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).

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, $N_{predicted}$, are of the general form shown in Equation 11-1.

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

Where:

$N_{predicted}$ = 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 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 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.
- *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:

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

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—however, these CMFs are only applicable to three- and four-leg stop-controlled 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 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.

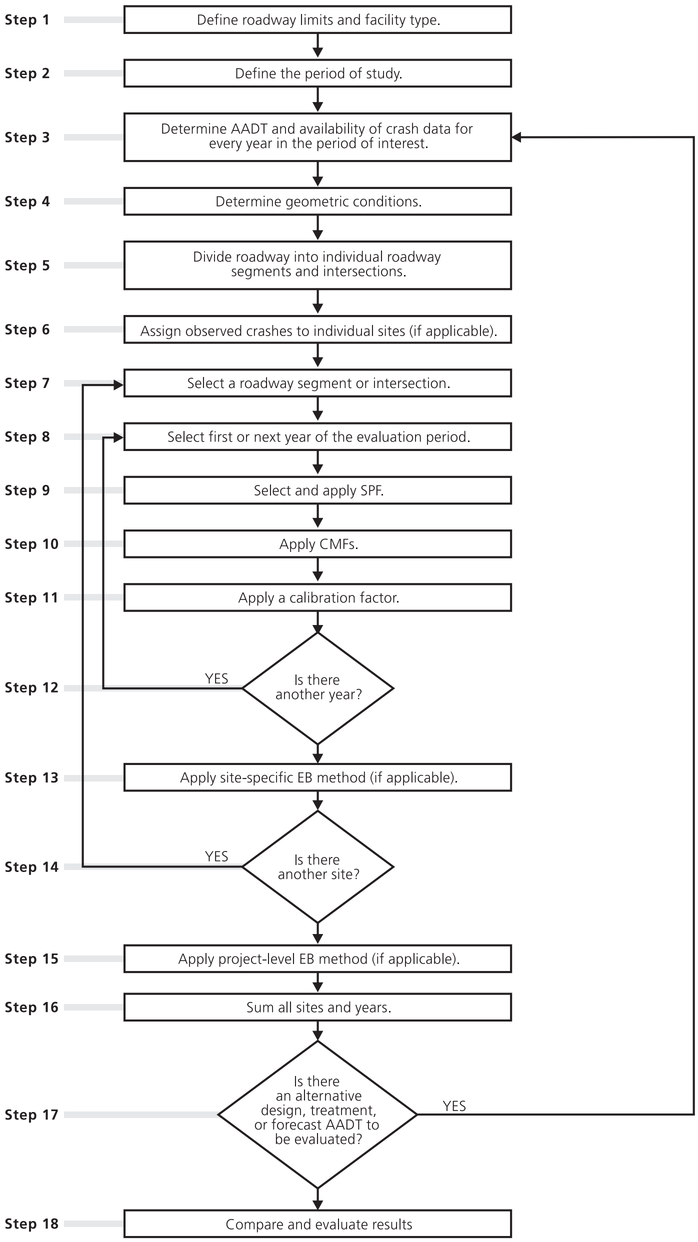


Figure 11-1. The HSM Predictive Method

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 (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 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 intersections)
- Presence of left-turn and right-turn lanes (stop-controlled intersections)
- Presence or absence of lighting (stop-controlled 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 14.

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, $N_{predicted}$, 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 $N_{predicted}$ 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 two-lane, two-way road 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 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.

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

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 (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).

