\times 1.000\times 1.000\times 1.000\times 1.117\times 1.117\times 1.000\times 1.000)\\
&= 0.042\times 1.367\\
&= 0.058 \text{ crashes/year}
\end{aligned}
$$

The CMFs are applied to the multiple-vehicle property-damage-only SPF as follows:

$$
\begin{aligned}
N_{p*,\,rps,1EN,\,mv,\,pdo} &= N_{spf,\,rps,1EN,\,mv,\,pdo}\times\left(CMF_{1,rps,1EN,mv,pdo}\times\ldots\times CMF_{8,rps,1EN,mv,pdo}\right)\\
&= 0.079\times(1.067\times 1.000\times 1.000\times 1.000\times 1.106\times 1.106\times 1.000\times 1.000)\\
&= 0.079\times 1.305\\
&= 0.103 \text{ crashes/year}
\end{aligned}
$$

Single-Vehicle Crashes

The CMFs are applied to the single-vehicle fatal-and-injury SPF as follows:

$$
\begin{aligned}
N_{p*,\,rps,1EN,\,sv,\,fi} &= N_{spf,\,rps,1EN,\,sv,\,fi}\times\left(CMF_{1,rps,1EN,sv,\,fi}\times\ldots\times CMF_{8,rps,1EN,sv,\,fi}\right)\\
&= 0.174\times(1.296\times 1.000\times 1.000\times 1.000\times 1.117\times 1.117\times 1.000\times 1.000)\\
&= 0.174\times 1.617\\
&= 0.281 \text{ crashes/year}
\end{aligned}
$$

The CMFs are applied to the single-vehicle property-damage-only SPF as follows:

$$
\begin{aligned}
N_{p*,\,rps,1EN,\,sv,\,pdo} &= N_{spf,\,rps,1EN,\,sv,\,pdo}\times\left(CMF_{1,rps,1EN,sv,pdo}\times\ldots\times CMF_{8,rps,1EN,sv,pdo}\right)\\
&= 0.211\times(1.385\times 1.000\times 1.000\times 1.000\times 1.106\times 1.106\times 1.000\times 1.000)\\
&= 0.211\times 1.694\\
&= 0.358 \text{ crashes/year}
\end{aligned}
$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor of 1.00 has been determined for local conditions. As a result, $N_{p,rps,1EN,y,z} = N_{p*,rps,1EN,y,z}$ for both crash types y ($y = mv$: multiple-vehicle, sv: single-vehicle) and both crash severities z ($z = fi$: fatal-and-injury, pdo: property-damage-only). See Section B.1 of Appendix B for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 19-1 based on the results obtained in Steps 9 through 11 as follows.

Fatal-and-injury crashes:

$$\begin{aligned} N_{p,\,rps,1EN,\,at,\,fi} &= N_{p,\,rps,1EN,\,mv,\,fi} + N_{p,\,rps,1EN,\,sv,\,fi} \\ &= 0.058 + 0.281 \\ &= 0.339 \text{ crashes/year} \end{aligned}$$

Property-damage-only crashes:

$$\begin{aligned} N_{p,\,rps,1EN,\,at,\,pdo} &= N_{p,\,rps,1EN,\,mv,\,pdo} + N_{p,\,rps,1EN,\,sv,\,pdo} \\ &= 0.104 + 0.358 \\ &= 0.461 \text{ crashes/year} \end{aligned}$$

Step 12—If there is another year to be evaluated in the evaluation period for the selected site, return to Step 8. Otherwise, proceed to Step 13.
The study period is one year (2011), so steps 8 through 11 need not be repeated.

Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.
This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

Apply the site-specific EB Method to a future time period, if appropriate.
The site-specific EB Method is not applied in this sample problem because crash data are not available.

Apply the severity distribution functions (SDFs), if desired.
To apply the SDFs, the systematic component of crash severity likelihood V_j is computed for each severity level j using Equation 19-83 as follows:

$$V_j = a + \left(b \times \frac{P_{lb} + P_{rb}}{2}\right) + (c \times n) + (d \times I_{rural}) + (e \times I_{exr})$$

The coefficients a, b, c, d, and e are obtained from Table 19-43 for each severity level j. V_j is computed for fatal and incapacitating injury crashes as follows:

$$\begin{aligned} V_{K+A} &= -1.537 + \left(0.481 \times \frac{0.5 + 0.5}{2}\right) + (-0.228 \times 1.0) + (0.668 \times 0.0) + (0.426 \times 0.0) \\ &= -2.006 \end{aligned}$$

Similar calculations using the coefficients from Table 19-43 for non-incapacitating injury crashes yield the following results:

$$V_B = -0.415$$

Using these computed V_{K+A} and V_B values, and assuming a calibration factor $C_{sdf,\,rps+cds}$ of 1.0, the probability of occurrence of a fatal crash is computed using Equation 19-79 as follows:

$$
\begin{aligned}
P_{rps+cds,ac,at,K} &= \frac{\exp(V_{K+A})}{\dfrac{1.0}{C_{sdf,rps+cds}} + \exp(V_{K+A}) + \exp(V_B)} \times P_{K|K+A,rps+cds,ac,at} \\
&= \frac{\exp(-2.006)}{\dfrac{1.0}{1.0} + \exp(-2.006) + \exp(-0.415)} \times 0.248 \\
&= 0.018
\end{aligned}
$$

Similar calculations using Equations 19-80 and 19-81 yield the following results:

$$P_{rps+cds,ac,at,A} = 0.056$$

$$P_{rps+cds,ac,at,B} = 0.369$$

The probability of occurrence of a possible-injury crash is computed using Equation 19-82 as follows:

$$
\begin{aligned}
P_{rps+cds,ac,at,C} &= 1.0 - (P_{rps+cds,ac,at,K} + P_{rps+cds,ac,at,A} + P_{rps+cds,ac,at,B}) \\
&= 1.0 - (0.018 + 0.056 + 0.369) \\
&= 0.557
\end{aligned}
$$

The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 19-78 as follows:

$$
\begin{aligned}
N_{e,rps,1EN,at,K} &= N_{e,rps,1EN,at,fi} \times P_{rps+cds,ac,at,K} \\
&= 0.339 \times 0.018 \\
&= 0.006 \text{ crashes/year}
\end{aligned}
$$

Similar calculations using Equation 19-78 and the probabilities of occurrences of the other crash severities yield the following results:

$$N_{e,rps,1EN,at,A} = 0.019 \text{ crashes/year}$$

$$N_{e,rps,1EN,at,B} = 0.125 \text{ crashes/year}$$

$$N_{e,rps,1EN,at,C} = 0.189 \text{ crashes/year}$$

Apply the crash type distribution, if desired.
The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 19-6 and Table 19-9 by the predicted average crash frequencies obtained in Step 11.

WORKSHEETS

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

- Table 19-55. Ramp Segment Worksheet (1 of 4)—Sample Problem 3
- Table 19-56. Ramp Segment Worksheet (2 of 4)—Sample Problem 3
- Table 19-57. Ramp Segment Worksheet (3 of 4)—Sample Problem 3
- Table 19-58. Ramp Segment Worksheet (4 of 4)—Sample Problem 3
- Table 19-59. Ramp Barrier Worksheet—Sample Problem 3

Filled versions of these worksheets are provided below. A blank version of the corresponding worksheets used in all Sample Problems is provided in Appendix 19A.

Table 19-55 is a summary of general information about the ramp segment, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 3. The input data include area type, crash data, basic roadway data, and alignment data.

Table 19-56 is a summary of general information about the ramp segment, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 3. The input data include cross section data, roadside data, ramp access data, and traffic data.

Table 19-57 is a tabulation of the CMF and SPF computations for Sample Problem 3.

Table 19-58 is a tabulation of the crash severity and crash type distributions for Sample Problem 3.

Table 19-59 is used to complete the barrier calculations for Sample Problem 3.

Table 19-55. Ramp Segment Worksheet (1 of 4)—Sample Problem 3

General Information						Location Information	
Analyst						Roadway	
Agency or company						Roadway section	
Date performed						Study year	
Area type	X	Urban		Rural			

Input Data				
Crash Data		Crash Period	Study Year	Complete the study year column. Complete the crash period column if the EB Method is used.
Crash data time period				First year -- Last year --
Count of multiple-vehicle FI crashes $N^*_{o,w,n,mv,fi}$		--		
Count of single-vehicle FI crashes $N^*_{o,w,n,sv,fi}$		--		
Count of multiple-vehicle PDO crashes $N^*_{o,w,n,mv,pdo}$		--		
Count of single-vehicle PDO crashes $N^*_{o,w,n,sv,pdo}$		--		
Basic Roadway Data				
Number of through lanes n		1		Same value for crash period and study year.
Segment length L (mi)		--	0.3	
Average traffic speed on the freeway V_{frwy} (mi/h)		--	65	
Segment type		Entrance		Choices: Entrance, Exit, C-D road, Connector
Type of control at crossroad ramp terminal		--	Yield	Choices: Stop, Yield, Signal, None
Alignment Data				
Horizontal Curve Data				
1	Presence of horizontal curve 1	--	In Seg.	Choices: No, In segment, Off segment.
	Curve radius R_1 (ft)	--	475	If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.
	Length of curve L_{c1} (mi)	--	0.08	
	Length of curve in segment $L_{c1,seg}$ (mi)	--	0.08	
	Ramp-mile of beginning of curve in dir. of travel X_1 (mi)	--	0.07	
2	Presence of horizontal curve 2	--	No	Choices: No, In segment, Off segment
	Curve radius R_2 (ft)	--	--	If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.
	Length of curve L_{c2} (mi)	--	--	
	Length of curve in segment $L_{c2,seg}$ (mi)	--	--	
	Ramp-mile of beginning of curve in dir. of travel X_2 (mi)	--	--	
3	Presence of horizontal curve 3	--	No	Choices: No, In segment, Off segment
	Curve radius R_3 (ft)	--	--	If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.
	Length of curve L_{c3} (mi)	--	--	
	Length of curve in segment $L_{c3,seg}$ (mi)	--	--	
	Ramp-mile of beginning of curve in dir. of travel X_3 (mi)	--	--	
4	Presence of horizontal curve 4	--	No	Choices: No, In segment, Off segment
	Curve radius R_4 (ft)	--	--	If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.
	Length of curve L_{c4} (mi)	--	--	
	Length of curve in segment $L_{c4,seg}$ (mi)	--	--	
	Ramp-mile of beginning of curve in dir. of travel X_4 (mi)	--	--	

Table 19-56. Ramp Segment Worksheet (2 of 4)—Sample Problem 3

Input Data						
Cross Section Data		Crash Period		Study Year		Complete the study year column. Complete the crash period column if the EB Method is used.
Lane width W_l (ft)		--		14		
Right shoulder width W_{rs} (ft)		--		8		
Left shoulder width W_{ls} (ft)		--		4		
Presence of lane add or lane drop		--		No		Choices: No, Lane add, Lane drop
Length of taper in segment $L_{add,\,seg}$ or $L_{drop,\,seg}$ (mi)		--		--		If “Lane add” or “Lane drop”, enter length.
Roadside Data						
Presence of barrier on right side of roadway		--	Y/N	Y	Y/N	If Yes, then use the ramp barrier worksheet.
Presence of barrier on left side of roadway		--	Y/N	Y	Y/N	If Yes, then use the ramp barrier worksheet.
Ramp Access Data						
Ramp Entrance						
Ent. ramp	Presence of speed-change lane in segment	--	Y/N	N	Y/N	If Yes, then enter data in the next row.
	Length of s-c lane in segment $L_{en,seg}$ (mi)	--		--		
Exit ramp	Presence of speed-change lane in segment	--	Y/N	N	Y/N	If Yes, then enter data in the next row.
	Length of s-c lane in segment $L_{ex,seg}$ (mi)	--		--		
Weave	Presence of a weaving section in segment	--	Y/N	--	Y/N	If Yes, then enter data in the next two rows.
	Length of weaving section L_{wev} (mi)	--		--		
	Length of weaving section in seg. $L_{wev,\,seg}$ (mi)	--		--		
Traffic Data						
Segment AADT $AADT_r$ or $AADT_c$ (veh/day)		--		7,250		

Table 19-57. Ramp Segment Worksheet (3 of 4)—Sample Problem 3

Crash Modification Factors									
Complete the study year column. Complete the crash period column if the EB Method is used.		Fatal and Injury				Property Damage Only			
		Multiple Vehicle		Single Vehicle		Multiple Vehicle		Single Vehicle	
	Equation	Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year
Horizontal curve $CMF_{1, w, x, y, z}$	19-33	--	1.096	--	1.296	--	1.067	--	1.385
Lane width $CMF_{2, w, x, y, fi}$	19-34	--	1.000	--	1.000				
Right shoulder width $CMF_{3, w, x, y, z}$	19-35	--	1.000	--	1.000	--	1.000	--	1.000
Left shoulder width $CMF_{4, w, x, y, z}$	19-36	--	1.000	--	1.000	--	1.000	--	1.000
Right side barrier $CMF_{5, w, x, y, z}$	19-37	--	1.117	--	1.117	--	1.106	--	1.106
Left side barrier $CMF_{6, w, x, y, z}$	19-38	--	1.117	--	1.117	--	1.106	--	1.106
Lane add or drop $CMF_{7, w, x, y, fi}$	19-39	--	1.000	--	1.000				
Ramp speed-change lane $CMF_{8, w, x, mv, fi}$	19-40	--	1.000						
Weaving section $CMF_{9, cds, ac, y, z}$	19-41	--	1.000	--	1.000	--	1.000	--	1.000
Combined CMF (multiply all CMFs evaluated)		--	1.367	--	1.617	--	1.305	--	1.694

Expected Average Crash Frequency[a]								
Complete the study year column. Complete the crash period column if the ***site-specific*** EB Method is used.	Fatal and Injury				Property Damage Only			
	Multiple Vehicle		Single Vehicle		Multiple Vehicle		Single Vehicle	
	Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year
Calibration factor $C_{w, x, y, z}$	1.00		1.00		1.00		1.00	
Overdispersion parameter $k_{w, x, y, z}$	--		--		--		--	
Observed crash count $N^*_{o, w, x, y, z}$ (cr)	--		--		--		--	
Reference year r	--		--		--		--	
Predicted average crash freq. for reference year $N_{p, w, x, y, z, r}$ (cr/yr)	--		--		--		--	
Predicted number of crashes for crash period (sum all years) $N^*_{p, w, x, y, z}$ (cr)	--		--		--		--	
Equivalent years associated with crash count $C_{b, w, x, y, z, r}$ (yr)	--		--		--		--	
Adjusted average crash freq. for ref. year given N^*_o, $N_{a, w, x, y, z, r}$ (cr/yr)	--		--		--		--	
Study year s		2011		2011		2011		2011
Predicted average crash freq. for study year $N_{p, w, x, y, z, s}$ (cr/yr)		0.058		0.281		0.103		0.358
Expected average crash freq. for study year $N_{e, w, x, y, z, s}$ (cr/yr)		0.058		0.281		0.103		0.358
Expected average crash freq. for study year (all crash types) $N_{e, w, x, at, z, s}$ (cr/yr)		0.339				0.461		

[a] If the EB Method is not used, then substitute the word "predicted" for the word "expected" and substitute the subscript "p" for the subscript "e".

Table 19-58. Ramp Segment Worksheet (4 of 4)—Sample Problem 3

Expected Average Crash Frequency[a]

Crash Severity Distribution

	K	A	B	C	Total FI	PDO	Total FI + PDO
Proportion by injury level	0.018	0.056	0.369	0.557	1.000		
Expected average crash freq. for study year (all crash types) $N_{e,w,x,at,z,s}$ (cr/yr)	0.006	0.019	0.125	0.189	0.339	0.462	0.801

Crash Type Distribution

Crash Type Category	Table	Fatal and Injury		Property Damage Only		Total
		Proportion	Expected Average Crash Frequency for Study Year $N_{e,w,x,y,fi,s}$ (cr/yr)	Proportion	Expected Average Crash Frequency for Study Year $N_{e,w,x,y,pdo,s}$ (cr/yr)	Expected Average Crash Frequency for Study Year $N_{e,w,x,y,as,s}$ (cr/yr)
Multiple-Vehicle Crashes	19-6					
Head-on		0.015	0.001	0.009	0.001	0.002
Right-angle		0.010	0.001	0.005	0.001	0.001
Rear-end		0.707	0.041	0.550	0.057	0.098
Sideswipe		0.129	0.007	0.335	0.035	0.042
Other multiple-vehicle crashes		0.139	0.008	0.101	0.011	0.019
Total		1.000	0.058	1.000	0.104	0.162
Single-Vehicle Crashes	19-9					
Crash with animal		0.003	0.001	0.005	0.002	0.003
Crash with fixed object		0.718	0.202	0.834	0.299	0.501
Crash with other object		0.015	0.004	0.023	0.008	0.012
Crash with parked vehicle		0.012	0.003	0.012	0.004	0.008
Other single-vehicle crashes		0.252	0.071	0.126	0.045	0.116
Total		1.000	0.282	1.000	0.358	0.640

[a] If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e”.

