Chapter 12—Predictive Method for Urban and Suburban Arterials

12.1. INTRODUCTION

This chapter presents the predictive method for urban and suburban arterial facilities. A general introduction to the *Highway Safety Manual* (HSM) predictive method is provided in the Part C—Introduction and Applications Guidance.

The predictive method for urban or suburban arterial facilities provides a structured methodology to estimate the expected average crash frequency, crash severity, and collision types for facilities with known characteristics. All types of crashes involving vehicles of all types, bicycles, and pedestrians are included, with the exception of crashes between bicycles and pedestrians. The predictive method can be applied to existing sites, design alternatives to existing sites, new sites, or for alternative traffic volume projections. An estimate can be made for crash frequency in a period of time that occurred in the past (i.e., what did or would have occurred) or in the future (i.e., what is expected to occur). The development of the SPFs in Chapter 12 is documented by Harwood et al. (8, 9). The CMFs used in this chapter have been reviewed and updated by Harkey et al. (6) and in related work by Srinivasan et al. (13). The SPF coefficients, default collision type distributions, and default nighttime crash proportions have been adjusted to a consistent basis by Srinivasan et al. (14).

This chapter presents the following information about the predictive method for urban and suburban arterial facilities:

- A concise overview of the predictive method.
- The definitions of the facility types included in Chapter 12, and site types for which predictive models have been developed for Chapter 12.
- The steps of the predictive method in graphical and descriptive forms.
- Details for dividing an urban or suburban arterial facility into individual sites, consisting of intersections and roadway segments.
- Safety performance functions (SPFs) for urban and suburban arterials.
- Crash modification factors (CMFs) applicable to the SPFs in Chapter 12.
- Guidance for applying the Chapter 12 predictive method, and limitations of the predictive method specific to Chapter 12.
- Sample problems illustrating the application of the Chapter 12 predictive method for urban and suburban arterials.

12.2. OVERVIEW OF THE PREDICTIVE METHOD

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

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

The predictive models used within the Chapter 12 predictive method are described in detail in Section 12.3.

The predictive models used in Chapter 12 to predict average crash frequency, $N_{\text{predicted}}$, are of the general form shown in Equation 12-1.

$$N_{\text{predicted}} = (N_{spf\ x} \times (CMF_{1x} \times CMF_{2x} \times \ldots \times CMF_{yx}) + N_{pedx} + N_{bikex}) \times C_x \quad (12\text{-}1)$$

Where:

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

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

N_{pedx} = predicted average number of vehicle-pedestrian collisions per year for site type *x*;

N_{bikex} = predicted average number of vehicle-bicycle collisions per year for site type *x*;

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

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

The predictive models in Chapter 12 provide estimates of the crash severity and collision type distributions for roadway segments and intersections. The SPFs in Chapter 12 address two general crash severity levels: fatal-and-injury and property-damage-only crashes. Fatal-and-injury crashes include crashes involving all levels of injury severity including fatalities, incapacitating injuries, nonincapacitating injuries, and possible injuries. The relative proportions of crashes for the two severity levels are determined from separate SPFs for each severity level. The default estimates of the crash severity and crash type distributions are provided with the SPFs for roadway segments and intersections in Section 12.6.

12.3. URBAN AND SUBURBAN ARTERIALS—DEFINITIONS AND PREDICTIVE MODELS IN CHAPTER 12

This section provides the definitions of the facility and site types and the predictive models for each of the site types included in Chapter 12. These predictive models are applied following the steps of the predictive method presented in Section 12.4.

12.3.1. Definition of Chapter 12 Facility Types

The predictive method in Chapter 12 addresses the following urban and suburban arterial facilities: two- and four-lane undivided facilities, four-lane divided facilities, and three- and five-lane facilities with center two-way left-turn lanes. Divided arterials are nonfreeway facilities (i.e., facilities without full control of access) that have lanes in the two directions of travel separated by a raised or depressed median. Such facilities may have occasional grade-separated interchanges, but these are not the primary form of access. The predictive models do not apply to any section of an arterial within the limits of an interchange which has free-flow ramp terminals on the arterial of interest. Arterials with a flush separator (i.e., a painted median) between the lanes in the two directions of travel are considered undivided facilities, not divided facilities. Separate prediction models are provided for arterials with a flush separator that serves as a center two-way left-turn lane. Chapter 12 does not address arterial facilities with six or more lanes.

The terms “highway” and “road” are used interchangeably in this chapter and apply to all urban and suburban arterials independent of official state or local highway designation.