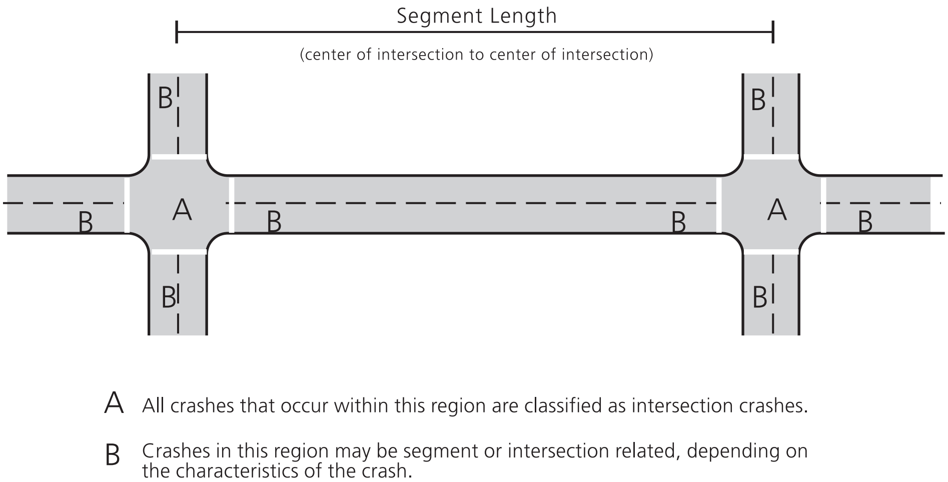


Figure 11-2. Definition of Segments and Intersections

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 (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
Four-leg signalized intersections	Equations 11-11 and 11-12, Tables 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:

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

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:

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

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

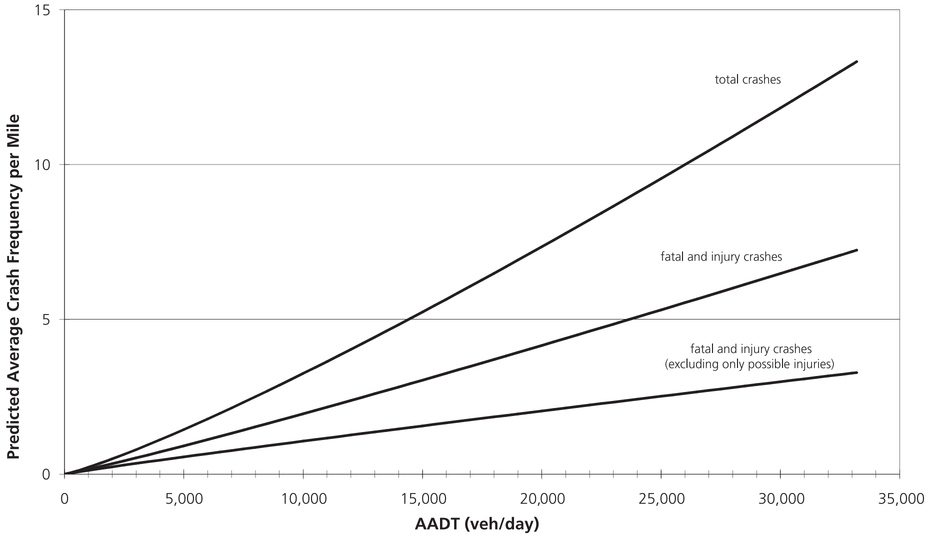


Figure 11-3. Graphical Form of the SPF for Undivided Roadway Segments (from Equation 11-7 and Table 11-3)

The default proportions in Table 11-3 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:

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

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 undivided 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:

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

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.

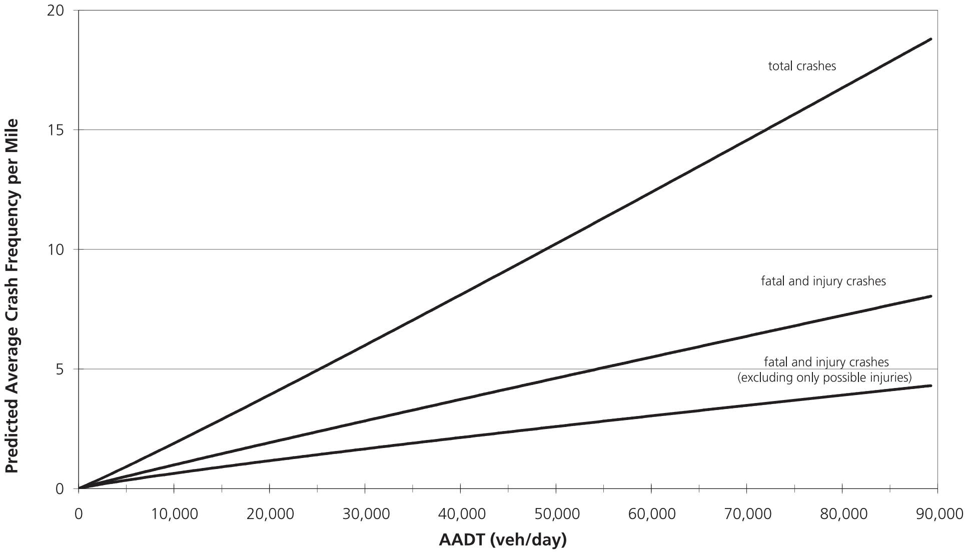


Figure 11-4. Graphical Form of SPF for Rural Multilane Divided Roadway Segments (from Equation 11-9 and Table 11-5)