Table 19-59. Ramp Barrier Worksheet—Sample Problem 3

Input Data						
Segment length L (mi)	0.3		Crash period	X	Study year	
Left shoulder width W_{ls} (ft)	4	Right shoulder width W_{rs} (ft)				8
Individual Right Side Barrier Element Data						
Barrier Location	Length $L_{rb,i}$ (mi)	Width from Edge of Traveled Way to Face of Right Side Barrier $W_{off,r,i}$ (ft)				Ratio $L_{rb,i}/(W_{off,r,i}-W_{rs})$
1. Bridge	0.10	9				0.10
2. Sign support	0.05	9s				0.05
3.						
4.						
5.						
6.						
7.						
Sum1	0.15	Sum2				0.15
Individual Left Side Barrier Element Data						
Barrier Location	Length $L_{lb,i}$ (mi)	Width from Edge of Traveled Way to Face of Left Side Barrier $W_{off,l,i}$ (ft)				Ratio $L_{lb,i}/(W_{off,l,i}-W_{ls})$
1. Bridge	0.10	5				0.10
2. Sign support	0.05	5				0.05
3.						
4.						
5.						
6.						
7.						
Sum3	0.15	Sum4				0.15
Right Side Barrier Calculations						
Proportion of segment length with barrier in median $P_{rb} = \text{Sum1}/L$	0.500	Width from edge of shoulder to barrier face $W_{rcb} = \text{Sum1}/\text{Sum2}$ (ft)				1.000
Left Side Barrier Calculations						
Proportion of segment length with barrier in median $P_{lb} = \text{Sum3}/L$	0.500	Width from edge of shoulder to barrier face $W_{lcb} = \text{Sum3}/\text{Sum4}$ (ft)				1.000

19.14.4. Sample Problem 4

The Site/Facility
A signalized diamond interchange ramp terminal on an urban arterial.

The Question
What is the predicted average crash frequency of the ramp terminal for a one-year period?

The Facts
The study year is 2011. The conditions present during this year are provided in the following list:

- D4 configuration
- No non-ramp public street leg present
- 1.0 mi to the next public street intersection on the outside crossroad leg
- 0.1 mi to the adjacent ramp terminal
- Protected-permissive left-turn operational mode on the inside crossroad leg
  - 12-ft left-turn bay present
- Signal control for the exit ramp right-turn movement
- 12-ft crossroad median width
- 4 through lanes on the crossroad (2 on each approach)
- 3 lanes on the exit ramp approach (developed at a distance of 150 ft from the ramp terminal)
- No right-turn channelization or bays
- No driveways present
- 28,000 veh/day on the crossroad (same for both legs)
- 7,100 veh/day on the exit ramp leg
- 6,750 veh/day on the entrance ramp leg

Assumptions
Crash type distributions used are the default values presented in Table 19-16.

The calibration factor is 1.00.

Results
Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the ramp terminal in Sample Problem 4 is determined to be 5.3 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 7.1 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the ramp terminal in Sample Problem 4, only Steps 9 through 13 are conducted. No other steps are necessary because only one ramp terminal is analyzed for a one-year period and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate SPF.
For a ramp terminal, an SPF value for all crash types is determined. The SPF for fatal-and-injury crashes is calculated from Equation 19-28 and Table 19-15 as follows:

$$
\begin{aligned}
N_{spf,\,D4,\,SG4,\,at,\,fi} &= \exp\left(a + b \times \ln\left[c \times AADT_{xrd}\right] + d \times \ln\left[c \times AADT_{ex} + c \times AADT_{en}\right]\right) \\
&= \exp\left(-2.335 + 1.191 \times \ln\left[0.001 \times 28{,}000\right] + 0.131 \times \ln\left[0.001 \times 7{,}100 + 0.001 \times 6{,}750\right]\right) \\
&= 7.228 \text{ crashes/year}
\end{aligned}
$$

Similarly, the SPF for property-damage-only crashes is calculated from Equation 19-28 and Table 19-15 to yield the following result:

$$N_{spf,\,D4,\,SG4,\,at,\,pdo} = 9.869 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs.
Each CMF used in the calculation of the predicted average crash frequency of the ramp terminal is calculated in this step.

Exit Ramp Capacity (*CMF*$_{10,\,D4,\,SG4,\,at,\,fi}$)
$CMF_{10,\,D4,\,SG4,\,at,\,fi}$ is calculated from Equation 19-42 as follows:

$$CMF_{10,\,D4,\,SG4,\,at,\,fi} = \left(1.0 - P_{ex}\right) \times 1.0 + P_{ex} \times \exp\left(a \times \frac{c \times AADT_{ex}}{n_{ex,\,eff}}\right)$$

For a signalized exit-ramp right-turn movement, the effective number of lanes serving exit ramp traffic $n_{ex,\,eff}$ is computed using the second portion of Equation 19-43 as follows:

$$
\begin{aligned}
n_{ex,\,eff} &= 0.5 \times n_{ex} \\
&= 0.5 \times 3 \\
&= 1.5
\end{aligned}
$$

The proportion of total leg AADT on the exit ramp leg P_{ex} is computed using Equation 19-44 as follows:

$$
\begin{aligned}
P_{ex} &= \frac{AADT_{ex}}{AADT_{in} + AADT_{out} + AADT_{en} + AADT_{ex}} \\
&= \frac{7{,}100}{28{,}000 + 28{,}000 + 6{,}750 + 7{,}100} \\
&= 0.102
\end{aligned}
$$

From Table 19-32, $a = 0.0668$ and $c = 0.001$ for signal-controlled ramp terminals. $CMF_{10,\,D4,\,SG4,\,at,\,fi}$ is calculated as follows:

$$
\begin{aligned}
CMF_{10,\,D4,\,SG4,\,at,\,fi} &= \left(1.0 - 0.102\right) \times 1.0 + 0.102 \times \exp\left(0.0668 \times \frac{0.001 \times 7{,}100}{1.5}\right) \\
&= 1.038
\end{aligned}
$$

Crossroad Left-Turn Lane (*CMF*$_{11,\,D4,\,SG4,\,at,\,z}$)
$CMF_{11,\,D4,\,SG4,\,at,\,fi}$ is calculated from Equation 19-45 as follows:

$$CMF_{11,\,D4,\,SG4,\,at,\,fi} = \left[\left(1.0 - P_{in}\right) \times 1.0 + P_{in} \times a^{I_{bay,\,lt,\,in}}\right] \times \left[\left(1.0 - P_{out}\right) \times 1.0 + P_{out} \times a^{I_{bay,\,lt,\,out}}\right]$$

The proportion of total leg AADT on the crossroad leg between ramps P_{in} is computed using Equation 19-46 as follows:

$$P_{in} = \frac{AADT_{in}}{AADT_{in} + AADT_{out} + AADT_{en} + AADT_{ex}}$$
$$= \frac{28,000}{28,000 + 28,000 + 6,750 + 7,100}$$
$$= 0.401$$

The proportion of total leg AADT on the crossroad leg outside of the interchange P_{out} is computed using Equation 19-47 as follows:

$$P_{out} = \frac{AADT_{out}}{AADT_{in} + AADT_{out} + AADT_{en} + AADT_{ex}}$$
$$= \frac{28,000}{28,000 + 28,000 + 6,750 + 7,100}$$
$$= 0.401$$

From Table 19-33, $a = 0.65$ for signal-controlled ramp terminals. $CMF_{11,\,D4,\,SG4,\,at,\,fi}$ is calculated as follows:

$$CMF_{11,\,D4,\,SG4,\,at,\,fi} = \left[(1.0 - 0.401) \times 1.0 + 0.401 \times 0.65\right]^{1} \times \left[(1.0 - 0.401) \times 1.0 + 0.401 \times 0.65\right]^{0}$$
$$= 0.860$$

Similar calculations using the property-damage-only coefficient from Table 19-33 yield the following results:

$$CMF_{11,\,D4,\,SG4,\,at,\,pdo} = 0.872$$

Crossroad Right-Turn Lane ($CMF_{12,\,D4,\,SG4,\,at,\,z}$)
The ramp terminal does not have right-turn lanes or bays on the crossroad legs, which is the base condition for the crossroad right-turn lane CMF. Hence, $CMF_{12,\,D4,\,SG4,\,at,\,fi}$ and $CMF_{12,\,D4,\,SG4,\,at,\,pdo}$ are equal to 1.000.

Access Point Frequency ($CMF_{13,\,D4,\,SG4,\,at,\,z}$)
The ramp terminal has no unsignalized driveways or unsignalized public street approaches on the outside leg, which are the base conditions for the access point frequency CMF. Hence, $CMF_{13,\,D4,\,SG4,\,at,\,fi}$ and $CMF_{13,\,D4,\,SG4,\,at,\,pdo}$ are equal to 1.000.

Segment Length ($CMF_{14,\,D4,\,SG4,\,at,\,z}$)
$CMF_{14,\,D4,\,SG4,\,at,\,fi}$ is calculated from Equation 19-50 as follows:

$$CMF_{14,\,D4,\,SG4,\,at,\,fi} = \exp\left(a \times \left[\frac{1.0}{L_{rmp}} + \frac{1.0}{L_{str}} - 0.333\right]\right)$$

From Table 19-36, $a = 0.0185$ for fatal-and-injury crashes. $CMF_{14,\,D4,\,SG4,\,at,\,fi}$ is calculated as follows:

$$CMF_{14,\,D4,\,SG4,\,at,\,fi} = \exp\left(0.0185 \times \left[\frac{1.0}{0.1} + \frac{1.0}{1.0} - 0.333\right]\right)$$
$$= 0.821$$

Similar calculations using the property-damage-only coefficient from Table 19-36 yield the following results:

$$CMF_{14,\,D4,\,SG4,\,at,\,pdo} = 0.820$$

Median Width ($CMF_{15,\ D4,\ SG4,\ at,\ z}$)
The crossroad has a 12-ft median, which is the base condition for the median width CMF. Hence, $CMF_{15,\ D4,\ SG4,\ at,\ fi}$ and $CMF_{15,\ D4,\ SG4,\ at,\ pdo}$ are equal to 1.000.

Protected Left-Turn Operation ($CMF_{16,\ D4,\ SG4,\ at,\ z}$)
Protected-only left-turn operational mode is not used on the crossroad legs, which is the base condition for the protected left-turn operation CMF. Hence, $CMF_{16,\ D4,\ SG4,\ at,\ fi}$ and $CMF_{16,\ D4,\ SG4,\ at,\ pdo}$ are equal to 1.000.

Channelized Right Turn on Crossroad ($CMF_{17,\ D4,\ SG4,\ at,\ z}$)
Right-turn channelization is not used on the crossroad legs, which is the base condition for the channelized right turn on crossroad CMF. Hence, $CMF_{17,\ D4,\ SG4,\ at,\ fi}$ and $CMF_{17,\ D4,\ SG4,\ at,\ pdo}$ are equal to 1.000.

Channelized Right Turn on Exit Ramp ($CMF_{18,\ D4,\ SG4,\ at,\ z}$)
Right-turn channelization is not used on the exit-ramp leg, which is the base condition for the channelized right turn on exit ramp CMF. Hence, $CMF_{18,\ D4,\ SG4,\ at,\ fi}$ and $CMF_{18,\ D4,\ SG4,\ at,\ pdo}$ are equal to 1.000.

Non-Ramp Public Street Leg ($CMF_{19,\ D4,\ SG4,\ at,\ z}$)
A non-ramp public street leg is not present at the ramp terminal, which is the base condition for the non-ramp public street leg CMF. Hence, $CMF_{19,\ D4,\ SG4,\ at,\ fi}$ and $CMF_{19,\ D4,\ SG4,\ at,\ pdo}$ are equal to 1.000.

Crashes
The CMFs are applied to the fatal-and-injury SPF as follows:

$$\begin{aligned}
N_{p*,\ D4,SG4,at,\ fi} &= N_{spf,\ D4,SG4,at,\ fi} ´\ (CMF_{10,D4,SG4,at,\ fi} ´\ \ldots ´\ CMF_{19,D4,SG4,at,\ fi}) \\
&= 7.228 ´\ (1.038 ´\ 0.860 ´\ 1.000 ´\ 1.000 ´\ 0.821 ´\ 1.000 ´\ 1.000 ´\ 1.000 ´\ 1.000 ´\ 1.000) \\
&= 7.228 ´\ 0.733 \\
&= 5.294 \text{ crashes/year}
\end{aligned}$$

The CMFs are applied to the property-damage-only SPF as follows:

$$\begin{aligned}
N_{p*,\ D4,SG4,at,\ pdo} &= N_{spf,\ D4,SG4,at,\ pdo} ´\ (CMF_{10,D4,SG4,at,\ pdo} ´\ \ldots ´\ CMF_{19,D4,SG4,at,\ pdo}) \\
&= 9.869 ´\ (1.000 ´\ 0.872 ´\ 1.000 ´\ 1.000 ´\ 0.820 ´\ 1.000 ´\ 1.000 ´\ 1.000 ´\ 1.000 ´\ 1.000) \\
&= 9.869 ´\ 0.715 \\
&= 7.052 \text{ crashes/year}
\end{aligned}$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor of 1.00 has been determined for local conditions. See Section B.1 of Appendix B for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 19-1 based on the results obtained in Steps 9 through 11 as follows.

Fatal-and-injury crashes:

$$\begin{aligned}
N_{p,\ D4,SG4,at,\ fi} &= N_{p*,\ D4,SG4,at,\ fi} ´\ C_{D4,SG4,at,\ fi} \\
&= 5.294 ´\ 1.00 \\
&= 5.294 \text{ crashes/year}
\end{aligned}$$

Property-damage-only crashes:

$$
\begin{aligned}
N_{p,\ D4,\ SG4,\ at,\ pdo} &= N_{p^*,\ D4,\ SG4,\ at,\ pdo} \times C_{D4,\ SG4,\ at,\ pdo} \\
&= 7.052 \times 1.00 \\
&= 7.052 \text{ crashes/year}
\end{aligned}
$$

Step 12—If there is another year to be evaluated in the evaluation period for the selected site, return to Step 8. Otherwise, proceed to Step 13.
The study period is one year (2011), so steps 8 through 11 need not be repeated.

Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.
This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

Apply the site-specific EB Method to a future time period, if appropriate.
The site-specific EB Method is not applied in this sample problem because crash data are not available.

Apply the severity distribution functions (SDFs), if desired.
To apply the SDFs, the systematic component of crash severity likelihood V_j is computed for each severity level j using Equation 19-88 as follows:

$$
V_j = a + \left(b \times I_{p,lt}\right) + \left(c \times [n_{dw} + n_{ps}]\right) + \left(d \times I_{ps}\right) + \left(e \times I_{rural}\right)
$$

The coefficients a, b, c, d, and e are obtained from Table 19-44 for each severity level j. V_j is computed for fatal and incapacitating injury crashes as follows:

$$
\begin{aligned}
V_{K+A} &= -3.257 + \left(-0.288 \times 0.0\right) + \left(0.0991 \times [0.0 + 0.0]\right) + \left(1.171 \times 0.0\right) + \left(0.619 \times 0.0\right) \\
&= -3.257
\end{aligned}
$$

Similar calculations using the coefficients from Table 19-44 for non-incapacitating injury crashes yield the following results:

$$
V_B = -1.511
$$

Using these computed V_{K+A} and V_B values, and assuming a calibration factor $C_{sdf,\ aS,\ x}$ of 1.0, the probability of occurrence of a fatal crash is computed using Equation 19-84 as follows:

$$
\begin{aligned}
P_{aS,SG,at,K} &= \frac{\exp\left(V_{K+A}\right)}{\dfrac{1.0}{C_{sdf,aS,x}} + \exp\left(V_{K+A}\right) + \exp\left(V_B\right)} \times P_{K|K+A,aS,x,at} \\
&= \frac{\exp\left(-3.257\right)}{\dfrac{1.0}{1.0} + \exp\left(-3.257\right) + \exp\left(-1.511\right)} \times 0.0385 \\
&= 0.001
\end{aligned}
$$

Similar calculations using Equation 19-85 and Equation 19-86 yield the following results:

$$
P_{aS,SG,at,A} = 0.029
$$

$$
P_{aS,SG,at,B} = 0.175
$$

The probability of occurrence of a possible-injury crash is computed using Equation 19-87 as follows:

$$
\begin{aligned}
P_{aS,SG,at,C} &= 1.0 - (P_{aS,SG,at,K} + P_{aS,SG,at,A} + P_{aS,SG,at,B}) \\
&= 1.0 - (0.001 + 0.029 + 0.175) \\
&= 0.794
\end{aligned}
$$

The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 19-78 as follows:

$$
\begin{aligned}
N_{e,D4,SG4,at,K} &= N_{e,D4,SG4,at,FI} \times P_{aS,SG,at,K} \\
&= 5.294 \times 0.001 \\
&= 0.006 \text{ crashes/year}
\end{aligned}
$$

Similar calculations using Equation 19-78 and the probabilities of occurrences of the other crash severities yield the following results:

$$N_{e,D4,SG,at,A} = 0.156 \text{ crashes/year}$$

$$N_{e,D4,SG,at,B} = 0.928 \text{ crashes/year}$$

$$N_{e,D4,SG,at,C} = 4.204 \text{ crashes/year}$$

Apply the crash type distribution, if desired.
The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 19-16 by the predicted average crash frequencies obtained in Step 11.