Classifying an area as urban, suburban, or rural is subject to the roadway characteristics, surrounding population and land uses and is at the user’s discretion. In the HSM, the definition of “urban” and “rural” areas is based on Federal Highway Administration (FHWA) guidelines which classify “urban” areas as places inside urban boundaries where the population is greater than 5,000 persons. “Rural” areas are defined as places outside urban areas where the population is less than 5,000 persons. The HSM uses the term “suburban” to refer to outlying portions of an urban area; the predictive method does not distinguish between urban and suburban portions of a developed area. The term “arterial” refers to facilities the meet the FHWA definition of “roads serving major traffic movements (high-speed, high volume) for travel between major points” (5).

Table 12-1 identifies the specific site types on urban and suburban arterial highways that have predictive models. In Chapter 12, separate SPFs are used for each individual site to predict multiple-vehicle nondriveway collisions, single-vehicle collisions, driveway-related collisions, vehicle-pedestrian collisions, and vehicle-bicycle collisions for both roadway segments and intersections. These are combined to predict the total average crash frequency at an individual site.

Table 12-1. Urban and Suburban Arterial Site Type SPFs included in Chapter 12

Site Type	Site Types with SPFs in Chapter 12
Roadway Segments	Two-lane undivided arterials (2U)
	Three-lane arterials including a center two-way left-turn lane (TWLTL) (3T)
	Four-lane undivided arterials (4U)
	Four-lane divided arterials (i.e., including a raised or depressed median) (4D)
	Five-lane arterials including a center TWLTL (5T)
Intersections	Unsignalized three-leg intersection (stop control on minor-road approaches) (3ST)
	Signalized three-leg intersections (3SG)
	Unsignalized four-leg intersection (stop control on minor-road approaches) (4ST)
	Signalized four-leg intersection (4SG)

These specific site types are defined as follows:

- *Two-lane undivided arterial (2U)*—a roadway consisting of two lanes with a continuous cross-section providing two directions of travel in which the lanes are not physically separated by either distance or a barrier.
- *Three-lane arterials (3T)*—a roadway consisting of three lanes with a continuous cross-section providing two directions of travel in which center lane is a two-way left-turn lane (TWLTL).
- *Four-lane undivided arterials (4U)*—a roadway consisting of four lanes with a continuous cross-section providing two directions of travel in which the lanes are not physically separated by either distance or a barrier.
- *Four-lane divided arterials (i.e., including a raised or depressed median) (4D)*—a roadway consisting of two lanes with a continuous cross-section providing two directions of travel in which the lanes are physically separated by either distance or a barrier.
- *Five-lane arterials including a center TWLTL (5T)*—a roadway consisting of five lanes with a continuous cross-section providing two directions of travel in which the center lane is a two-way left-turn lane (TWLTL).

- *Three-leg intersection with stop control (3ST)*—an intersection of a urban or suburban arterial and a minor road. A stop sign is provided on the minor road approach to the intersection only.
- *Three-leg signalized intersection (3SG)*—an intersection of a urban or suburban arterial and one minor road. Signalized control is provided at the intersection by traffic lights.
- *Four-leg intersection with stop control (4ST)*—an intersection of a urban or suburban arterial and two minor roads. A stop sign is provided on both the minor road approaches to the intersection.
- *Four-leg signalized intersection (4SG)*—an intersection of a urban or suburban arterial and two minor roads. Signalized control is provided at the intersection by traffic lights.

12.3.2. Predictive Models for Urban and Suburban Arterial Roadway Segments

The predictive models can be used to estimate total average crashes (i.e., all crash severities and collision types) or can be used to predict average frequency of specific crash severity types or specific collision types. The predictive model for an individual roadway segment or intersection combines the SPF, CMFs, and a calibration factor. Chapter 12 contains separate predictive models for roadway segments and for intersections.

The predictive models for roadway segments estimate the predicted average crash frequency of non-intersection-related crashes. Non-intersection-related crashes may include crashes that occur within the limits of an intersection but are not related to the intersection. The roadway segment predictive models estimate crashes that would occur regardless of the presence of the intersection.

The predictive models for roadway segments are presented in Equations 12-2 and 12-3 below.

$$N_{\text{predicted } rs} = C_r \times (N_{br} + N_{pedr} + N_{biker}) \tag{12-2}$$

$$N_{br} = N_{spf\,rs} \times (CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{nr}) \tag{12-3}$$

Where:

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

N_{br} = predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions);

$N_{spf\,rs}$ = predicted total average crash frequency of an individual roadway segment for base conditions (excluding vehicle-pedestrian and vehicle-bicycle collisions);

N_{pedr} = predicted average crash frequency of vehicle-pedestrian collisions for an individual roadway segment;

N_{biker} = predicted average crash frequency of vehicle-bicycle collisions for an individual roadway segment;

$CMF_{1r} \ldots CMF_{nr}$ = crash modification factors for roadway segments; and

C_r = calibration factor for roadway segments of a specific type developed for use for a particular geographical area.