The default proportions in Table 11-5 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

Collision Type	Proportion of Crashes by Collision Type and Crash Severity Level			
	Severity Level			
	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 four-leg signalized rural multilane highway intersections are defined in Section 11.3.

SPFs have been developed for 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 three types of intersections are:

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

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) on rural multilane highways are applicable to the following base conditions:

- Intersection skew angle 0°
- 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, and 11-7 (for total crashes only):

$$N_{spf\ int} = exp[a + b \times In(AADT_{maj}) + c \times In(AADT_{min})] \tag{11-11}$$

or

$$N_{spf\ int} = exp[a + d \times In(AADT_{total})] \tag{11-12}$$

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

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 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 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]
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.

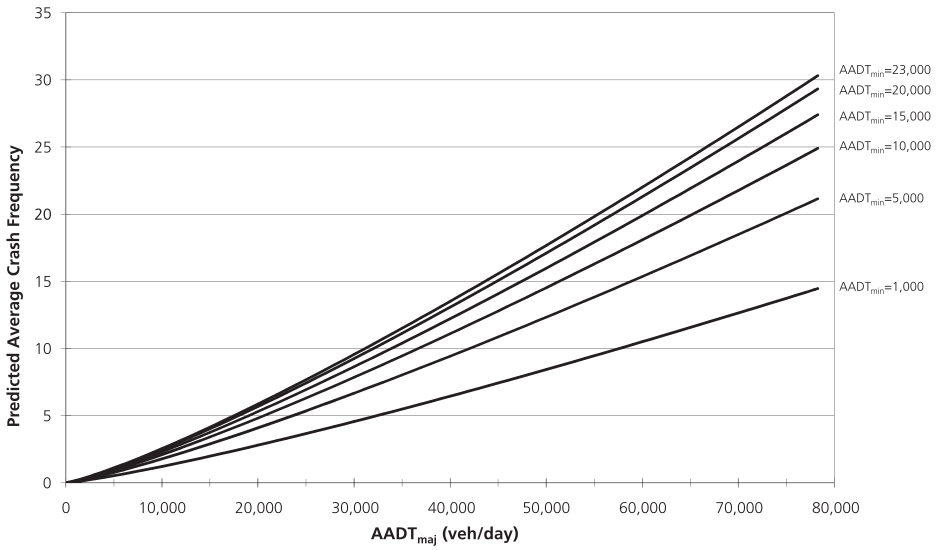


Figure 11-5. Graphical Form of SPF for Three-Leg Stop-Controlled Intersections—for Total Crashes Only (from Equation 11-11 and Table 11-7)