WORKSHEETS

The step-by-step instructions are provided to illustrate the predictive method for calculating the predicted average crash frequency for a ramp terminal. To apply the predictive method steps to multiple terminals, a series of worksheets are provided for determining the predicted average crash frequency. The worksheets are:

- Table 19-60. Ramp Terminal Worksheet (1 of 4)—Sample Problem 4
- Table 19-61. Ramp Terminal Worksheet (2 of 4)—Sample Problem 4
- Table 19-62. Ramp Terminal Worksheet (3 of 4)—Sample Problem 4
- Table 19-63. Ramp Terminal Worksheet (4 of 4)—Sample Problem 4

Filled versions of these worksheets are provided below. A blank version of the corresponding worksheets used in all Sample Problems is provided in Appendix 19A.

Table 19-60 is a summary of general information about the ramp terminal, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 4. The input data include area type, crash data, basic intersection data, alignment data, traffic control data, and cross section data.

Table 19-61 is a summary of general information about the ramp terminal, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 4. The input data include cross section data, access data, and traffic data.

Table 19-62 is a tabulation of the CMF and SPF computations for Sample Problem 4.

Table 19-63 is a tabulation of the crash severity and crash type distributions for Sample Problem 4.

Table 19-60. Ramp Terminal Worksheet (1 of 4)—Sample Problem 4

General Information						Location Information	
Analyst						Roadway	
Agency or company						Intersection	
Date performed						Study year	
Area type	X	Urban		Rural			

Input Data							
Crash Data			Crash Period		Study Year		Complete the study year column. Complete the crash period column if the EB Method is used.
Crash data time period							First year | -- | Last year
Count of FI crashes $N^*_{o,w,x,at,fi}$			--				
Count of PDO crashes $N^*_{o,w,x,at,pdo}$			--				
Basic Intersection Data							
Ramp terminal configuration			D4				Choices: D3ex, D3en, D4, A4, B4, A2, B2, SP, TD Same choice for crash period and study year.
Ramp terminal traffic control type			Signal				Choices: Signal, One-way-stop, All-way stop
Presence of a non-ramp public street leg I_{ps}			--	Y/N	N	Y/N	
Alignment Data							
Exit ramp skew angle I_{sk} (degrees)			--		--		
Distance to the next public street intersection on the outside crossroad leg L_{str} (mi)			--		1.0		
Distance to the adjacent ramp terminal L_{rmp} (mi)			--		0.1		
Traffic Control							
Left-Turn Operational Mode							
Crossroad	Inside approach	Prot.-only mode $I_{p,lt,in}$	--	Y/N	--	Y/N	
	Outside approach	Prot.-only mode $I_{p,lt,out}$	--	Y/N	--	Y/N	
Right-Turn Control Type							
Ramp	Exit ramp approach	Right-turn control type	--		Signal		Choices: Signal, Stop, Yield, Merge, Free (FFO, FFI, FF2)
Cross Section Data							
Crossroad median width W_m (ft)			--		12		
Number of Lanes							
Crossroad	Inside approach	Through lanes $n_{th,in}$	2				Same choice for crash period and study year.
	Outside approach	Through lanes $n_{th,out}$	2				Same choice for crash period and study year.
Ramp	Exit ramp approach	All lanes n_{ex}	3				Same choice for crash period and study year.
Right-Turn Channelization							
Crossroad	Inside approach	Chan. present $I_{ch,in}$	--	Y/N	--	Y/N	
	Outside approach	Chan. present $I_{ch,out}$	--	Y/N	N	Y/N	
Ramp	Exit ramp approach	Chan. present $I_{ch,ex}$	--	Y/N	N	Y/N	

Table 19-61. Ramp Terminal Worksheet (2 of 4)—Sample Problem 4

Input Data							
Cross Section Data			Crash Period		Study Year		Complete the study year column. Complete the crash period column if the EB Method is used.
Left-Turn Lane or Bay							
Crossroad	Inside approach	Lane or bay present $I_{bay,\,lt,\,in}$	--	Y/N	Y	Y/N	If Yes, then enter data in the next row.
		Lane or bay width $W_{b,\,in}$ (ft)	--		12		
	Outside approach	Lane or bay present $I_{bay,lt,out}$	--	Y/N	N	Y/N	If Yes, then enter data in the next row.
		Lane or bay width $W_{b,out}$(ft)	--		--		
Right-Turn Lane or Bay							
Crossroad	Inside approach	Lane or bay present $I_{bay,\,rt,\,in}$	--	Y/N	--	Y/N	
	Outside approach	Lane or bay present $I_{bay,rt,out}$	--	Y/N	N	Y/N	
Access Data							
Number of driveways on the outside crossroad leg n_{dw}			--		0		
Number of public street approaches on the outside crossroad leg n_{ps}			--		--		
Number of exit ramps with free-flow right turns onto crossroad (SP Only):							
Traffic Data							
Crossroad	Inside leg	$AADT_{in}$ (veh/day)	--		28,000		
	Outside leg	$AADT_{out}$ (veh/day)	--		28,000		
Ramp	Exit ramp	$AADT_{ex}$ (veh/day)	--		7,100		
	Entrance ramp	$AADT_{en}$ (veh/day)	--		6,750		

Table 19-62. Ramp Terminal Worksheet (3 of 4)—Sample Problem 4

Crash Modification Factors		Fatal and Injury		Property Damage Only	
Complete the study year column. Complete the crash period column if the EB Method is used.		Crash Period	Study Year	Crash Period	Study Year
Signal Control	Equation				
Exit ramp capacity $CMF_{10, w, SGn, at, fi}$	19-42	--	1.038		
Crossroad left-turn lane $CMF_{11, w, SGn, at, z}$	19-45	--	0.860	--	0.872
Crossroad right-turn lane $CMF_{12, w, SGn, at, z}$	19-48	--	1.000	--	1.000
Access point frequency $CMF_{13, w, SGn, at, z}$	19-49	--	1.000	--	1.000
Segment length $CMF_{14, w, SGn, at, z}$	19-50	--	0.821	--	0.820
Median width $CMF_{15, w, SGn, at, z}$	19-51	--	1.000	--	1.000
Protected left-turn operation $CMF_{16, w, SGn, at, z}$	19-53	--	1.000	--	1.000
Chan. right turn on crossroad $CMF_{17, w, SGn, at, z}$	19-55	--	1.000	--	1.000
Chan. right turn on exit ramp $CMF_{18, w, SGn, at, z}$	19-56	--	1.000	--	1.000
Non-ramp public street leg $CMF_{19, w, SGn, at, z}$	19-57	--	1.000	--	1.000
Stop Control					
Exit ramp capacity $CMF_{10, w, ST, at, fi}$	19-42	--	--		
Crossroad left-turn lane $CMF_{11, w, ST, at, z}$	19-45	--	--	--	--
Crossroad right-turn lane $CMF_{12, w, ST, at, z}$	19-48	--	--	--	--
Access point frequency $CMF_{13, w, ST, at, fi}$	19-49	--	--		
Segment length $CMF_{14, w, ST, at, fi}$	19-50	--	--		
Median width $CMF_{15, w, ST, at, fi}$	19-51	--	--		
Skew angle $CMF_{20, w, ST, at, fi}$	19-58	--	--		
All-way stop-control (exclude CMF_{11}, CMF_{12}, CMF_{20})		--	--		
Combined CMF (multiply all CMFs evaluated)		--	0.733	--	0.715

Expected Average Crash Frequency [a]	Fatal and Injury		Property Damage Only	
Complete the study year column. Complete the crash period column if the ***site-specific*** EB Method is used.	Crash Period	Study Year	Crash Period	Study Year
Calibration factor $C_{aS, x, at, z}$	1.00		1.00	
Overdispersion parameter $k_{w, x, at, z}$	--		--	
Observed crash count $N^*_{o, w, x, at, z}$ (cr)	--		--	
Reference year r	--		--	
Predicted average crash freq. for reference year $N_{p, w, x, at, z, r}$ (cr/yr)	--		--	
Predicted number of crashes for crash period (sum all years) $N^*_{p, w, x, y, z}$ (cr)	--		--	
Equivalent years associated with crash count $C_{b, w, x, at, z, r}$ (yr)	--		--	
Adjusted average crash freq. for ref. year given N^*_o, $N_{a, w, x, at, z, r}$ (cr/yr)	--		--	
Study year s		2011		2011
Predicted average crash freq. for study year $N_{p, w, x, at, z, s}$ (cr/yr)		5.294		7.052
Expected average crash freq. for study year $N_{e, w, x, at, z, s}$ (cr/yr)		5.294		7.052

[a] If the EB Method is not used, then substitute “predicted” for “expected” and substitute the subscript “p” for the subscript “e”.

Table 19-63. Ramp Terminal Worksheet (4 of 4)—Sample Problem 4

Expected Average Crash Frequency							
Crash Severity Distribution							
	K	A	B	C	Total FI	PDO	Total FI + PDO
Proportion by injury level	0.001	0.029	0.175	0.794	1.000		
Expected average crash freq. for study year $N_{e, w, x, at, z, s}$ (cr/yr)	0.006	0.156	0.928	4.204	5.294	7.052	12.346

Crash Type Distribution

Crash Type Category Table 19-16, 19-21, or 19-45	Fatal and Injury		Property Damage Only		Total
	Prop7ortion	Expected Average Crash Frequency for Study Year $N_{e, w, x, at, fi, s}$ (cr/yr)	Proportion	Expected Average Crash Frequency for Study Year $N_{e, w, x, at, pdo, s}$ (cr/yr)	Expected Average Crash Frequency for Study Year $N_{e, w, x, at, as, s}$ (cr/yr)
Multiple-Vehicle Crashes					
Head-on	0.011	0.058	0.007	0.049	0.108
Right-angle	0.260	1.376	0.220	1.551	2.928
Rear-end	0.625	3.309	0.543	3.829	7.138
Sideswipe	0.042	0.222	0.149	1.051	1.273
Other multiple-vehicle crashes	0.009	0.048	0.020	0.141	0.189
Single-Vehicle Crashes					
Crash with animal	0.000	0.000	0.000	0.000	0.000
Crash with fixed object	0.033	0.175	0.050	0.353	0.527
Crash with other object	0.001	0.005	0.002	0.014	0.019
Crash with parked vehicle	0.001	0.005	0.002	0.014	0.019
Other single-vehicle crashes	0.018	0.095	0.007	0.049	0.145
Total	1.000	0.281	1.000	0.430	0.711

19.14.5. Sample Problem 5

The Site/Facility
A one-way stop-controlled partial cloverleaf interchange ramp terminal on an urban arterial.

The Question
What is the predicted average crash frequency of the ramp terminal for a one-year period?

The Facts
The study year is 2011. The conditions present during this year are provided in the following list:

- A4 configuration
- 1.0 mi to the next public street intersection on the outside crossroad leg

- 0.09 mi to the adjacent ramp terminal
- 0-degree skew angle on exit-ramp approach
- Merge control for the exit ramp right-turn movement
- 12-ft crossroad median width
- 4 through lanes on the crossroad
- 2 lanes on the exit ramp approach (developed at a distance of 200 ft from the ramp terminal)
- No right-turn channelization or bays
- 21,500 veh/day on the crossroad (same for both legs)
- 3,400 veh/day on the exit ramp leg
- 3,750 veh/day on the entrance ramp leg

Assumptions

- Crash type distributions used are the default values presented in Table 19-21.
- The calibration factor is 1.00.

Results
Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the ramp terminal in Sample Problem 5 is determined to be 1.2 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 2.7 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the ramp terminal in Sample Problem 5, only Steps 9 through 13 are conducted. No other steps are necessary because only one ramp terminal is analyzed for a one-year period and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate SPF.
For a ramp terminal, an SPF value for all crash types is determined. The SPF for fatal-and-injury crashes is calculated from Equation 19-31 and Table 19-18 as follows:

$$\begin{aligned} N_{spf,\,A4,\,ST,\,at,\,fi} &= \exp\left(a + b \times \ln\left[c \times AADT_{xrd}\right] + d \times \ln\left[c \times AADT_{ex} + c \times AADT_{en}\right]\right) \\ &= \exp\left(-3.223 + 0.582 \times \ln\left[0.001 \times 21{,}500\right] + 0.899 \times \ln\left[0.001 \times 3{,}400 + 0.001 \times 3{,}750\right]\right) \\ &= 1.392 \text{ crashes/year} \end{aligned}$$

Similarly, the SPF for property-damage-only crashes is calculated from Equation 19-31 and Table 19-18 to yield the following result:

$$N_{spf,\,A4,\,ST,\,at,\,pdo} = 2.715 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs.
Each CMF used in the calculation of the predicted average crash frequency of the ramp terminal is calculated in this step.

Exit Ramp Capacity ($CMF_{10,\,A4,\,ST,\,at,\,fi}$)
$CMF_{10,\,A4,\,ST,\,at,\,fi}$ is calculated from Equation 19-42 as follows:

$$CMF_{10,\,A4,\,ST,\,at,\,fi} = (1.0 - P_{ex}) \times 1.0 + P_{ex} \times \exp\left(a \times \frac{c \times AADT_{ex}}{n_{ex,\,eff}}\right)$$

For a merge-controlled exit-ramp right-turn movement, the effective number of lanes serving exit ramp traffic $n_{ex,\,eff}$ is computed using the first portion of Equation 19-43 as follows:

$$\begin{aligned} n_{ex,\,eff} &= 0.5 \times (n_{ex} - 1.0) + 1.0 \\ &= 0.5 \times (2 - 1.0) + 1.0 \\ &= 1.5 \end{aligned}$$

The proportion of total leg AADT on the exit ramp leg P_{ex} is computed using Equation 19-44 as follows:

$$\begin{aligned} P_{ex} &= \frac{AADT_{ex}}{AADT_{in} + AADT_{out} + AADT_{en} + AADT_{ex}} \\ &= \frac{3,400}{21,500 + 21,500 + 3,750 + 3,400} \\ &= 0.068 \end{aligned}$$

From Table 19-32, $a = 0.151$ and $c = 0.001$ for one-way stop-controlled ramp terminals. $CMF_{10,\,A4,\,ST,\,at,\,fi}$ is calculated as follows:

$$\begin{aligned} CMF_{10,\,A4,\,ST,\,at,\,fi} &= (1.0 - 0.068) \times 1.0 + 0.068 \times \exp\left(0.151 \times \frac{0.001 \times 3,400}{1.5}\right) \\ &= 1.028 \end{aligned}$$

Crossroad Left-Turn Lane (*$CMF_{11,\,A4,\,ST,\,at,\,z}$*)
The ramp terminal does not have left-turn lanes or bays on the crossroad legs, which is the base condition for the crossroad left-turn lane CMF. Hence, $CMF_{11,\,A4,\,ST,\,at,\,fi}$ and $CMF_{11,\,A4,\,ST,\,at,\,pdo}$ are equal to 1.000.

Crossroad Right-Turn Lane (*$CMF_{12,\,A4,\,ST,\,at,\,z}$*)
The ramp terminal does not have right-turn lanes or bays on the crossroad legs, which is the base condition for the crossroad right-turn lane CMF. Hence, $CMF_{12,\,A4,\,ST,\,at,\,fi}$ and $CMF_{12,\,A4,\,ST,\,at,\,pdo}$ are equal to 1.000.

Access Point Frequency (*$CMF_{13,\,A4,\,ST,\,at,\,fi}$*)
The ramp terminal has no unsignalized public street approaches on the outside leg, which is the base condition for the access point frequency CMF. Hence, $CMF_{13,\,A4,\,ST,\,at,\,fi}$ is equal to 1.000.

Segment Length (*$CMF_{14,\,A4,\,ST,\,at,\,fi}$*)
$CMF_{14,\,A4,\,ST,\,at,\,fi}$ is calculated from Equation 19-50 as follows:

$$CMF_{14,\,A4,\,ST,\,at,\,fi} = \exp\left(a \times \left[\frac{1.0}{L_{rmp}} + \frac{1.0}{L_{str}} - 0.333\right]\right)$$

From Table 19-36, $a = -0.0141$ for fatal-and-injury crashes. $CMF_{14,\,A4,\,ST,\,at,\,fi}$ is calculated as follows:

$$\begin{aligned} CMF_{14,\,A4,\,ST,\,at,\,fi} &= \exp\left(-0.0141 \times \left[\frac{1.0}{0.09} + \frac{1.0}{1.0} - 0.333\right]\right) \\ &= 0.847 \end{aligned}$$

Median Width (*$CMF_{15,\,A4,\,ST,\,at,\,fi}$*)

The crossroad has a 12-ft median, which is the base condition for the median width CMF. Hence, $CMF_{15,\text{ A4, ST, at, fi}}$ is equal to 1.000.

Skew Angle (*$CMF_{20,\text{ A4, }ST,\ at,\ fi}$*)
The ramp terminal has no skew, which is the base condition for the skew angle CMF. Hence, $CMF_{20,\text{ A4, ST, at, fi}}$ is equal to 1.000.

Crashes
The CMFs are applied to the fatal-and-injury SPF as follows:

$$
\begin{aligned}
N_{p^*,\ A4,\ ST,\ at,\ fi} &= N_{spf,\ A4,\ ST,\ at,\ fi} \times \left(CMF_{10,A4,ST,at,fi} \times \ldots \times CMF_{15,A4,ST,at,fi} \times CMF_{20,A4,ST,at,fi}\right) \\
&= 1.392 \times (1.028 \times 1.000 \times 1.000 \times 1.000 \times 0.847 \times 1.000 \times 1.000) \\
&= 1.392 \times 0.871 \\
&= 1.212 \text{ crashes/year}
\end{aligned}
$$

The CMFs are applied to the property-damage-only SPF as follows:

$$
\begin{aligned}
N_{p^*,\ A4,\ ST,\ at,\ pdo} &= N_{spf,\ A4,\ ST,\ at,\ pdo} \times \left(CMF_{11,A4,ST,at,pdo} \times CMF_{12,A4,ST,at,pdo}\right) \\
&= 2.715 \times (1.000 \times 1.000) \\
&= 2.715 \times 1.000 \\
&= 2.715 \text{ crashes/year}
\end{aligned}
$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor of 1.00 has been determined for local conditions. See Section B.1 of Appendix B for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 19-1 based on the results obtained in Steps 9 through 11 as follows.

Fatal-and-injury crashes:

$$
\begin{aligned}
N_{p,\ A4,\ ST,\ at,\ fi} &= N_{p^*,\ A4,\ ST,\ at,\ fi} \times C_{A4,\ ST,\ at,\ fi} \\
&= 1.212 \times 1.00 \\
&= 1.212 \text{ crashes/year}
\end{aligned}
$$

Property-damage-only crashes:

$$
\begin{aligned}
N_{p,\ A4,\ ST,\ at,\ pdo} &= N_{p^*,\ A4,\ ST,\ at,\ pdo} \times C_{A4,\ ST,\ at,\ pdo} \\
&= 2.715 \times 1.00 \\
&= 2.715 \text{ crashes/year}
\end{aligned}
$$

Step 12—If there is another year to be evaluated in the evaluation period for the selected site, return to Step 8. Otherwise, proceed to Step 13.
The study period is one year (2011), so steps 8 through 11 need not be repeated.

Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.
This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

Apply the site-specific EB Method to a future time period, if appropriate.
The site-specific EB Method is not applied in this sample problem because crash data are not available.

Apply the severity distribution functions (SDFs), if desired.
To apply the SDFs, the systematic component of crash severity likelihood V_j is computed for each severity level j using Equation 19-88 as follows:

$$V_j = a + (b \times I_{p,lt}) + (c \times [n_{dw} + n_{ps}]) + (d \times I_{ps}) + (e \times I_{rural})$$

The coefficients a, b, c, d, and e are obtained from Table 19-44 for each severity level j. V_j is computed for fatal and incapacitating injury crashes as follows:

$$\begin{aligned} V_{K+A} &= -3.168 + (0.00 \times 0.0) + (0.00 \times [0.0 + 0.0]) + (0.00 \times 0.0) + (0.891 \times 0.0) \\ &= -3.168 \end{aligned}$$

Similar calculations using the coefficients from Table 19-44 for non-incapacitating injury crashes yield the following results:

$$V_B = -1.476$$

Using these computed V_{K+A} and V_B values, and assuming a calibration factor $C_{sdf,\,aS,\,x}$ of 1.0, the probability of occurrence of a fatal crash is computed using Equation 19-84 as follows:

$$\begin{aligned} P_{aS,ST,at,K} &= \frac{\exp(V_{K+A})}{\frac{1.0}{C_{sdf,aS,x}} + \exp(V_{K+A}) + \exp(V_B)} \times P_{K|K+A,aS,x,at} \\ &= \frac{\exp(-3.168)}{\frac{1.0}{1.0} + \exp(-3.168) + \exp(-1.476)} \times 0.160 \\ &= 0.005 \end{aligned}$$

Similar calculations using Equation 19-85 and Equation 19-86 yield the following results:

$$P_{aS,ST,at,A} = 0.028$$

$$P_{aS,ST,at,B} = 0.180$$

The probability of occurrence of a possible-injury crash is computed using Equation 19-87 as follows:

$$\begin{aligned} P_{aS,ST,at,C} &= 1.0 - (P_{aS,ST,at,K} + P_{aS,ST,at,A} + P_{aS,ST,at,B}) \\ &= 1.0 - (0.005 + 0.028 + 0.180) \\ &= 0.787 \end{aligned}$$

The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 19-78 as follows:

$$\begin{aligned} N_{e,A4,ST,at,K} &= N_{e,A4,ST,at,fi} \times P_{aS,ST,at,K} \\ &= 1.212 \times 0.005 \\ &= 0.006 \text{ crashes/year} \end{aligned}$$

Similar calculations using Equation 19-78 and the probabilities of occurrences of the other crash severities yield the following results:

$N_{e,A4,ST,at,A}$ = 0.034 crashes/year

$N_{e,A4,ST,at,B}$ = 0.218 crashes/year

$N_{e,A4,ST,at,C}$ = 0.954 crashes/year

Apply the crash type distribution, if desired.
The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 19-21 by the predicted average crash frequencies obtained in Step 11.

WORKSHEETS

The step-by-step instructions are provided to illustrate the predictive method for calculating the predicted average crash frequency for a ramp terminal. To apply the predictive method steps to multiple terminals, a series of worksheets are provided for determining the predicted average crash frequency. The worksheets are:

- Table 19-64. Ramp Terminal Worksheet (1 of 4)—Sample Problem 5
- Table 19-65. Ramp Terminal Worksheet (2 of 4)—Sample Problem 5
- Table 19-66. Ramp Terminal Worksheet (3 of 4)—Sample Problem 5
- Table 19-67. Ramp Terminal Worksheet (4 of 4)—Sample Problem 5

Filled versions of these worksheets are provided below. A blank version of the corresponding worksheets used in all Sample Problems is provided in Appendix 19A.

Table 19-64 is a summary of general information about the ramp terminal, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 5. The input data include area type, crash data, basic intersection data, alignment data, traffic control data, and cross section data.

Table 19-65 is a summary of general information about the ramp terminal, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 5. The input data include cross section data, access data, and traffic data.

Table 19-66 is a tabulation of the CMF and SPF computations for Sample Problem 5.

Table 19-67 is a tabulation of the crash severity and crash type distributions for Sample Problem 5.

Table 19-64. Ramp Terminal Worksheet (1 of 4)—Sample Problem 5

General Information						Location Information
Analyst						Roadway
Agency or company						Intersection
Date performed						Study year
Area type	X	Urban		Rural		

Input Data								
Crash Data			Crash Period		Study Year		Complete the study year column. Complete the crash period column if the EB Method is used.	
Crash data time period							First year --	Last year
Count of FI crashes $N^*_{o, w, x, at, fi}$			--					
Count of PDO crashes $N^*_{o, w, x, at, pdo}$			--					
Basic Intersection Data								
Ramp terminal configuration			A4				Choices: D3ex, D3en, D4, A4, B4, A2, B2, SP, TD Same choice for crash period and study year.	
Ramp terminal traffic control type			One-way stop				Choices: Signal, One-way-stop, All-way stop	
Presence of a non-ramp public street leg I_{ps}			--	Y/N	--	Y/N		
Alignment Data								
Exit ramp skew angle I_{sk} (degrees)			--		0			
Distance to the next public street intersection on the outside crossroad leg L_{str} (mi)			--		1.0			
Distance to the adjacent ramp terminal L_{rmp} (mi)			--		0.09			
Traffic Control								
Left-Turn Operational Mode								
Crossroad	Inside approach	Prot.-only mode $I_{p, lt, in}$	--	Y/N	--	Y/N		
	Outside approach	Prot.-only mode $I_{p, lt, out}$	--	Y/N	--	Y/N		
Right-Turn Control Type								
Ramp	Exit ramp approach	Right-turn control type	--		Merge		Choices: Signal, Stop, Yield, Merge, Free (FF0, FF1, FF2)	
Cross Section Data								
Crossroad median width W_m (ft)			--		12			
Number of Lanes								
Crossroad	Inside approach	Through lanes $n_{th, in}$	2				Same choice for crash period and study year.	
	Outside approach	Through lanes $n_{th, out}$	2				Same choice for crash period and study year.	
Ramp	Exit ramp approach	All lanes n_{ex}	2				Same choice for crash period and study year.	
Right-Turn Channelization								
Crossroad	Inside approach	Chan. present $I_{ch, in}$	--	Y/N	--	Y/N		
	Outside approach	Chan. present $I_{ch, out}$	--	Y/N	--	Y/N		
Ramp	Exit ramp approach	Chan. present $I_{ch, ex}$	--	Y/N	--	Y/N		

Table 19-65. Ramp Terminal Worksheet (2 of 4)—Sample Problem 5

Input Data							
Cross Section Data			Crash Period		Study Year		Complete the study year column. Complete the crash period column if the EB Method is used.
Left-Turn Lane or Bay							
Crossroad	Inside approach	Lane or bay present $I_{bay,lt,in}$	--	Y/N	--	Y/N	If Yes, then enter data in the next row.
		Lane or bay width $W_{b,in}$ (ft)	--		--		
	Outside approach	Lane or bay present $I_{bay,lt,out}$	--	Y/N	--	Y/N	If Yes, then enter data in the next row.
		Lane or bay width $W_{b,out}$(ft)	--		--		
Right-Turn Lane or Bay							
Crossroad	Inside approach	Lane or bay present $I_{bay,rt,in}$	--	Y/N	N	Y/N	
	Outside approach	Lane or bay present $I_{bay,rt,out}$	--	Y/N	N	Y/N	
Access Data							
Number of driveways on the outside crossroad leg n_{dw}			--		--		
Number of public street approaches on the outside crossroad leg n_{ps}			--		--		
Number of exit ramps with free-flow right turns onto crossroad (SP Only):							
Traffic Data							
Crossroad	Inside leg	$AADT_{in}$ (veh/day)	--		21,500		
	Outside leg	$AADT_{out}$ (veh/day)	--		21,500		
Ramp	Exit ramp	$AADT_{ex}$ (veh/day)	--		3,400		
	Entrance ramp	$AADT_{en}$ (veh/day)	--		3,750		

Table 19-66. Ramp Terminal Worksheet (3 of 4)—Sample Problem 5

Crash Modification Factors		Fatal and Injury		Property Damage Only	
Complete the study year column. Complete the crash period column if the EB Method is used.	Equation	Crash Period	Study Year	Crash Period	Study Year
Signal Control					
Exit ramp capacity $CMF_{10,\,w,\,SGn,\,at,\,fi}$	19-42	--	--		
Crossroad left-turn lane $CMF_{11,\,w,\,SGn,\,at,\,z}$	19-45	--	--	--	--
Crossroad right-turn lane $CMF_{12,\,w,\,SGn,\,at,\,z}$	19-48	--	--	--	--
Access point frequency $CMF_{13,\,w,\,SGn,\,at,\,z}$	19-49	--	--	--	--
Segment length $CMF_{14,\,w,\,SGn,\,at,\,z}$	19-50	--	--	--	--
Median width $CMF_{15,\,w,\,SGn,\,at,\,z}$	19-51	--	--	--	--
Protected left-turn operation $CMF_{16,\,w,\,SGn,\,at,\,z}$	19-53	--	--	--	--
Chan. right turn on crossroad $CMF_{17,\,w,\,SGn,\,at,\,z}$	19-55	--	--	--	--
Chan. right turn on exit ramp $CMF_{18,\,w,\,SGn,\,at,\,z}$	19-56	--	--	--	--
Non-ramp public street leg $CMF_{19,\,w,\,SGn,\,at,\,z}$	19-57	--	--	--	--
Stop Control					
Exit ramp capacity $CMF_{10,\,w,\,ST,\,at,\,fi}$	19-42	--	1.028		
Crossroad left-turn lane $CMF_{11,\,w,\,ST,\,at,\,z}$	19-45	--	1.000	--	1.000
Crossroad right-turn lane $CMF_{12,\,w,\,ST,\,at,\,z}$	19-48	--	1.000	--	1.000
Access point frequency $CMF_{13,\,w,\,ST,\,at,\,fi}$	19-49	--	1.000		
Segment length $CMF_{14,\,w,\,ST,\,at,\,fi}$	19-50	--	0.847		
Median width $CMF_{15,\,w,\,ST,\,at,\,fi}$	19-51	--	1.000		
Skew angle $CMF_{20,\,w,\,ST,\,at,\,fi}$	19-58	--	1.000		
All-way stop-control (exclude CMF_{11}, CMF_{12}, CMF_{20})		--	--		
Combined CMF (multiply all CMFs evaluated)		--	0.871	--	1.000

Expected Average Crash Frequency [a]	Fatal and Injury		Property Damage Only	
Complete the study year column. Complete the crash period column if the ***site-specific*** EB Method is used.	Crash Period	Study Year	Crash Period	Study Year
Calibration factor $C_{aS,\,x,\,at,\,z}$	1.00		1.00	
Overdispersion parameter $k_{w,\,x,\,at,\,z}$	--		--	
Observed crash count $N^{*}_{o,\,w,\,x,\,at,\,z}$ (cr)	--		--	
Reference year r	--		--	
Predicted average crash freq. for reference year $N_{p,\,w,\,x,\,at,\,z,\,r}$ (cr/yr)	--		--	
Predicted number of crashes for crash period (sum all years) $N^{*}_{p,\,w,\,x,\,y,\,z}$ (cr)	--		--	
Equivalent years associated with crash count $C_{b,\,w,\,x,\,at,\,z,\,r}$ (yr)	--		--	
Adjusted average crash freq. for ref. year given N^{*}_{o}, $N_{a,\,w,\,x,\,at,\,z,\,r}$ (cr/yr)	--		--	
Study year s		2011		2011
Predicted average crash freq. for study year $N_{p,\,w,\,x,\,at,\,z,\,s}$ (cr/yr)		1.212		2.715
Expected average crash freq. for study year $N_{e,\,w,\,x,\,at,\,z,\,s}$ (cr/yr)		1.212		2.715

[a] If the EB Method is not used, then substitute “predicted” for “expected” and substitute the subscript “p” for the subscript “e”.

Table 19-67. Ramp Terminal Worksheet (4 of 4)—Sample Problem 5

Expected Average Crash Frequency

Crash Severity Distribution

	K	A	B	C	Total FI	PDO	Total FI + PDO
Proportion by injury level	0.005	0.028	0.180	0.787	1.000		
Expected average crash freq. for study year $N_{e, w, x, at, z, s}$ (cr/yr)	0.006	0.034	0.218	0.954	1.212	2.715	3.927

Crash Type Distribution

Crash Type Category Table 19-21	Fatal and Injury		Property Damage Only		Total
	Proportion	Expected Average Crash Frequency for Study Year $N_{e, w, x, at, fi, s}$ (cr/yr)	Proportion	Expected Average Crash Frequency for Study Year $N_{e, w, x, at, pdo, s}$ (cr/yr)	Expected Average Crash Frequency for Study Year $N_{e, w, x, at, as, s}$ (cr/yr)
Multiple-Vehicle Crashes					
Head-on	0.017	0.021	0.012	0.033	0.053
Right-angle	0.458	0.055	0.378	1.026	1.581
Rear-end	0.373	0.452	0.377	1.023	1.476
Sideswipe	0.025	0.030	0.079	0.214	0.245
Other multiple-vehicle crashes	0.017	0.021	0.016	0.043	0.064
Single-Vehicle Crashes					
Crash with animal	0.000	0.000	0.000	0.000	0.000
Crash with fixed object	0.085	0.103	0.110	0.299	0.402
Crash with other object	0.000	0.000	0.000	0.000	0.000
Crash with parked vehicle	0.000	0.000	0.008	0.022	0.022
Other single-vehicle crashes	0.025	0.030	0.020	0.054	0.085
Total	1.000	1.212	1.000	2.715	3.927

19.14.6. Sample Problem 6

The Site/Facility
An all-way stop-controlled partial cloverleaf interchange ramp terminal on an urban arterial.

The Question
What is the predicted average crash frequency of the ramp terminal for a one-year period?

The Facts
The study year is 2011. The conditions present during this year are provided in the following list:

- B2 configuration
- 1.0 mi to the next public street intersection on the outside crossroad leg

- 0.15 mi to the adjacent ramp terminal
- Stop control for the exit ramp right-turn movement
- 12-ft crossroad median width
- 4 through lanes on the crossroad
- 2 lanes on the exit ramp approach (developed at a distance of 125 ft from the ramp terminal)
- 14,000 veh/day on the crossroad (same for both legs)
- 1,450 veh/day on the exit ramp leg
- 1,300 veh/day on the entrance ramp leg

Assumptions

- Crash type distributions used are the default values presented in Table 19-45.
- The calibration factor is 1.00.

Results

Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the ramp terminal in Sample Problem 6 is determined to be 0.2 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 0.9 crashes per year (rounded to one decimal place).