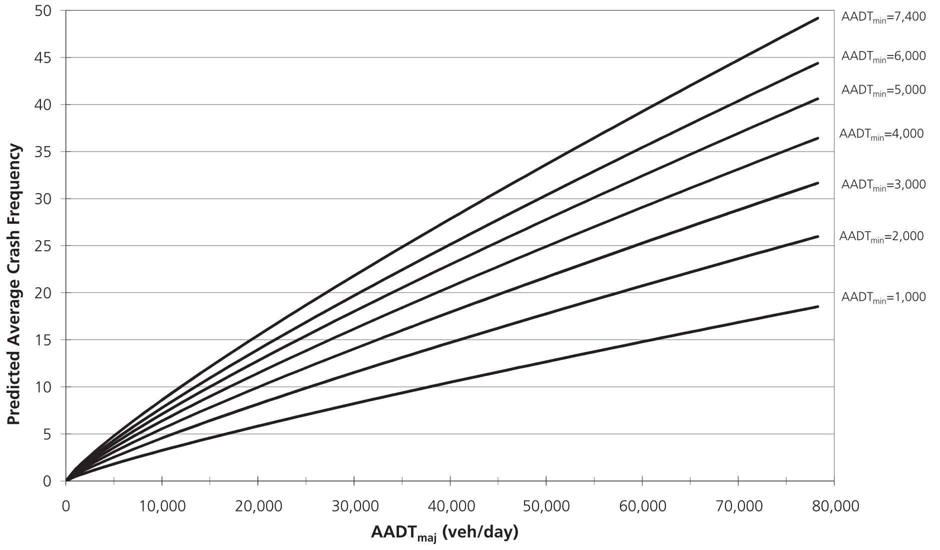


Figure 11-6. Graphical Form of SPF for Four-Leg Stop-Controlled Intersections—for Total Crashes Only (from Equation 11-11 and Table 11-7)

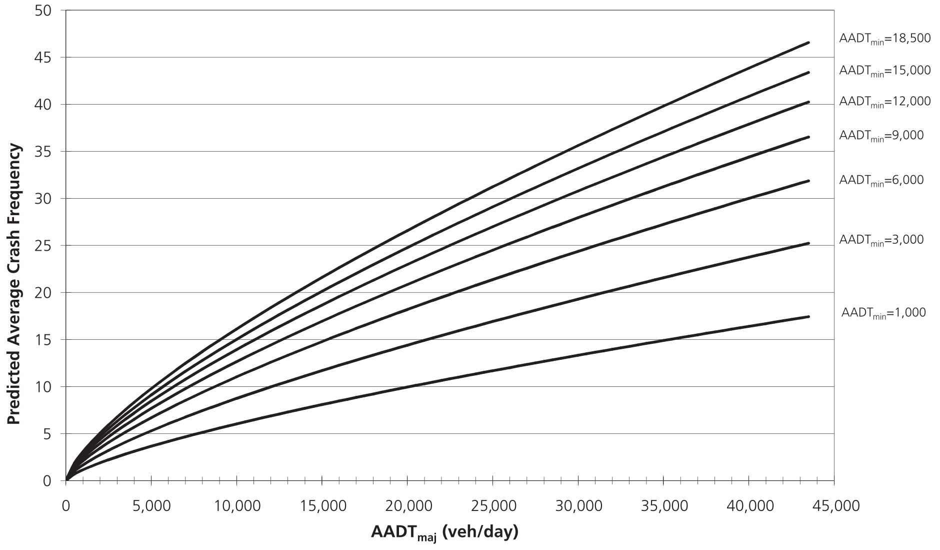


Figure 11-7. Graphical Form of SPF for Four-leg Signalized Intersections—for Total Crashes Only (from Equation 11-11 and Table 11-7)

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	—	—	—	—	0.054	0.083	0.093	0.034
Sideswipe	—	—	—	—	0.106	0.047	0.039	0.147
Rear-end	—	—	—	—	0.492	0.472	0.314	0.505
Angle	—	—	—	—	0.256	0.315	0.407	0.215
Single	—	—	—	—	0.062	0.041	0.078	0.077
Other	—	—	—	—	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 SPFs	CMF_{1i}	Intersection Angle	Tables 11-20, 11-21
	CMF_{2i}	Left-Turn Lane on Major Road	Tables 11-20, 11-21
	CMF_{3i}	Right-Turn Lane on Major Road	Tables 11-20, 11-21
	CMF_{4i}	Lighting	Tables 11-20, 11-21

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.

CMF1ru—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 Daily Traffic (AADT) (vehicles per day)		
Lane Width	**< 400**	**400 to 2000**	**> 2000**
9 ft or less	1.04	$1.04 + 2.13 \times 10^{-4}(AADT - 400)$	1.38
10 ft	1.02	$1.02 + 1.31 \times 10^{-4}(AADT - 400)$	1.23
11 ft	1.01	$1.01 + 1.88 \times 10^{-5}(AADT - 400)$	1.04
12 ft or more	1.00	1.00	1.00

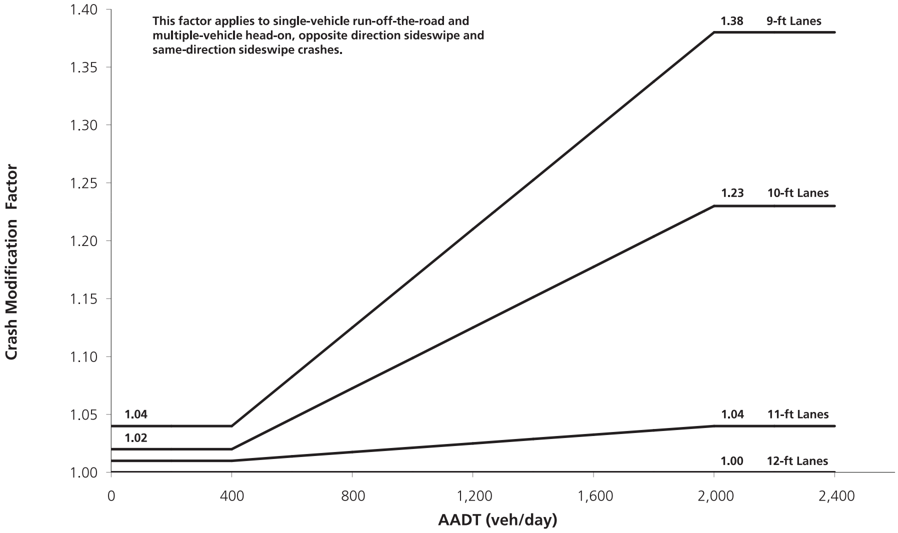


Figure 11-8. CMF_{RA} for Lane Width on Undivided Segments

$CMF2_{ru}$—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	$1.10 + 2.5 \times 10^{-4}(AADT - 400)$	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

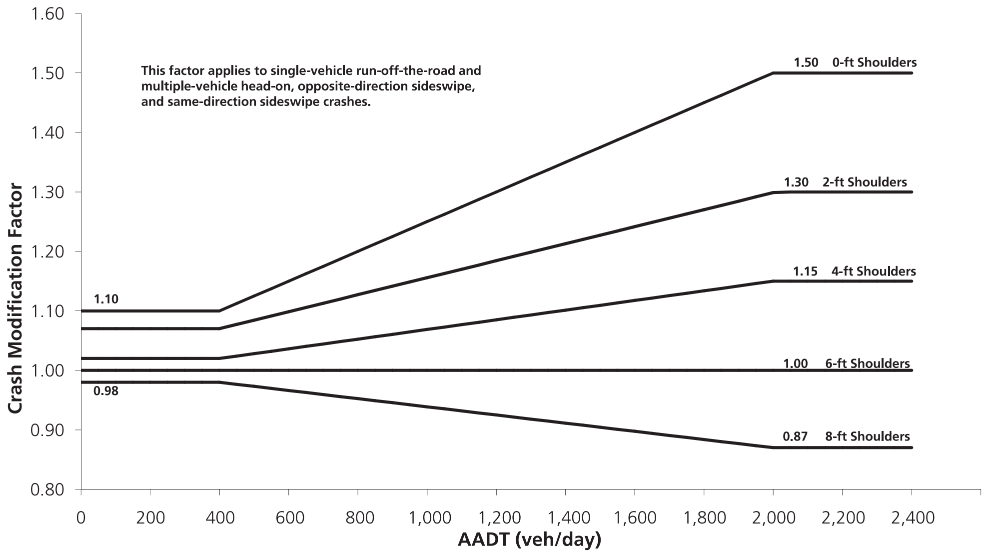


Figure 11-9. CMF_{WRA} for Shoulder Width on Undivided Segments

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	$1.03 + 1.38 \times 10^{-4}(AADT - 400)$	1.25
10 ft	1.01	$1.01 + 8.75 \times 10^{-5}(AADT - 400)$	1.15
11 ft	1.01	$1.01 + 1.25 \times 10^{-5}(AADT - 400)$	1.03
12 ft	1.00	1.00	1.00