As stated in the interim predictive method for all-way stop control in Section 19.10, the ramp terminal is evaluated as a one-way stop-controlled terminal, but with a smaller set of CMFs in Step 10. None of the CMFs apply to the property-damage-only SPF.

Steps

Step 1 through 8

To determine the predicted average crash frequency of the ramp terminal in Sample Problem 6, only Steps 9 through 13 are conducted. No other steps are necessary because only one ramp terminal is analyzed for a one-year period and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate SPF.

For a ramp terminal, an SPF value for all crash types is determined. The SPF for fatal-and-injury crashes is calculated from Equation 19-31 and Table 19-17 as follows:

$$\begin{aligned} N_{spf,\ B2,ST,at,\ fi} &= \exp\left(a + b \times \ln\left[c \times AADT_{xrd}\right] + d \times \ln\left[c \times AADT_{ex} + c \times AADT_{en}\right]\right) \\ &= \exp\left(-2.687 + 0.260 \times \ln\left[0.001 \times 14{,}000\right] + 0.947 \times \ln\left[0.001 \times 1{,}450 + 0.001 \times 1{,}300\right]\right) \\ &= 0.352 \text{ crashes/year} \end{aligned}$$

Similarly, the SPF for property-damage-only crashes is calculated from Equation 19-31 and Table 19-17 to yield the following result:

$$N_{spf,\ B2,ST,at,\ pdo} = 0.881 \text{ crashes/year}$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs.

Each CMF used in the calculation of the predicted average crash frequency of the ramp terminal is calculated in this step.

Exit Ramp Capacity (*CMF*10, B2, ST, at, fi)

$CMF_{10,\,B2,\,ST,\,at,\,fi}$ is calculated from Equation 19-42 as follows:

$$CMF_{10,\,B2,\,ST,\,at,\,fi} = (1.0 - P_{ex}) \times 1.0 + P_{ex} \times \exp\left(a \times \frac{c \times AADT_{ex}}{n_{ex,\,eff}}\right)$$

For a stop-controlled exit-ramp right-turn movement, the effective number of lanes serving exit ramp traffic $n_{ex,\,eff}$ is computed using the second portion of Equation 19-43 as follows:

$$\begin{aligned} n_{ex,\,eff} &= 0.5 \times n_{ex} \\ &= 0.5 \times 2 \\ &= 1.0 \end{aligned}$$

The proportion of total leg AADT on the exit ramp leg P_{ex} is computed using Equation 19-44 as follows:

$$\begin{aligned} P_{ex} &= \frac{AADT_{ex}}{AADT_{in} + AADT_{out} + AADT_{en} + AADT_{ex}} \\ &= \frac{1{,}450}{14{,}000 + 14{,}000 + 1{,}300 + 1{,}450} \\ &= 0.047 \end{aligned}$$

From Table 19-32, $a = 0.151$ and $c = 0.001$ for one-way stop-controlled ramp terminals. $CMF_{10,\,B2,\,ST,\,at,\,fi}$ is calculated as follows:

$$\begin{aligned} CMF_{10,\,B2,\,ST,\,at,\,fi} &= (1.0 - 0.047) \times 1.0 + 0.047 \times \exp\left(0.151 \times \frac{0.001 \times 1{,}450}{1.0}\right) \\ &= 1.012 \end{aligned}$$

Access Point Frequency (*CMF*13, B2, ST, at, fi)

The ramp terminal has no unsignalized public street approaches on the outside leg, which is the base condition for the access point frequency CMF. Hence, $CMF_{13,\,B2,\,ST,\,at,\,fi}$ is equal to 1.000.

Segment Length (*CMF*14, B2, ST, at, fi)

$CMF_{14,\,B2,\,ST,\,at,\,fi}$ is calculated from Equation 19-50 as follows:

$$CMF_{14,\,B2,\,ST,\,at,\,fi} = \exp\left(a \times \left[\frac{1.0}{L_{rmp}} + \frac{1.0}{L_{str}} - 0.333\right]\right)$$

From Table 19-36, $a = -0.0141$ for fatal-and-injury crashes. $CMF_{14,\,B2,\,ST,\,at,\,fi}$ is calculated as follows:

$$\begin{aligned} CMF_{14,\,B2,\,ST,\,at,\,fi} &= \exp\left(-0.0141 \times \left[\frac{1.0}{0.15} + \frac{1.0}{1.0} - 0.333\right]\right) \\ &= 0.902 \end{aligned}$$

Median Width (*CMF*15, B2, ST, at, fi)

The crossroad has a 12-ft median, which is the base condition for the median width CMF. Hence, $CMF_{15,\,B2,\,ST,\,at,\,fi}$ is equal to 1.000.

All-Way Stop Control (*CMF*awsc)

As stated in Section 19.10, the all-way stop control CMF, CMF_{awsc}, is equal to 0.686. It applies to fatal-and-injury crashes only.

Crashes

The CMFs are applied to the fatal-and-injury SPF as follows:

$$
\begin{aligned}
N_{p*,\,B2,\,ST,\,at,\,fi} &= N_{spf,\,B2,\,ST,\,at,\,fi} \times \begin{pmatrix} CMF_{10,B2,ST,at,fi} \times CMF_{13,B2,ST,at,fi} \times \\ CMF_{14,B2,ST,at,fi} \times CMF_{15,B2,ST,at,fi} \times CMF_{awsc} \end{pmatrix} \\
&= 0.352 \times (1.012 \times 1.000 \times 0.902 \times 1.000 \times 0.686) \\
&= 0.352 \times 0.626 \\
&= 0.221 \text{ crashes/year}
\end{aligned}
$$

The CMFs are applied to the property-damage-only SPF as follows:

$$
\begin{aligned}
N_{p*,\,B2,\,ST,\,at,\,pdo} &= N_{spf,\,B2,\,ST,\,at,\,pdo} \\
&= 0.881 \text{ crashes/year}
\end{aligned}
$$

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

It is assumed that a calibration factor of 1.00 has been determined for local conditions. See Section B.1 of Appendix B for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency

The predicted average crash frequency is calculated using Equation 19-1 based on the results obtained in Steps 9 through 11 as follows.

Fatal-and-injury crashes:

$$
\begin{aligned}
N_{p,\,B2,\,ST,\,at,\,fi} &= N_{p*,\,B2,\,ST,\,at,\,fi} \times C_{B2,\,ST,\,at,\,fi} \\
&= 0.221 \times 1.00 \\
&= 0.221 \text{ crashes/year}
\end{aligned}
$$

Property-damage-only crashes:

$$
\begin{aligned}
N_{p,\,B2,\,ST,\,at,\,pdo} &= N_{p*,\,B2,\,ST,\,at,\,pdo} \times C_{B2,\,ST,\,at,\,pdo} \\
&= 0.881 \times 1.00 \\
&= 0.881 \text{ crashes/year}
\end{aligned}
$$

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

The study period is one year (2011), so steps 8 through 11 need not be repeated.

Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.

This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

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

The site-specific EB Method is not applied in this sample problem because crash data are not available.

Apply the severity distribution functions (SDFs), if desired.

To apply the SDFs, the systematic component of crash severity likelihood V_j is computed for each severity level j using Equation 19-88 as follows:

$$V_j = a + \left(b \times I_{p,lt}\right) + \left(c \times [n_{dw} + n_{ps}]\right) + \left(d \times I_{ps}\right) + \left(e \times I_{rural}\right)$$

The coefficients *a*, *b*, *c*, *d*, and *e* are obtained from Table 19-44 for each severity level *j*. V_j is computed for fatal and incapacitating injury crashes as follows:

$$\begin{aligned} V_{K+A} &= -3.168 + \left(0.00 \times 0.0\right) + \left(0.00 \times [0.0 + 0.0]\right) + \left(0.00 \times 0.0\right) + \left(0.891 \times 0.0\right) \\ &= -3.168 \end{aligned}$$

Similar calculations using the coefficients from Table 19-44 for non-incapacitating injury crashes yield the following results:

$$V_B = -1.476$$

Using these computed V_{K+A} and V_B values, and assuming a calibration factor $C_{sdf,\,aS,\,x}$ of 1.0, the probability of occurrence of a fatal crash is computed using Equation 19-84 as follows:

$$\begin{aligned} P_{aS,ST,at,K} &= \frac{\exp\left(V_{K+A}\right)}{\dfrac{1.0}{C_{sdf,aS,x}} + \exp\left(V_{K+A}\right) + \exp\left(V_B\right)} \times P_{K|K+A,aS,x,at} \\ &= \frac{\exp\left(-3.168\right)}{\dfrac{1.0}{1.0} + \exp\left(-3.168\right) + \exp\left(-1.476\right)} \times 0.160 \\ &= 0.005 \end{aligned}$$

Similar calculations using Equation 19-85 and Equation 19-86 yield the following results:

$$P_{aS,ST,at,A} = 0.028$$

$$P_{aS,ST,at,B} = 0.180$$

The probability of occurrence of a possible-injury crash is computed using Equation 19-87 as follows:

$$\begin{aligned} P_{aS,ST,at,C} &= 1.0 - \left(P_{aS,ST,at,K} + P_{aS,ST,at,A} + P_{aS,ST,at,B}\right) \\ &= 1.0 - (0.005 + 0.028 + 0.180) \\ &= 0.787 \end{aligned}$$

The probability of occurrence of a fatal crash is multiplied by the fatal-and-injury crash frequency obtained in Step 11 using Equation 19-78 as follows:

$$\begin{aligned} N_{e,B2,ST,at,K} &= N_{e,B2,ST,at,fi} \times P_{aS,ST,at,K} \\ &= 0.221 \times 0.005 \\ &= 0.001 \text{ crashes/year} \end{aligned}$$

Similar calculations using Equation 19-78 and the probabilities of occurrences of the other crash severities yield the following results:

$N_{e,B2,ST,at,A}$ = 0.006 crashes/year

$N_{e,B2,ST,at,B}$ = 0.040 crashes/year

$N_{e,B2,ST,at,C}$ = 0.174 crashes/year

Apply the crash type distribution, if desired.
The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 19-45 by the predicted average crash frequencies obtained in Step 11.

WORKSHEETS

The step-by-step instructions are provided to illustrate the predictive method for calculating the predicted average crash frequency for a ramp terminal. To apply the predictive method steps to multiple terminals, a series of worksheets are provided for determining the predicted average crash frequency. The worksheets are:

- Table 19-68. Ramp Terminal Worksheet (1 of 4)—Sample Problem 6
- Table 19-69. Ramp Terminal Worksheet (2 of 4)—Sample Problem 6
- Table 19-70. Ramp Terminal Worksheet (3 of 4)—Sample Problem 6
- Table 19-71. Ramp Terminal Worksheet (4 of 4)—Sample Problem 6

Filled versions of these worksheets are provided below. A blank version of the corresponding worksheets used in all Sample Problems is provided in Appendix 19A.

Table 19-68 is a summary of general information about the ramp terminal, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 6. The input data include area type, crash data, basic intersection data, alignment data, traffic control data, and cross section data.

Table 19-69 is a summary of general information about the ramp terminal, analysis, input data (i.e., “The Facts”), and assumptions for Sample Problem 6. The input data include cross section data, access data, and traffic data.

Table 19-70 is a tabulation of the CMF and SPF computations for Sample Problem 6.

Table 19-71 is a tabulation of the crash severity and crash type distributions for Sample Problem 6.

Table 19-68. Ramp Terminal Worksheet (1 of 4)—Sample Problem 6

General Information						Location Information	
Analyst						Roadway	
Agency or company						Intersection	
Date performed						Study year	
Area type	X	Urban		Rural			

Input Data							
Crash Data			Crash Period		Study Year	Complete the study year column. Complete the crash period column if the EB Method is used.	
Crash data time period						First year	Last year
Count of FI crashes $N^{*}_{o, w, x, at, fi}$							
Count of PDO crashes $N^{*}_{o, w, x, at, pdo}$							
Basic Intersection Data							
Ramp terminal configuration			B2			Choices: D3ex, D3en, D4, A4, B4, A2, B2, SP, TD Same choice for crash period and study year.	
Ramp terminal traffic control type			All-way stop			Choices: Signal, One-way-stop, All-way stop	
Presence of a non-ramp public street leg I_{ps}				Y/N	--	Y/N	
Alignment Data							
Exit ramp skew angle I_{sk} (degrees)					--		
Distance to the next public street intersection on the outside crossroad leg L_{str} (mi)					1.0		
Distance to the adjacent ramp terminal L_{rmp} (mi)					0.15		
Traffic Control							
Left-Turn Operational Mode							
Crossroad	Inside approach	Prot.-only mode $I_{p, lt, in}$		Y/N	--	Y/N	
	Outside approach	Prot.-only mode $I_{p, lt, out}$		Y/N	--	Y/N	
Right-Turn Control Type							
Ramp	Exit ramp approach	Right-turn control type			Stop	Choices: Signal, Stop, Yield, Merge, Free (FF0, FF1, FF2)	
Cross Section Data							
Crossroad median width W_m (ft)					12		
Number of Lanes							
Crossroad	Inside approach	Through lanes $n_{th, in}$	2			Same choice for crash period and study year.	
	Outside approach	Through lanes $n_{th, out}$	2			Same choice for crash period and study year.	
Ramp	Exit ramp approach	All lanes n_{ex}	2			Same choice for crash period and study year.	
Right-Turn Channelization							
Crossroad	Inside approach	Chan. present $I_{ch, in}$		Y/N	--	Y/N	
	Outside approach	Chan. present $I_{ch, out}$		Y/N	--	Y/N	
Ramp	Exit ramp approach	Chan. present $I_{ch, ex}$		Y/N	--	Y/N	

Table 19-69. Ramp Terminal Worksheet (2 of 4)—Sample Problem 6

Input Data							
Cross Section Data			Crash Period		Study Year		Complete the study year column. Complete the crash period column if the EB Method is used.
Left-Turn Lane or Bay							
Crossroad	Inside approach	Lane or bay present $I_{bay,\,lt,\,in}$		Y/N	--	Y/N	If Yes, then enter data in the next row.
		Lane or bay width $W_{b,\,in}$ (ft)			--		
	Outside approach	Lane or bay present $I_{bay,lt,out}$		Y/N	--	Y/N	If Yes, then enter data in the next row.
		Lane or bay width $W_{b,out}$(ft)			--		
Right-Turn Lane or Bay							
Crossroad	Inside approach	Lane or bay present $I_{bay,\,rt,\,in}$		Y/N	--	Y/N	
	Outside approach	Lane or bay present $I_{bay,rt,out}$		Y/N	--	Y/N	
Access Data							
Number of driveways on the outside crossroad leg n_{dw}					--		
Number of public street approaches on the outside crossroad leg n_{ps}					--		
Number of exit ramps with free-flow right turns onto crossroad (SP Only):							
Traffic Data							
Crossroad	Inside leg	$AADT_{in}$ (veh/day)			14,000		
	Outside leg	$AADT_{out}$ (veh/day)			14,000		
Ramp	Exit ramp	$AADT_{ex}$ (veh/day)			1,450		
	Entrance ramp	$AADT_{en}$ (veh/day)			1,300		

Table 19-70. Ramp Terminal Worksheet (3 of 4)—Sample Problem 6

Crash Modification Factors					
Complete the study year column. Complete the crash period column if the EB Method is used.	Equation	Fatal and Injury		Property Damage Only	
		Crash Period	Study Year	Crash Period	Study Year
Signal Control					
Exit ramp capacity $CMF_{10,\,w,\,SGn,\,at,\,fi}$	19-42	--	--		
Crossroad left-turn lane $CMF_{11,\,w,\,SGn,\,at,\,z}$	19-45	--	--	--	--
Crossroad right-turn lane $CMF_{12,\,w,\,SGn,\,at,\,z}$	19-48	--	--	--	--
Access point frequency $CMF_{13,\,w,\,SGn,\,at,\,z}$	19-49	--	--	--	--
Segment length $CMF_{14,\,w,\,SGn,\,at,\,z}$	19-50	--	--	--	--
Median width $CMF_{15,\,w,\,SGn,\,at,\,z}$	19-51	--	--	--	--
Protected left-turn operation $CMF_{16,\,w,\,SGn,\,at,\,z}$	19-53	--	--	--	--
Chan. right turn on crossroad $CMF_{17,\,w,\,SGn,\,at,\,z}$	19-55	--	--	--	--
Chan. right turn on exit ramp $CMF_{18,\,w,\,SGn,\,at,\,z}$	19-56	--	--	--	--
Non-ramp public street leg $CMF_{19,\,w,\,SGn,\,at,\,z}$	19-57	--	--	--	--
Stop Control					
Exit ramp capacity $CMF_{10,\,w,\,ST,\,at,\,fi}$	19-42	--	1.012		
Crossroad left-turn lane $CMF_{11,\,w,\,ST,\,at,\,z}$	19-45	--	--	--	--
Crossroad right-turn lane $CMF_{12,\,w,\,ST,\,at,\,z}$	19-48	--	--	--	--
Access point frequency $CMF_{13,\,w,\,ST,\,at,\,fi}$	19-49	--	1.000		
Segment length $CMF_{14,\,w,\,ST,\,at,\,fi}$	19-50	--	0.902		
Median width $CMF_{15,\,w,\,ST,\,at,\,fi}$	19-51	--	1.000		
Skew angle $CMF_{20,\,w,\,ST,\,at,\,fi}$	19-58	--	--		
All-way stop-control (exclude CMF_{11}, CMF_{12}, CMF_{20})		--	0.686		
Combined CMF (multiply all CMFs evaluated)		--	0.626	--	1.000

Expected Average Crash Frequency[a]				
Complete the study year column. Complete the crash period column if the ***site-specific*** EB Method is used.	Fatal and Injury		Property Damage Only	
	Crash Period	Study Year	Crash Period	Study Year
Calibration factor $C_{aS,\,x,\,at,\,z}$	1.00		1.00	
Overdispersion parameter $k_{w,\,x,\,at,\,z}$	--		--	
Observed crash count $N^*_{o,\,w,\,x,\,at,\,z}$ (cr)	--		--	
Reference year r	--		--	
Predicted average crash freq. for reference year $N_{p,\,w,\,x,\,at,\,z,\,r}$ (cr/yr)	--		--	
Predicted number of crashes for crash period (sum all years) $N^*_{p,\,w,\,x,\,y,\,z}$ (cr)	--		--	
Equivalent years associated with crash count $C_{b,\,w,\,x,\,at,\,z,\,r}$ (yr)	--		--	
Adjusted average crash freq. for ref. year given N^*_o, $N_{a,\,w,\,x,\,at,\,z,\,r}$ (cr/yr)	--		--	
Study year s		2011		2011
Predicted average crash freq. for study year $N_{p,\,w,\,x,\,at,\,z,\,s}$ (cr/yr)		0.221		0.881
Expected average crash freq. for study year $N_{e,\,w,\,x,\,at,\,z,\,s}$ (cr/yr)		0.221		0.881

[a] If the EB Method is not used, then substitute "predicted" for "expected" and substitute the subscript "p" for the subscript "e".