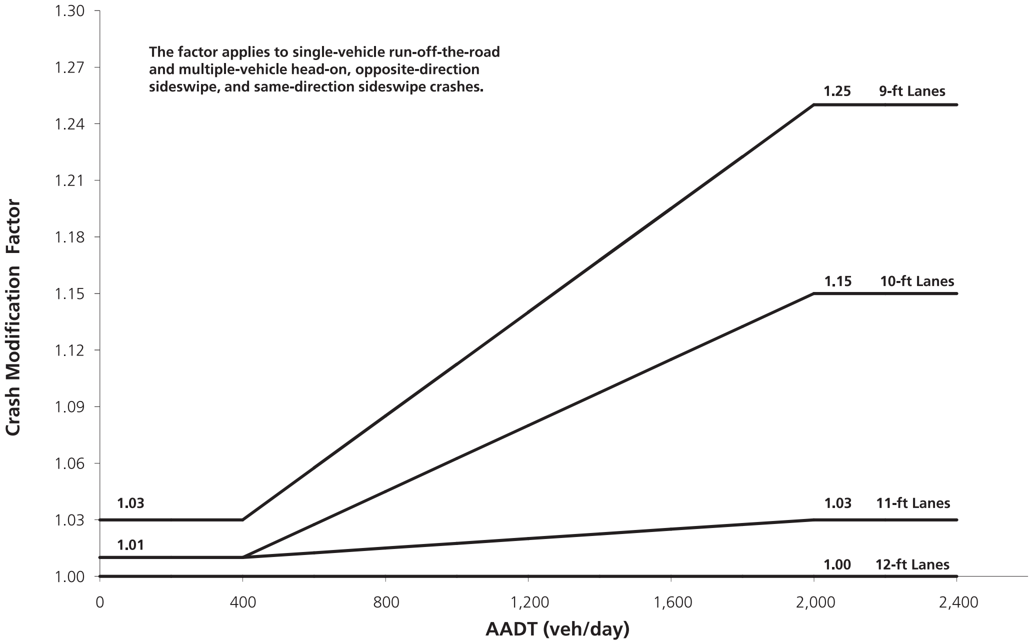


Figure 11-10. CMF_{RA} for Lane Width on Divided Roadway Segments

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 13-9 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. Except where separate CMFs by crash severity level are shown, each of the CMFs applies to all of the crash severity levels shown in Table 11-7. As noted earlier, CMFs are not available for 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

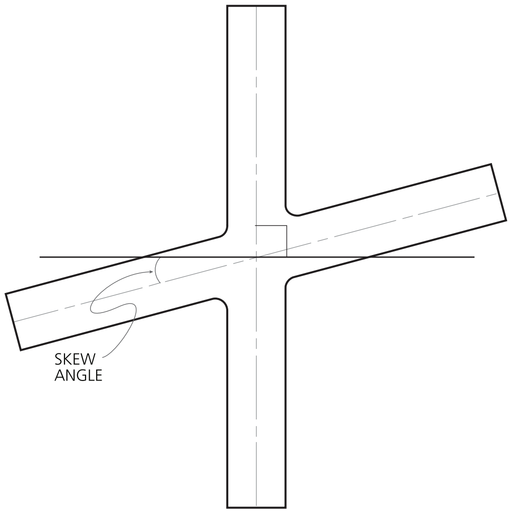
Table 11-21. CMFs for Four-Leg Intersection with Minor-Road Stop Control (4ST)

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

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:

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

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

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

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:

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

The CMF for fatal-and-injury crashes is:

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

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 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

[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

Intersection Type	Crash Severity Level	Number of Non-Stop-Controlled Approaches with Right-Turn Lanes[a]	
		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

[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 (not including vehicle-pedestrian and vehicle-bicycle collisions). 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

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 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, 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 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
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:

$$N_{spf\ rd} = e^{(a + b \times In(AADT) + In(L))}$$

$$= e^{(-9.025 + 1.049 \times In(10{,}000) + In(1.5))} = 2.835 \text{ crashes/year}$$

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.

$CMF_{comb} = 1.04 \times 1.02$

$= 1.06$

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:

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

$= 2.835 \times 1.10 \times (1.06)$

$= 3.305$ 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:

$$N_{spf\,ru} = e^{(a + b \times In(AADT) + In(L))}$$

$$= e^{(-9.653 + 1.176 \times In(8{,}000) + In(0.1))} = 0.250 \text{ crashes/year}$$

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).

$$CMF_{4ru} = 1 - [(1 - 0.72 \times 0.361 - 0.83 \times 0.639) \times 0.255] = 0.95$$

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:

$$N_{\text{predicted } rs} = N_{spf\ ru} \times C_r \times (CMF_{1ru} \times CMF_{2ru} \times \ldots \times CMF_{5ru})$$

$$= 0.250 \times 1.10 \times (1.05)$$

$$= 0.289 \text{ crashes/year}$$

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:

$$N_{spf\ int} = exp[a + b \times In(AADT_{maj}) + c \times In(AADT_{min})]$$

$$= exp[-12.526 + 1.204 \times In(8{,}000) + 0.236 \times In(1{,}000)] = 0.928 \text{ crashes/year}$$

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:

$$CMF_{1i} = \frac{0.016 \times skew}{(0.98 + 0.16 \times skew)} + 1.0$$

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

$$CMF_{1i} = \frac{0.016 \times 30}{(0.98 + 0.16 \times 30)} + 1.0 = 1.08$$

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.

$CMF_{comb} = 1.08 \times 0.56 \times 0.90 = 0.54$

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:

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

$= 0.928 \times 1.50 \times (0.54) = 0.752$ 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, 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	1.08	0.56	1.00	0.90	0.54
Fatal and injury (FI)	1.09	0.45	1.00	0.90	0.44

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			**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)**
Crash Severity Level	**a**	**b**	**c**					
Total	–12.526	1.204	0.236	0.928	0.460	0.54	1.50	0.752
Fatal and injury (FI)	–12.664	1.107	0.272	0.433	0.569	0.44	1.50	0.286
Fatal and injury[a] (FI[a])	–11.989	1.013	0.228	0.270	0.566	0.44	1.50	0.178
Property damage only (PDO)	—	—	—	—	—	—	—	$(7)_{total}–(7)_{FI}$ 0.466

[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 $_{(total)}$**	$N_{predicted\ int\ (total)}$ **(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 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	0.752	1.000	0.286	1.000	0.178	1.000	0.466
		$(2)*(3)_{total}$		$(4)*(5)_{FI}$		$(6)*(7)_{FI^a}$		$(8)*(9)_{PDO}$
Head-on collision	0.029	0.022	0.043	0.012	0.052	0.009	0.020	0.009
Sideswipe collision	0.133	0.100	0.058	0.017	0.057	0.010	0.179	0.083
Rear-end collision	0.289	0.217	0.247	0.071	0.142	0.025	0.315	0.147
Angle collision	0.263	0.198	0.369	0.106	0.381	0.068	0.198	0.092
Single-vehicle collision	0.234	0.176	0.219	0.063	0.284	0.051	0.244	0.114
Other collision	0.052	0.039	0.064	0.018	0.084	0.015	0.044	0.021

[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	0.752
Fatal and injury (FI)	0.286
Fatal and injury[a] (FI[a])	0.178
Property damage only (PDO)	0.466

[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 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	0.752	0.286	0.466	3	0.460	0.743	1.330
Combined (Sum of Column)	4.347	2.189	2.158	9	—	—	5.747

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

$$w = \frac{1}{1 + 0.460 \times (0.752)} = 0.743$$

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: $N_{expected} = 0.681 \times 3.306 + (1 - 0.681) \times 4 = 3.527$

Segment 2: $N_{expected} = 0.649 \times 0.289 + (1 - 0.649) \times 2 = 0.890$

Intersection 1: $N_{expected} = 0.743 \times 0.752 + (1 - 0.743) \times 3 = 1.330$

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	**$N_{predicted}$**	**$N_{expected}$**
Total	$(2)_{comb}$ from Worksheet SP4A	$(8)_{comb}$ from Worksheet SP4A
	4.347	5.7
Fatal and injury (FI)	$(3)_{comb}$ from Worksheet SP4A	$(3)_{total}*(2)_{FI}/(2)_{total}$
	2.189	2.9
Property damage only (PDO)	$(4)_{comb}$ from Worksheet SP4A	$(3)_{total}*(2)_{PDO}/(2)_{total}$
	2.158	2.8