Table 19-71. Ramp Terminal Worksheet (4 of 4)—Sample Problem 6

Expected Average Crash Frequency

Crash Severity Distribution

	K	A	B	C	Total FI	PDO	Total FI + PDO
Proportion by injury level	0.005	0.028	0.180	0.787	1.000		
Expected average crash freq. for study year $N_{e, w, x, at, z, s}$ (cr/yr)	0.001	0.006	0.040	0.174	0.221	0.881	1.102

Crash Type Distribution

Crash Type Category Table 19-21	Fatal and Injury		Property Damage Only		Total
	Proportion	Expected Average Crash Frequency for Study Year $N_{e, w, x, at, fi, s}$ (cr/yr)	Proportion	Expected Average Crash Frequency for Study Year $N_{e, w, x, at, pdo, s}$ (cr/yr)	Expected Average Crash Frequency for Study Year $N_{e, w, x, at, as, s}$ (cr/yr)
Multiple-Vehicle Crashes					
Head-on	0.017	0.000	0.012	0.000	0.000
Right-angle	0.458	0.040	0.378	0.293	0.333
Rear-end	0.373	0.160	0.377	0.440	0.601
Sideswipe	0.025	0.000	0.079	0.000	0.000
Other multiple-vehicle crashes	0.017	0.000	0.016	0.000	0.000
Single-Vehicle Crashes					
Crash with animal	0.000	0.000	0.000	0.000	0.000
Crash with fixed object	0.085	0.000	0.110	0.147	0.147
Crash with other object	0.000	0.000	0.000	0.000	0.000
Crash with parked vehicle	0.000	0.000	0.008	0.000	0.000
Other single-vehicle crashes	0.025	0.020	0.020	0.000	0.020
Total	1.000	0.221	1.000	0.881	1.102

19.14.7. Sample Problem 7

The Site/Facility

A single-point diamond interchange crossroad ramp terminal.

The Question

What is the predicted average crash frequency of the crossroad ramp terminal for a one-year period?

The Facts

- None of the right turns from the exit ramps to the crossroad are free-flow
- 31,250 veh/day on the crossroad (same for both legs)
- 10,500 veh/day on both of the exit ramp legs combined
- 8,200 veh/day on both of the entrance ramp legs combined

Assumptions

Crash type distributions used are the default values presented in Table 19-XB.

Severity distributions are the default values from Table 19-XC.

The calibration factor is 1.10.

Results

Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the ramp terminal in Sample Problem 7 is determined to be 3.2 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 8.3 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8

To determine the predicted average crash frequency of the ramp terminal in Sample Problem 7, only Steps 9 through 13 are conducted. No other steps are necessary because only one ramp terminal is analyzed for a one-year period and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate SPF.

For a ramp terminal, an SPF value for all crash types is determined. The SPF for fatal-and-injury crashes is calculated from Equation 19-XA and Table 19-XA as follows:

$$N_{spf,SP,at,fi} = exp\left(a + b \times ln(AADT_{xrd}) + c \times ln(AADT_{ramp})\right)$$
$$= exp(-16.71 + 0.88 \times ln(31{,}250) + 0.88 \times ln(18{,}700))$$
$$= 2.868\ crashes/year$$

Similarly, the SPF for property-damage-only crashes is calculated from Equation 19-XA and Table 19-XA to yield the following result:

$$N_{spf,SP,at,pdo} = exp\left(-15.60 + 0.61 \times \ln(31{,}250) + 1.15 \times \ln(18{,}700)\right)$$
$$= 7.577\ crashes/year$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs.

The combined CMF value for Sample Problem 7 is 1.0 since there are no CMFs for the single-point diamond interchange ramp terminal.

Fatal-and-injury crashes:

$$N_{p*,SP,at,fi} = N_{spf,SP,at,fi} \times CMF_{SP,at,fi}$$
$$= 2.868 \times 1.0$$
$$= 2.868\ crashes/year$$

Property-damage-only crashes:

$$N_{p^*,SP,at,pdo} = N_{spf,SP,at,pdo} \times CMF_{SP,at,pdo}$$
$$= 7.577 \times 1.0$$
$$= 7.577 \text{ crashes/year}$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor of 1.10 has been determined for local conditions. See Section B.1 of Appendix B for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 19-1 based on the results obtained in Steps 9 through 11 as follows.

Fatal-and-injury crashes:

$$N_{p,SP,at,fi} = N_{p^*,SP,at,fi} \times C_{SP,at,fi}$$
$$= 2.868 \times 1.10$$
$$= 3.155 \text{ crashes/year}$$

Property-damage-only crashes:

$$N_{p,SP,at,pdo} = N_{p^*,SP,at,pdo} \times C_{SP,at,pdo}$$
$$= 7.577 \times 1.10$$
$$= 8.334 \text{ crashes/year}$$

Step 12—If there is another year to be evaluated in the evaluation period for the selected site, return to Step 8. Otherwise, proceed to Step 13.
The study period is one year, so steps 8 through 11 need not be repeated.

Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.
This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

Apply the site-specific EB Method to a future time period, if appropriate.
The site-specific EB Method is not applied in this sample problem because crash data are not available.

Apply the severity distributions, if desired.

The crash severity distributions are applied by multiplying the default crash severity distribution proportions in Table 19-XC by the predicted average crash frequencies in Step 11. Apply the crash type distribution, if desired.
The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 19-XB by the predicted average crash frequencies obtained in Step 11.

WORKSHEETS

The step-by-step instructions are provided to illustrate the predictive method for calculating the predicted average crash frequency for a ramp terminal. To apply the predictive method steps to multiple terminals, a series of worksheets are provided for determining the predicted average crash frequency. The worksheets are:

- Table 19-SPXA. Ramp Terminal Worksheet (1 of 4)—Sample Problem 7
- Table 19-SPXB. Ramp Terminal Worksheet (2 of 4)—Sample Problem 7
- Table 19-SPXC. Ramp Terminal Worksheet (3 of 4)—Sample Problem 7
- Table 19-SPXD. Ramp Terminal Worksheet (4 of 4)—Sample Problem 7

Filled versions of these worksheets are provided below. A blank version of the corresponding worksheets used in all Sample Problems is provided in Appendix 19A.

Table 19-SPXA is a summary of general information about the ramp terminal, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 7. The input data include area type, crash data, basic intersection data, alignment data, traffic control data, and cross section data.

Table 19-SPXB is a summary of general information about the ramp terminal, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 7. The input data include cross section data, access data, and traffic data.

Table 19-SPXC is a tabulation of the CMF and SPF computations for Sample Problem 7.

Table 19-SPXD is a tabulation of the crash severity and crash type distributions for Sample Problem 7.

Table 19-SPXA. Ramp Terminal Worksheet (1 of 4)—Sample Problem 7

General Information						Location Information	
Analyst						Roadway	
Agency or company						Intersection	
Date performed						Study year	
Area type	X	Urban		Rural			

Input Data							
Crash Data			Crash Period		Study Year		Complete the study year column. Complete the crash period column if the EB Method is used.
Crash data time period							First year | -- | Last year
Count of FI crashes $N^*_{o,w,x,at,fi}$			--				
Count of PDO crashes $N^*_{o,w,x,at,pdo}$			--				
Basic Intersection Data							
Ramp terminal configuration			SP				Choices: D3ex, D3en, D4, A4, B4, A2, B2, SP, TD Same choice for crash period and study year.
Ramp terminal traffic control type			--				Choices: Signal, One-way-stop, All-way stop
Presence of a non-ramp public street leg I_{ps}			--	Y/N	N	Y/N	
Alignment Data							
Exit ramp skew angle I_{sk} (degrees)			--		--		
Distance to the next public street intersection on the outside crossroad leg L_{str} (mi)			--		--		
Distance to the adjacent ramp terminal L_{rmp} (mi)			--		--		
Traffic Control							
Left-Turn Operational Mode							
Crossroad	Inside approach	Prot.-only mode $I_{p,lt,in}$	--	Y/N	--	Y/N	
	Outside approach	Prot.-only mode $I_{p,lt,out}$	--	Y/N	--	Y/N	
Right-Turn Control Type							
Ramp	Exit ramp approach	Right-turn control type	--		Signal, FF0		Choices: Signal, Stop, Yield, Merge, Free (FF0, FF1, FF2)
Cross Section Data							
Crossroad median width W_m (ft)			--		--		
Number of Lanes							
Crossroad	Inside approach	Through lanes $n_{th,in}$	--				Same choice for crash period and study year.
	Outside approach	Through lanes $n_{th,out}$	--				Same choice for crash period and study year.
Ramp	Exit ramp approach	All lanes n_{ex}	--				Same choice for crash period and study year.
Right-Turn Channelization							
Crossroad	Inside approach	Chan. present $I_{ch,in}$	--	Y/N	--	Y/N	
	Outside approach	Chan. present $I_{ch,out}$	--	Y/N	--	Y/N	
Ramp	Exit ramp approach	Chan. present $I_{ch,ex}$	--	Y/N	--	Y/N	

Table 19-61. Ramp Terminal Worksheet (2 of 4)—Sample Problem 7

Input Data							
Cross Section Data			Crash Period		Study Year		Complete the study year column. Complete the crash period column if the EB Method is used.
Left-Turn Lane or Bay							
Crossroad	Inside approach	Lane or bay present $I_{bay,\,lt,\,in}$	--	Y/N	--	Y/N	If Yes, then enter data in the next row.
		Lane or bay width $W_{b,\,in}$ (ft)	--				
	Outside approach	Lane or bay present $I_{bay,lt,out}$	--	Y/N	--	Y/N	If Yes, then enter data in the next row.
		Lane or bay width $W_{b,out}$(ft)	--		--		
Right-Turn Lane or Bay							
Crossroad	Inside approach	Lane or bay present $I_{bay,\,rt,\,in}$	--	Y/N	--	Y/N	
	Outside approach	Lane or bay present $I_{bay,rt,out}$	--	Y/N	--	Y/N	
Access Data							
Number of driveways on the outside crossroad leg n_{dw}			--		--		
Number of public street approaches on the outside crossroad leg n_{ps}			--		--		
Number of exit ramps with free-flow right turns onto crossroad (SPUI Only):					0		
Traffic Data							
Crossroad	Inside leg	$AADT_{in}$ (veh/day)	--		31,250		
	Outside leg	$AADT_{out}$ (veh/day)	--		31,250		
Ramp	Exit ramp	$AADT_{ex}$ (veh/day)	--		10,500		
	Entrance ramp	$AADT_{en}$ (veh/day)	--		8,200		

Table 19-62. Ramp Terminal Worksheet (3 of 4)—Sample Problem 7

Crash Modification Factors					
Complete the study year column. Complete the crash period column if the EB Method is used.		Fatal and Injury		Property Damage Only	
		Crash Period	Study Year	Crash Period	Study Year
Signal Control	Equation				
Exit ramp capacity $CMF_{10,\ w,\ SGn,\ at,\ fi}$	19-42	--	--		
Crossroad left-turn lane $CMF_{11,\ w,\ SGn,\ at,\ z}$	19-45	--	--	--	--
Crossroad right-turn lane $CMF_{12,\ w,\ SGn,\ at,\ z}$	19-48	--	--	--	--
Access point frequency $CMF_{13,\ w,\ SGn,\ at,\ z}$	19-49	--	--	--	--
Segment length $CMF_{14,\ w,\ SGn,\ at,\ z}$	19-50	--	--	--	--
Median width $CMF_{15,\ w,\ SGn,\ at,\ z}$	19-51	--	--	--	--
Protected left-turn operation $CMF_{16,\ w,\ SGn,\ at,\ z}$	19-53	--	--	--	--
Chan. right turn on crossroad $CMF_{17,\ w,\ SGn,\ at,\ z}$	19-55	--	--	--	--
Chan. right turn on exit ramp $CMF_{18,\ w,\ SGn,\ at,\ z}$	19-56	--	--	--	--
Non-ramp public street leg $CMF_{19,\ w,\ SGn,\ at,\ z}$	19-57	--	--	--	--
Stop Control					
Exit ramp capacity $CMF_{10,\ w,\ ST,\ at,\ fi}$	19-42	--	--		
Crossroad left-turn lane $CMF_{11,\ w,\ ST,\ at,\ z}$	19-45	--	--	--	--
Crossroad right-turn lane $CMF_{12,\ w,\ ST,\ at,\ z}$	19-48	--	--	--	--
Access point frequency $CMF_{13,\ w,\ ST,\ at,\ fi}$	19-49	--	--		
Segment length $CMF_{14,\ w,\ ST,\ at,\ fi}$	19-50	--	--		
Median width $CMF_{15,\ w,\ ST,\ at,\ fi}$	19-51	--	--		
Skew angle $CMF_{20,\ w,\ ST,\ at,\ fi}$	19-58	--	--		
All-way stop-control (exclude CMF_{11}, CMF_{12}, CMF_{20})		--	--		
Combined CMF (multiply all CMFs evaluated)		--	1.000	--	1.000

Expected Average Crash Frequency[a]				
Complete the study year column. Complete the crash period column if the ***site-specific*** EB Method is used.	Fatal and Injury		Property Damage Only	
	Crash Period	Study Year	Crash Period	Study Year
Calibration factor $C_{aS,\ x,\ at,\ z}$	1.10		1.10	
Overdispersion parameter $k_{w,\ x,\ at,\ z}$	--		--	
Observed crash count $N^*_{o,\ w,\ x,\ at,\ z}$ (cr)	--		--	
Reference year r	--		--	
Predicted average crash freq. for reference year $N_{p,\ w,\ x,\ at,\ z,\ r}$ (cr/yr)	--		--	
Predicted number of crashes for crash period (sum all years) $N^*_{p,\ w,\ x,\ y,\ z}$ (cr)	--		--	
Equivalent years associated with crash count $C_{b,\ w,\ x,\ at,\ z,\ r}$ (yr)	--		--	
Adjusted average crash freq. for ref. year given N^*_o, $N_{o,\ w,\ x,\ at,\ z,\ r}$ (cr/yr)	--		--	
Study year s		2011		2011
Predicted average crash freq. for study year $N_{p,\ w,\ x,\ at,\ z,\ s}$ (cr/yr)		3.155		8.334
Expected average crash freq. for study year $N_{e,\ w,\ x,\ at,\ z,\ s}$ (cr/yr)		3.155		8.334

[a] If the EB Method is not used, then substitute "predicted" for "expected" and substitute the subscript "p" for the subscript "e".

Table 19-63. Ramp Terminal Worksheet (4 of 4)—Sample Problem 7

Expected Average Crash Frequency

Crash Severity Distribution

	K	A	B	C	Total FI	PDO	Total FI + PDO
Proportion by injury level	0.006	0.047	0.278	0.669	1.000		
Expected average crash freq. for study year $N_{e,w,x,at,z,s}$ (cr/yr)	0.019	0.148	0.877	2.111	3.155	8.334	11.490

Crash Type Distribution

Crash Type Category (Table 19-16, 19-21, 19-XB, 19-XE, or 19-45)	Fatal and Injury		Property Damage Only		Total
	Proportion	Expected Average Crash Frequency for Study Year $N_{e,w,x,at,fi,s}$ (cr/yr)	Proportion	Expected Average Crash Frequency for Study Year $N_{e,w,x,at,pdo,s}$ (cr/yr)	Expected Average Crash Frequency for Study Year $N_{e,w,x,at,as,s}$ (cr/yr)
Multiple-Vehicle Crashes					
Head-on	0.034	0.107	0.006	0.050	0.157
Right-angle	0.129	0.407	0.080	0.667	1.074
Rear-end	0.662	2.089	0.744	6.201	8.290
Sideswipe	0.040	0.127	0.112	0.933	1.060
Other multiple-vehicle crashes	0.011	0.035	0.006	0.050	0.085
Single-Vehicle Crashes					
Crash with animal	0.000	0.000	0.000	0.000	0.000
Crash with fixed object	0.046	0.146	0.046	0.383	0.529
Crash with other object	0.002	0.007	0.001	0.008	0.015
Crash with parked vehicle	0.000	0.000	0.000	0.000	0.000
Other single-vehicle crashes	0.013	0.042	0.005	0.042	0.083
Crash with pedestrian	0.021	0.067	0.000	0.000	0.067
Crash with bicycle	0.042	0.133	0.000	0.000	0.133
Total	1.000	3.155	1.000	8.334	11.490

19.14.8. Sample Problem 8

The Site/Facility
A tight diamond interchange crossroad ramp terminal.

The Question
What is the predicted average crash frequency of the crossroad ramp terminal for a one-year period?

The Facts
- 31,250 veh/day on the crossroad (same for both legs)
- 10,500 veh/day on both of the exit ramp legs combined
- 8,200 veh/day on both of the entrance ramp legs combined

Assumptions
Crash type distributions used are the default values presented in Table 19-XE.

Severity distributions are the default values from Table 19-XF.

The calibration factor is 1.10.

Results
Using the predictive method steps as outlined below, the predicted average fatal-and-injury crash frequency for the ramp terminal in Sample Problem 8 is determined to be 3.8 crashes per year, and the predicted average property-damage-only crash frequency is determined to be 9.7 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the ramp terminal in Sample Problem 8, only Steps 9 through 13 are conducted. No other steps are necessary because only one ramp terminal is analyzed for a one-year period and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate SPF.
For a ramp terminal, an SPF value for all crash types is determined. The SPF for fatal-and-injury crashes is calculated from Equation 19-XB and Table 19-XD as follows:

$$
\begin{aligned}
N_{spf,TD,at,fi} &= exp\left(a + b \times ln(AADT_{xrd}) + c \times ln\left(AADT_{ramp}\right)\right) \\
&= exp\left(-11.90 + 0.50 \times ln(31{,}250) + 0.81 \times ln(18{,}700)\right) \\
&= 3.463\ crashes/year
\end{aligned}
$$

Similarly, the SPF for property-damage-only crashes is calculated from Equation 19-XB and Table 19-XD to yield the following result:

$$
\begin{aligned}
N_{spf,TD,at,pdo} &= exp\left(-11.99 + 0.77 \times ln(31{,}250) + 0.63 \times ln(18{,}700)\right) \\
&= 8.813\ crashes/year
\end{aligned}
$$

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs.
The combined CMF value for Sample Problem 8 is 1.0 since there are no CMFs for the tight~~single-point~~ diamond interchange ramp terminal.

Fatal-and-injury crashes:

$$N_{p*,TD,at,fi} = N_{spf,TD,at,fi} \times CMF_{TD,at,fi}$$
$$= 3.463 \times 1.0$$
$$= 3.463\ crashes/year$$

Property-damage-only crashes:

$$N_{p*,TD,at,PDO} = N_{spf,TD,at,pdo} \times CMF_{TD,at,pdo}$$
$$= 8.813 \times 1.0$$
$$= 8.813\ crashes/year$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed that a calibration factor of 1.10 has been determined for local conditions. See Section B.1 of Appendix B for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 19-1 based on the results obtained in Steps 9 through 11 as follows.

Fatal-and-injury crashes:

$$N_{p,TD,at,fi} = N_{p*,TD,at,fi} \times C_{TD,at,fi}$$
$$= 3.463 \times 1.10$$
$$= 3.809\ crashes/year$$

Property-damage-only crashes:

$$N_{p,TD,at,pdo} = N_{p*,TD,at,pdo} \times C_{TD,at,pdo}$$
$$= 8.813 \times 1.10$$
$$= 9.694\ crashes/year$$

Step 12—If there is another year to be evaluated in the evaluation period for the selected site, return to Step 8. Otherwise, proceed to Step 13.
The study period is one year, so steps 8 through 11 need not be repeated.

Step 13—Apply site-specific EB Method (if applicable) and apply SDFs.
This step consists of three optional sets of calculations—site-specific EB Method, severity distribution functions, and crash type distribution.

Apply the site-specific EB Method to a future time period, if appropriate.
The site-specific EB Method is not applied in this sample problem because crash data are not available.

Apply the severity distributions, if desired.

The crash severity distributions are applied by multiplying the default crash severity distribution proportions in Table 19-XF by the predicted average crash frequencies in Step 11. Apply the crash type distribution, if desired.

The crash type distributions are applied by multiplying the default crash type distribution proportions in Table 19-XE by the predicted average crash frequencies obtained in Step 11.

WORKSHEETS

The step-by-step instructions are provided to illustrate the predictive method for calculating the predicted average crash frequency for a ramp terminal. To apply the predictive method steps to multiple terminals, a series of worksheets are provided for determining the predicted average crash frequency. The worksheets are:

- Table 19-SPXE. Ramp Terminal Worksheet (1 of 4)—Sample Problem 8
- Table 19-SPXF. Ramp Terminal Worksheet (2 of 4)—Sample Problem 8
- Table 19-SPXG. Ramp Terminal Worksheet (3 of 4)—Sample Problem 8
- Table 19-SPXH. Ramp Terminal Worksheet (4 of 4)—Sample Problem 8

Filled versions of these worksheets are provided below. A blank version of the corresponding worksheets used in all Sample Problems is provided in Appendix 19A.

Table 19-SPXE is a summary of general information about the ramp terminal, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 8. The input data include area type, crash data, basic intersection data, alignment data, traffic control data, and cross section data.

Table 19-SPXF is a summary of general information about the ramp terminal, analysis, input data (i.e., "The Facts"), and assumptions for Sample Problem 8. The input data include cross section data, access data, and traffic data.

Table 19-SPXG is a tabulation of the CMF and SPF computations for Sample Problem 8.

Table 19-SPXH is a tabulation of the crash severity and crash type distributions for Sample Problem 8.

Table 19-SPXE. Ramp Terminal Worksheet (1 of 4)—Sample Problem 8

General Information						Location Information	
Analyst						Roadway	
Agency or company						Intersection	
Date performed						Study year	
Area type	X	Urban		Rural			

Input Data

Crash Data			Crash Period		Study Year		Complete the study year column. Complete the crash period column if the EB Method is used.
Crash data time period							First year -- Last year
Count of FI crashes $N^*_{o,w,x,at,fi}$			--				
Count of PDO crashes $N^*_{o,w,x,at,pdo}$			--				
Basic Intersection Data							
Ramp terminal configuration			TD				Choices: D3ex, D3en, D4, A4, B4, A2, B2, SP, TD Same choice for crash period and study year.
Ramp terminal traffic control type			--				Choices: Signal, One-way-stop, All-way stop
Presence of a non-ramp public street leg I_{ps}			--	Y/N	N	Y/N	
Alignment Data							
Exit ramp skew angle I_{sk} (degrees)			--		--		
Distance to the next public street intersection on the outside crossroad leg L_{str} (mi)			--		--		
Distance to the adjacent ramp terminal L_{rmp} (mi)			--		--		
Traffic Control							
Left-Turn Operational Mode							
Crossroad	Inside approach	Prot.-only mode $I_{p,lt,in}$	--	Y/N	--	Y/N	
	Outside approach	Prot.-only mode $I_{p,lt,out}$	--	Y/N	--	Y/N	
Right-Turn Control Type							
Ramp	Exit ramp approach	Right-turn control type	--		--		Choices: Signal, Stop, Yield, Merge, Free (FF0, FF1, FF2)
Cross Section Data							
Crossroad median width W_m (ft)			--		--		
Number of Lanes							
Crossroad	Inside approach	Through lanes $n_{th,in}$	--				Same choice for crash period and study year.
	Outside approach	Through lanes $n_{th,out}$	--				Same choice for crash period and study year.
Ramp	Exit ramp approach	All lanes n_{ex}	--				Same choice for crash period and study year.
Right-Turn Channelization							
Crossroad	Inside approach	Chan. present $I_{ch,in}$	--	Y/N	--	Y/N	
	Outside approach	Chan. present $I_{ch,out}$	--	Y/N	--	Y/N	
Ramp	Exit ramp approach	Chan. present $I_{ch,ex}$	--	Y/N	--	Y/N	

Table 19-61. Ramp Terminal Worksheet (2 of 4)—Sample Problem 8

Input Data							
Cross Section Data			Crash Period		Study Year		Complete the study year column. Complete the crash period column if the EB Method is used.
Left-Turn Lane or Bay							
Crossroad	Inside approach	Lane or bay present $I_{bay,\,lt,\,in}$	--	Y/N	--	Y/N	If Yes, then enter data in the next row.
		Lane or bay width $W_{b,\,in}$ (ft)	--				
	Outside approach	Lane or bay present $I_{bay,lt,out}$	--	Y/N	--	Y/N	If Yes, then enter data in the next row.
		Lane or bay width $W_{b,out}$(ft)	--		--		
Right-Turn Lane or Bay							
Crossroad	Inside approach	Lane or bay present $I_{bay,\,rt,\,in}$	--	Y/N	--	Y/N	
	Outside approach	Lane or bay present $I_{bay,rt,out}$	--	Y/N	--	Y/N	
Access Data							
Number of driveways on the outside crossroad leg n_{dw}			--		--		
Number of public street approaches on the outside crossroad leg n_{ps}			--		--		
Number of exit ramps with free-flow right turns onto crossroad (SPUI Only):					--		
Traffic Data							
Crossroad	Inside leg	$AADT_{in}$ (veh/day)	--		31,250		
	Outside leg	$AADT_{out}$ (veh/day)	--		31,250		
Ramp	Exit ramp	$AADT_{ex}$ (veh/day)	--		10,500		
	Entrance ramp	$AADT_{en}$ (veh/day)	--		8,200		

Table 19-62. Ramp Terminal Worksheet (3 of 4)—Sample Problem 8

Crash Modification Factors						
Complete the study year column. Complete the crash period column if the EB Method is used.		Fatal and Injury		Property Damage Only	
		Crash Period	Study Year	Crash Period	Study Year
Signal Control	Equation				
Exit ramp capacity $CMF_{10, w, SGn, at, fi}$	19-42	--	--		
Crossroad left-turn lane $CMF_{11, w, SGn, at, z}$	19-45	--	--	--	--
Crossroad right-turn lane $CMF_{12, w, SGn, at, z}$	19-48	--	--	--	--
Access point frequency $CMF_{13, w, SGn, at, z}$	19-49	--	--	--	--
Segment length $CMF_{14, w, SGn, at, z}$	19-50	--	--	--	--
Median width $CMF_{15, w, SGn, at, z}$	19-51	--	--	--	--
Protected left-turn operation $CMF_{16, w, SGn, at, z}$	19-53	--	--	--	--
Chan. right turn on crossroad $CMF_{17, w, SGn, at, z}$	19-55	--	--	--	--
Chan. right turn on exit ramp $CMF_{18, w, SGn, at, z}$	19-56	--	--	--	--
Non-ramp public street leg $CMF_{19, w, SGn, at, z}$	19-57	--	--	--	--
Stop Control					
Exit ramp capacity $CMF_{10, w, ST, at, fi}$	19-42	--	--		
Crossroad left-turn lane $CMF_{11, w, ST, at, z}$	19-45	--	--	--	--
Crossroad right-turn lane $CMF_{12, w, ST, at, z}$	19-48	--	--	--	--
Access point frequency $CMF_{13, w, ST, at, fi}$	19-49	--	--		
Segment length $CMF_{14, w, ST, at, fi}$	19-50	--	--		
Median width $CMF_{15, w, ST, at, fi}$	19-51	--	--		
Skew angle $CMF_{20, w, ST, at, fi}$	19-58	--	--		
All-way stop-control (exclude CMF_{11}, CMF_{12}, CMF_{20})		--	--		
Combined CMF (multiply all CMFs evaluated)		--	1.000	--	1.000

Expected Average Crash Frequency [a]				
Complete the study year column. Complete the crash period column if the ***site-specific*** EB Method is used.	Fatal and Injury		Property Damage Only	
	Crash Period	Study Year	Crash Period	Study Year
Calibration factor $C_{aS, x, at, z}$	1.10		1.10	
Overdispersion parameter $k_{w, x, at, z}$	--		--	
Observed crash count $N^*_{o, w, x, at, z}$ (cr)	--		--	
Reference year r	--		--	
Predicted average crash freq. for reference year $N_{p, w, x, at, z, r}$ (cr/yr)	--		--	
Predicted number of crashes for crash period (sum all years) $N^*_{p, w, x, y, z}$ (cr)	--		--	
Equivalent years associated with crash count $C_{b, w, x, at, z, r}$ (yr)	--		--	
Adjusted average crash freq. for ref. year given N^*_o, $N_{a, w, x, at, z, r}$ (cr/yr)	--		--	
Study year s		2011		2011
Predicted average crash freq. for study year $N_{p, w, x, at, z, s}$ (cr/yr)		3.809		9.694
Expected average crash freq. for study year $N_{e, w, x, at, z, s}$ (cr/yr)		3.809		9.694

[a] If the EB Method is not used, then substitute "predicted" for "expected" and substitute the subscript "p" for the subscript "e".

Table 19-63. Ramp Terminal Worksheet (4 of 4)—Sample Problem 8

Expected Average Crash Frequency							
Crash Severity Distribution							
	K	A	B	C	Total FI	PDO	Total FI + PDO
Proportion by injury level	0.003	0.0615	0.329	0.6068	1.000		
Expected average crash freq. for study year $N_{e, w, x, at, z, s}$ (cr/yr)	0.011	0.234	1.253	2.311	3.809	9.694	13.503

Crash Type Distribution

Crash Type Category — Table 19-16, 19-21, 19-XB, 19-XE, or 19-45	Fatal and Injury		Property Damage Only		Total
	Proportion	Expected Average Crash Frequency for Study Year $N_{e, w, x, at, fi, s}$ (cr/yr)	Proportion	Expected Average Crash Frequency for Study Year $N_{e, w, x, at, pdo, s}$ (cr/yr)	Expected Average Crash Frequency for Study Year $N_{e, w, x, at, as, s}$ (cr/yr)
Multiple-Vehicle Crashes					
Head-on	0.010	0.038	0.005	0.048	0.087
Right-angle	0.436	1.661	0.239	2.317	3.978
Rear-end	0.444	1.691	0.579	5.613	7.304
Sideswipe	0.028	0.107	0.124	1.202	1.309
Other multiple-vehicle crashes	0.012	0.046	0.014	0.136	0.181
Single-Vehicle Crashes					
Crash with animal	0.000	0.000	0.000	0.000	0.000
Crash with fixed object	0.013	0.050	0.032	0.310	0.360
Crash with other object	0.000	0.000	0.001	0.010	0.010
Crash with parked vehicle	0.000	0.000	0.000	0.000	0.000
Other single-vehicle crashes	0.010	0.038	0.004	0.039	0.077
Crash with pedestrian	0.017	0.065	0.000	0.000	0.065
Crash with bicycle	0.030	0.114	0.002	0.019	0.134
Total	1.000	3.809	1.000	8.334	13.503

19.15. REFERENCES

(1) Bonneson, J., S. Geedipally, M. Pratt, and D. Lord. *Safety Prediction Methodology and Analysis Tool for Freeways and Interchanges.* Final Report. NCHRP Project 17-45. Texas Transportation Institute, College Station, Texas, 2012. http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2512

(2) Harwood, D. W., M. T. Pietrucha, M. D. Wooldridge, R. E. Brydia, and K. Fitzpatrick. *NCHRP Report 375: Median Intersection Design*. National Cooperative Highway Research Association, Transportation Research Board, Washington, DC, 1995.

~~(2)~~(3) Torbic, D.J., D.J. Cook, K.M. Bauer, J.R. Grotheer, D.W. Harwood, I.B. Potts, R.J. Porter, J.P. Gooch, K. Kersavage, J. Medina, and J. Taylor. Intersection Crash Prediction Methods for the *Highway Safety Manual*, Final Report of NCHRP Project 17-68, MRIGlobal, 2020.