11.12.5. 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)
	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, k	N_{w0}
Site Type	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$			Equation A-8 (6)* (2)^2
Roadway Segments						
Segment 1	3.306	1.726	1.580	—	0.142	1.552
Segment 2	0.289	0.177	0.112	—	1.873	0.156
Intersections						
Intersection 1	0.752	0.286	0.466	—	0.460	0.260
Combined (sum of column)	4.347	2.189	2.158	9	—	1.968

Note: $N_{predicted\ w0}$ = Predicted number of total crashes assuming that crash frequencies are statistically independent

Worksheet SP5A. Continued

(1)	(8)	(9)	(10)	(11)	(12)	(13)
	N_{w1}	W_0	N_0	w_1	N_1	$N_{expected/comb}$
Site Type	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	0.685	—	—	—	—	—
Segment 2	0.736	—	—	—	—	—
Intersections						
Intersection 1	0.588	—	—	—	—	—
Combined (Sum of Column)	2.009	0.688	5.799	0.684	5.817	5.808

Note: $N_{predicted\ w0}$ = Predicted number of total crashes assuming that crash frequencies are statistically independent

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

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

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

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:

$$w_0 = \frac{1}{1+\frac{N_{\text{predicted } w0}}{N_{\text{predicted (total)}}}} = \frac{1}{1+\frac{1.968}{4.347}} = 0.688$$

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:

$$N_0 = w_0 \times N_{\text{predicted (total)}} + (1 - w_0) \times N_{\text{observed (total)}}$$

$$= 0.688 \times 4.347 + (1 - 0.688) \times 9 \quad = 5.799$$

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:

$$w_1 = \frac{1}{1+\frac{N_{\text{predicted } w1}}{N_{\text{predicted (total)}}}} = \frac{1}{1+\frac{2.009}{4.347}} = 0.684$$

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:

$$N_1 = w_1 \times N_{\text{predicted (total)}} + (1 - w_1) \times N_{\text{observed (total)}}$$

$$= 0.684 \times 4.347 + (1 - 0.684) \times 9 \quad = 5.817$$

Column 13—$N_{expected/comb}$

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

$$N_{\text{expected}/comb} = \frac{N_0 + N_1}{2} = \frac{5.799 + 5.817}{2} = 5.808$$

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
	4.347	5.8
Fatal and injury (FI)	$(3)_{comb}$ from Worksheet SP5A	$(3)_{total}*(2)_{FI}/(2)_{total}$
	2.189	2.9
Property damage only (PDO)	$(4)_{comb}$ from Worksheet SP5A	$(3)_{total}*(2)_{PDO}/(2)_{total}$
	2.158	2.9

11.12.6. 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 4.4 crashes per year, and the predicted crash reduction from the project is 8.1 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	8.2	3.3	4.9
Segment 2	1.4	0.3	1.1
Intersection 1	2.9	0.8	2.1
Total	12.5	4.4	8.1

[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, $N_{predicted\ rs}$
Crash Severity Level	from Table 11-5			from Equation 11-9	from Equation 11-10	(6) from Worksheet 1B (a)	Calibration Factor, C_r	(3)*(5)*(6)
	a	b	c					
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, $N_{predicted\ rs}$
Crash Severity Level	from Table 11-3			from Equation 11-7	from Equation 11-8	(6) from Worksheet 1B (b)	Calibration Factor, C_r	(3)*(5)*(6)
	a	b	c					
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** $_{(FI^a)}$	$N_{predicted\ rs\ (FI^a)}$ **(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**	$(7)_{FI^a}$ **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, 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 $_{(FI^a)}$	$N_{predicted\ int\ (FI^a)}$ (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, $N_{observed}$ (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							
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)
	Predicted Average Crash Frequency (crashes/year)			**Observed Crashes, $N_{observed}$ (crashes/year)**	**Overdispersion Parameter, k**	N_{w0}
Site Type	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$			**Equation A-8 (6)* (2)^2**
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 4A continued on next page.

Worksheet 4A. Continued

(1)	(8)	(9)	(10)	(11)	(12)	(13)
Site Type	N_{w1}	W_0	N_0	w_1	N_1	$N_{expected/comb}$
	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.