APPENDIX 19A WORKSHEETS FOR PREDICTIVE METHOD FOR RAMPS

Table 19A-1. Ramp Segment Worksheet (1 of 4)

General Information						Location Information		
Analyst						Roadway		
Agency or company						Roadway section		
Date performed						Study year		
Area type		Urban		Rural				

Input Data					
	Crash Data	Crash Period	Study Year	Complete the study year column. Complete the crash period column if the EB Method is used.	
	Crash data time period			First year	Last year
	Count of multiple-vehicle FI crashes $N^*_{o,w,n,mv,fi}$				
	Count of single-vehicle FI crashes $N^*_{o,w,n,sv,fi}$				
	Count of multiple-vehicle PDO crashes $N^*_{o,w,n,mv,pdo}$				
	Count of single-vehicle PDO crashes $N^*_{o,w,n,sv,pdo}$				
	Basic Roadway Data				
	Number of through lanes n			Same value for crash period and study year.	
	Segment length L (mi)				
	Average traffic speed on the freeway V_{frwy} (mi/h)				
	Segment type			Choices: Entrance, Exit, C-D road, Connector	
	Type of control at crossroad ramp terminal			Choices: Stop, Yield, Signal, None	
	Alignment Data				
	Horizontal Curve Data				
1	Presence of horizontal curve 1			Choices: No, In segment, Off segment.	
1	Curve radius R_1 (ft)			If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.	
1	Length of curve L_{c1} (mi)				
1	Length of curve in segment $L_{c1,seg}$ (mi)				
1	Ramp-mile of beginning of curve in dir. of travel X_1 (mi)				
2	Presence of horizontal curve 2			Choices: No, In segment, Off segment	
2	Curve radius R_2 (ft)			If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.	
2	Length of curve L_{c2} (mi)				
2	Length of curve in segment $L_{c2,seg}$ (mi)				
2	Ramp-mile of beginning of curve in dir. of travel X_2 (mi)				
3	Presence of horizontal curve 3			Choices: No, In segment, Off segment	
3	Curve radius R_3 (ft)			If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.	
3	Length of curve L_{c3} (mi)				
3	Length of curve in segment $L_{c3,seg}$ (mi)				
3	Ramp-mile of beginning of curve in dir. of travel X_3 (mi)				
4	Presence of horizontal curve 4			Choices: No, In segment, Off segment	
4	Curve radius R_4 (ft)			If "In segment" or "Off segment", enter data for curve radius, length, and ramp-mile.	
4	Length of curve L_{c4} (mi)				
4	Length of curve in segment $L_{c4,seg}$ (mi)				
4	Ramp-mile of beginning of curve in dir. of travel X_4 (mi)				

Table 19A-1. Ramp Segment Worksheet (2 of 4)

Input Data						
Cross Section Data		Crash Period		Study Year		Complete the study year column. Complete the crash period column if the EB Method is used.
Lane width W_l (ft)						
Right shoulder width W_{rs} (ft)						
Left shoulder width W_{ls} (ft)						
Presence of lane add or lane drop						Choices: No, Lane add, Lane drop
Length of taper in segment $L_{add, seg}$ or $L_{drop, seg}$ (mi)						If "Lane add" or "Lane drop", enter length.
Roadside Data						
Presence of barrier on right side of roadway			Y/N		Y/N	If Yes, then use the ramp barrier worksheet.
Presence of barrier on left side of roadway			Y/N		Y/N	If Yes, then use the ramp barrier worksheet.
Ramp Access Data						
Ramp Entrance						
Ent. ramp	Presence of speed-change lane in segment		Y/N		Y/N	If Yes, then enter data in the next row.
	Length of s-c lane in segment $L_{en,seg}$ (mi)					
Exit ramp	Presence of speed-change lane in segment		Y/N		Y/N	If Yes, then enter data in the next row.
	Length of s-c lane in segment $L_{ex,seg}$ (mi)					
Weave	Presence of a weaving section in segment		Y/N		Y/N	If Yes, then enter data in the next two rows.
	Length of weaving section L_{wev} (mi)					
	Length of weaving section in seg. $L_{wev, seg}$ (mi)					
Traffic Data						
Segment AADT $AADT_r$ or $AADT_c$ (veh/day)						

Table 19A-1. Ramp Segment Worksheet (3 of 4)

Crash Modification Factors

Complete the study year column. Complete the crash period column if the EB Method is used.	Equation	Fatal and Injury				Property Damage Only			
		Multiple Vehicle		Single Vehicle		Multiple Vehicle		Single Vehicle	
		Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year
Horizontal curve $CMF_{1,\,w,\,x,\,y,\,z}$	19-33								
Lane width $CMF_{2,\,w,\,x,\,y,\,fi}$	19-34								
Right shoulder width $CMF_{3,\,w,\,x,\,y,\,z}$	19-35								
Left shoulder width $CMF_{4,\,w,\,x,\,y,\,z}$	19-36								
Right side barrier $CMF_{5,\,w,\,x,\,y,\,z}$	19-37								
Left side barrier $CMF_{6,\,w,\,x,\,y,\,z}$	19-38								
Lane add or drop $CMF_{7,\,w,\,x,\,y,\,fi}$	19-39								
Ramp speed-change lane $CMF_{8,\,w,\,x,\,mv,\,fi}$	19-40								
Weaving section $CMF_{9,\,cds,\,ac,\,y,\,z}$	19-41								
Combined CMF (multiply all CMFs evaluated)									

Expected Average Crash Frequency [a]

Complete the study year column. Complete the crash period column if the ***site-specific*** EB Method is used.	Fatal and Injury				Property Damage Only			
	Multiple Vehicle		Single Vehicle		Multiple Vehicle		Single Vehicle	
	Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year	Crash Period	Study Year
Calibration factor $C_{w,\,x,\,y,\,z}$								
Overdispersion parameter $k_{w,\,x,\,y,\,z}$								
Observed crash count $N^*_{o,\,w,\,x,\,y,\,z}$ (cr)								
Reference year r								
Predicted average crash freq. for reference year $N_{p,\,w,\,x,\,y,\,z,\,r}$ (cr/yr)								
Predicted number of crashes for crash period (sum all years) $N^*_{p,\,w,\,x,\,y,\,z}$ (cr)								
Equivalent years associated with crash count $C_{b,\,w,\,x,\,y,\,z,\,r}$ (yr)								
Adjusted average crash freq. for ref. year given N^*_o, $N_{a,\,w,\,x,\,y,\,z,\,r}$ (cr/yr)								
Study year s								
Predicted average crash freq. for study year $N_{p,\,w,\,x,\,y,\,z,\,s}$ (cr/yr)								
Expected average crash freq. for study year $N_{e,\,w,\,x,\,y,\,z,\,s}$ (cr/yr)								
Expected average crash freq. for study year (all crash types) $N_{e,\,w,\,x,\,at,\,z,\,s}$ (cr/yr)								

[a] If the EB Method is not used, then substitute the word "predicted" for the word "expected" and substitute the subscript "p" for the subscript "e".

Table 19A-1. Ramp Segment Worksheet (4 of 4)

Expected Average Crash Frequency [a]							
Crash Severity Distribution							
	K	A	B	C	Total FI	PDO	Total FI + PDO
Proportion by injury level					1.000		
Expected average crash freq. for study year (all crash types) $N_{e, w, x, at, z, s}$ (cr/yr)							

Crash Type Distribution

Crash Type Category	Table	Fatal and Injury		Property Damage Only		Total
		Proportion	Expected Average Crash Frequency for Study Year $N_{e, w, x, y, fi, s}$ (cr/yr)	Proportion	Expected Average Crash Frequency for Study Year $N_{e, w, x, y, pdo, s}$ (cr/yr)	Expected Average Crash Frequency for Study Year $N_{e, w, x, y, as, s}$ (cr/yr)
Multiple-Vehicle Crashes	19-6					
Head-on						
Right-angle						
Rear-end						
Sideswipe						
Other multiple-vehicle crashes						
Total		1.000		1.000		
Single-Vehicle Crashes	19-9					
Crash with animal						
Crash with fixed object						
Crash with other object						
Crash with parked vehicle						
Other single-vehicle crashes						
Crash with pedestrian						
Crash with bicycle						
Total		1.000		1.000		

[a] If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e”.

Table 19A-2. Ramp Barrier Worksheet

Input Data						
Segment length L (mi)			Crash period		Study year	
Left shoulder width W_{ls} (ft)		Right shoulder width W_{rs} (ft)				
Individual Right Side Barrier Element Data						
Barrier Location	Length $L_{rb,i}$ (mi)	Width from Edge of Traveled Way to Face of Right Side Barrier $W_{off,r,i}$ (ft)				Ratio $L_{rb,i}/(W_{off,r,i} - W_{rs})$
1.						
2.						
3.						
4.						
5.						
6.						
7.						
Sum1		Sum2				
Individual Left Side Barrier Element Data						
Barrier Location	Length $L_{lb,i}$ (mi)	Width from Edge of Traveled Way to Face of Left Side Barrier $W_{off,l,i}$ (ft)				Ratio $L_{lb,i}/(W_{off,l,i} - W_{ls})$
1.						
2.						
3.						
4.						
5.						
6.						
7.						
Sum3		Sum4				
Right Side Barrier Calculations						
Proportion of segment length with barrier in median $P_{rb} = \text{Sum1} / L$		Width from edge of shoulder to barrier face $W_{rcb} = \text{Sum1} / \text{Sum2}$ (ft)				
Left Side Barrier Calculations						
Proportion of segment length with barrier in median $P_{lb} = \text{Sum3} / L$		Width from edge of shoulder to barrier face $W_{lcb} = \text{Sum3} / \text{Sum4}$ (ft)				

Table 19A-3. Ramp Terminal Worksheet (1 of 4)

General Information					Location Information	
Analyst					Roadway	
Agency or company					Intersection	
Date performed					Study year	
Area type		Urban		Rural		

Input Data

Crash Data			Crash Period		Study Year		Complete the study year column. Complete the crash period column if the EB Method is used.			
Crash data time period							First year		Last year	
Count of FI crashes $N^{*}_{o,w,x,at,fi}$										
Count of PDO crashes $N^{*}_{o,w,x,at,pdo}$										
Basic Intersection Data										
Ramp terminal configuration							Choices: D3ex, D3en, D4, A4, B4, A2, B2, SP, TD Same choice for crash period and study year.			
Ramp terminal traffic control mode							Choices: Signal, One-way-stop, All-way stop			
Presence of a non-ramp public street leg I_{ps}				Y/N		Y/N				
Alignment Data										
Exit ramp skew angle I_{sk} (degrees)										
Distance to the next public street intersection on the outside crossroad leg L_{str} (mi)										
Distance to the adjacent ramp terminal L_{rmp} (mi)										
Traffic Control										
Left-Turn Operational Mode										
Crossroad	Inside approach	Prot.-only mode $I_{p,lt,in}$		Y/N		Y/N				
	Outside approach	Prot.-only mode $I_{p,lt,out}$		Y/N		Y/N				
Right-Turn Control Mode										
Ramp	Exit ramp approach	Right-turn control mode					Choices: Signal, Stop, Yield, Merge, Free (FF0, FF1, FF2)			
Cross Section Data										
Crossroad median width W_m (ft)										
Number of Lanes										
Crossroad	Inside approach	Through lanes $n_{th,in}$					Same choice for crash period and study year.			
	Outside approach	Through lanes $n_{th,out}$					Same choice for crash period and study year.			
Ramp	Exit ramp approach	All lanes n_{ex}					Same choice for crash period and study year.			
Right-Turn Channelization										
Crossroad	Inside approach	Chan. present $I_{ch,in}$		Y/N		Y/N				
	Outside approach	Chan. present $I_{ch,out}$		Y/N		Y/N				
Ramp	Exit ramp approach	Chan. present $I_{ch,ex}$		Y/N		Y/N				

Table 19A-3. Ramp Terminal Worksheet (2 of 4)

Input Data							
Cross Section Data			Crash Period		Study Year		Complete the study year column. Complete the crash period column if the EB Method is used.
Left-Turn Lane or Bay							
Crossroad	Inside approach	Lane or bay present $I_{bay,\,lt,\,in}$		Y/N		Y/N	If Yes, then enter data in the next row.
		Lane or bay width $W_{b,\,in}$ (ft)					
	Outside approach	Lane or bay present $I_{bay,lt,out}$		Y/N		Y/N	If Yes, then enter data in the next row.
		Lane or bay width $W_{b,out}$(ft)					
Right-Turn Lane or Bay							
Crossroad	Inside approach	Lane or bay present $I_{bay,\,rt,\,in}$		Y/N		Y/N	
	Outside approach	Lane or bay present $I_{bay,rt,out}$		Y/N		Y/N	
Access Data							
Number of driveways on the outside crossroad leg n_{dw}							
Number of public street approaches on the outside crossroad leg n_{ps}							
Number of exit ramps with free-flow right turns onto crossroad (SP Only):							
Traffic Data							
Crossroad	Inside leg	$AADT_{in}$ (veh/day)					
	Outside leg	$AADT_{out}$ (veh/day)					
Ramp	Exit ramp	$AADT_{ex}$ (veh/day)					
	Entrance ramp	$AADT_{en}$ (veh/day)					

Table 19A-3. Ramp Terminal Worksheet (3 of 4)

Crash Modification Factors					
Complete the study year column. Complete the crash period column if the EB Method is used.	Equation	Fatal and Injury		Property Damage Only	
		Crash Period	Study Year	Crash Period	Study Year
Signal Control					
Exit ramp capacity $CMF_{10, w, SGn, at, fi}$	19-42				
Crossroad left-turn lane $CMF_{11, w, SGn, at, z}$	19-45				
Crossroad right-turn lane $CMF_{12, w, SGn, at, z}$	19-48				
Access point frequency $CMF_{13, w, SGn, at, z}$	19-49				
Segment length $CMF_{14, w, SGn, at, z}$	19-50				
Median width $CMF_{15, w, SGn, at, z}$	19-51				
Protected left-turn operation $CMF_{16, w, SGn, at, z}$	19-53				
Chan. right turn on crossroad $CMF_{17, w, SGn, at, z}$	19-55				
Chan. right turn on exit ramp $CMF_{18, w, SGn, at, z}$	19-56				
Non-ramp public street leg $CMF_{19, w, SGn, at, z}$	19-57				
Stop Control					
Exit ramp capacity $CMF_{10, w, ST, at, fi}$	19-42				
Crossroad left-turn lane $CMF_{11, w, ST, at, z}$	19-45				
Crossroad right-turn lane $CMF_{12, w, ST, at, z}$	19-48				
Access point frequency $CMF_{13, w, ST, at, fi}$	19-49				
Segment length $CMF_{14, w, ST, at, fi}$	19-50				
Median width $CMF_{15, w, ST, at, fi}$	19-51				
Skew angle $CMF_{20, w, ST, at, fi}$	19-58				
All-way stop-control (exclude CMF_{11}, CMF_{12}, CMF_{20})					
Combined CMF (multiply all CMFs evaluated)					

Expected Average Crash Frequency [a]				
Complete the study year column. Complete the crash period column if the *site-specific* EB Method is used.	Fatal and Injury		Property Damage Only	
	Crash Period	Study Year	Crash Period	Study Year
Calibration factor $C_{aS, x, at, z}$				
Overdispersion parameter $k_{w, x, at, z}$				
Observed crash count $N^*_{o, w, x, at, z}$ (cr)				
Reference year r				
Predicted average crash freq. for reference year $N_{p, w, x, at, z, r}$ (cr/yr)				
Predicted number of crashes for crash period (sum all years) $N^*_{p, w, x, y, z}$ (cr)				
Equivalent years associated with crash count $C_{b, w, x, at, z, r}$ (yr)				
Adjusted average crash freq. for ref. year given N^*_o, $N_{a, w, x, at, z, r}$ (cr/yr)				
Study year s				
Predicted average crash freq. for study year $N_{p, w, x, at, z, s}$ (cr/yr)				
Expected average crash freq. for study year $N_{e, w, x, at, z, s}$ (cr/yr)				

[a] If the EB Method is not used, then substitute the word "predicted" for the word "expected" and substitute the subscript "p" for the subscript "e".

Table 19A-3. Ramp Terminal Worksheet (4 of 4)

Expected Average Crash Frequency [a]

Crash Severity Distribution

	K	A	B	C	Total FI	PDO	Total FI + PDO
Proportion by injury level					1.000		
Expected average crash freq. for study year $N_{e,w,x,at,z,s}$ (cr/yr)							

Crash Type Distribution

Crash Type Category	Table 19-16, 19-21, 19-XB, 19-XE, or 19-45	Fatal and Injury: Proportion	Fatal and Injury: Expected Average Crash Frequency for Study Year $N_{e,w,x,at,fi,s}$ (cr/yr)	Property Damage Only: Proportion	Property Damage Only: Expected Average Crash Frequency for Study Year $N_{e,w,x,at,pdo,s}$ (cr/yr)	Total: Expected Average Crash Frequency for Study Year $N_{e,w,x,at,as,s}$ (cr/yr)
Multiple-Vehicle Crashes						
Head-on						
Right-angle						
Rear-end						
Sideswipe						
Other multiple-vehicle crashes						
Single-Vehicle Crashes						
Crash with animal						
Crash with fixed object						
Crash with other object						
Crash with parked vehicle						
Other single-vehicle crashes						
Total		1.000		1.000		

[a] If the EB Method is not used, then substitute the word “predicted” for the word “expected” and substitute the subscript “p” for the subscript “e”.