Equation 12-2 shows that roadway segment crash frequency is estimated as the sum of three components: N_{br}, N_{pedr}, and N_{biker}. The following equation shows that the SPF portion of N_{br}, designated as $N_{spf\,rs}$, is further separated into three components by collision type shown in Equation 12-4:

$$N_{spf\ rs} = N_{brmv} + N_{brsv} + N_{brdwy} \tag{12-4}$$

Where:

N_{brmv} = predicted average crash frequency of multiple-vehicle nondriveway collisions for base conditions;

N_{brsv} = predicted average crash frequency of single-vehicle crashes for base conditions; and

N_{brdwy} = predicted average crash frequency of multiple-vehicle driveway-related collisions.

Thus, the SPFs and adjustment factors are applied to determine five components: $N_{brmv,}$ N_{brsv}, N_{brdwy}, N_{pedr}, and N_{biker}, which together provide a prediction of total average crash frequency for a roadway segment.

Equations 12-2 through 12-4 are applied to estimate roadway segment crash frequencies for all crash severity levels combined (i.e., total crashes) or for fatal-and-injury or property-damage-only crashes.

12.3.3. Predictive Models for Urban and Suburban Arterial Intersections

The predictive models for intersections estimate the predicted total average crash frequency including those crashes that occur within the limits of an intersection and are a result of the presence of the intersection. The predictive model for an urban or suburban arterial intersection is given by:

$$N_{\text{predicted}\ int} = C_i \times (N_{bi} + N_{pedi} + N_{bikei}) \tag{12-5}$$

$$N_{bi} = N_{spf\ int} \times (CMF_{1i} \times CMF_{2i} \times \ldots \times CMF_{6i}) \tag{12-6}$$

Where:

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

N_{bi} = predicted average crash frequency of an intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions);

$N_{spf\ int}$ = predicted total average crash frequency of intersection-related crashes for base conditions (excluding vehicle-pedestrian and vehicle-bicycle collisions);

N_{pedi} = predicted average crash frequency of vehicle-pedestrian collisions;

N_{bikei} = predicted average crash frequency of vehicle-bicycle collisions;

$CMF_{1i} \ldots CMF_{6i}$ = crash modification factors for intersections; and

C_i = calibration factor for intersections developed for use for a particular geographical area.

The CMFs shown in Equation 12-6 do not apply to vehicle-pedestrian and vehicle-bicycle collisions. A separate set of CMFs that apply to vehicle-pedestrian collisions at signalized intersections is presented in Section 12.7.

Equation 12-5 shows that the intersection crash frequency is estimated as the sum of three components: N_{bi}, N_{pedi}, and N_{bikei}. The following equation shows that the SPF portion of N_{bi}, designated as $N_{spf\ int}$, is further separated into two components by collision type:

$$N_{spf\,int} = N_{bimv} + N_{bisv} \tag{12-7}$$

Where:

N_{bimv} = predicted average number of multiple-vehicle collisions for base conditions; and

N_{bisv} = predicted average number of single-vehicle collisions for base conditions.

Thus, the SPFs and adjustment factors are applied to determine four components of total intersection average crash frequency: N_{bimv}, N_{bisv}, N_{pedi}, and N_{bikei}.

The SPFs for urban and suburban arterial highways are presented in Section 12.6. The associated CMFs for each of the SPFs are presented in Section 12.7 and summarized in Table 12-18. Only the specific CMFs associated with each SPF are applicable to that SPF (as these CMFs have base conditions which are identical to the base conditions of the SPF). The calibration factors, C_r and C_i, are determined in Part C, Appendix A.1.1. Due to continual change in the crash frequency and severity distributions with time, the value of the calibration factors may change for the selected year of the study period.

12.4. PREDICTIVE METHOD STEPS FOR URBAN AND SUBURBAN ARTERIALS

The predictive method for urban and suburban arterials is shown in Figure 12-1. Applying the predictive method yields an estimate of the expected average crash frequency (and/or crash severity and collision types) for an urban or suburban arterial facility. The components of the predictive models in Chapter 12 are determined and applied in Steps 9, 10, and 11 of the predictive method. The information to apply each step is provided in the following sections and in Part C, Appendix A. In some situations, certain steps will not require any action. For example, a new facility will not have observed crash data and therefore steps relating to the EB Method require no action.

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

The following explains the details of each step of the method as applied to urban and suburban arterials.

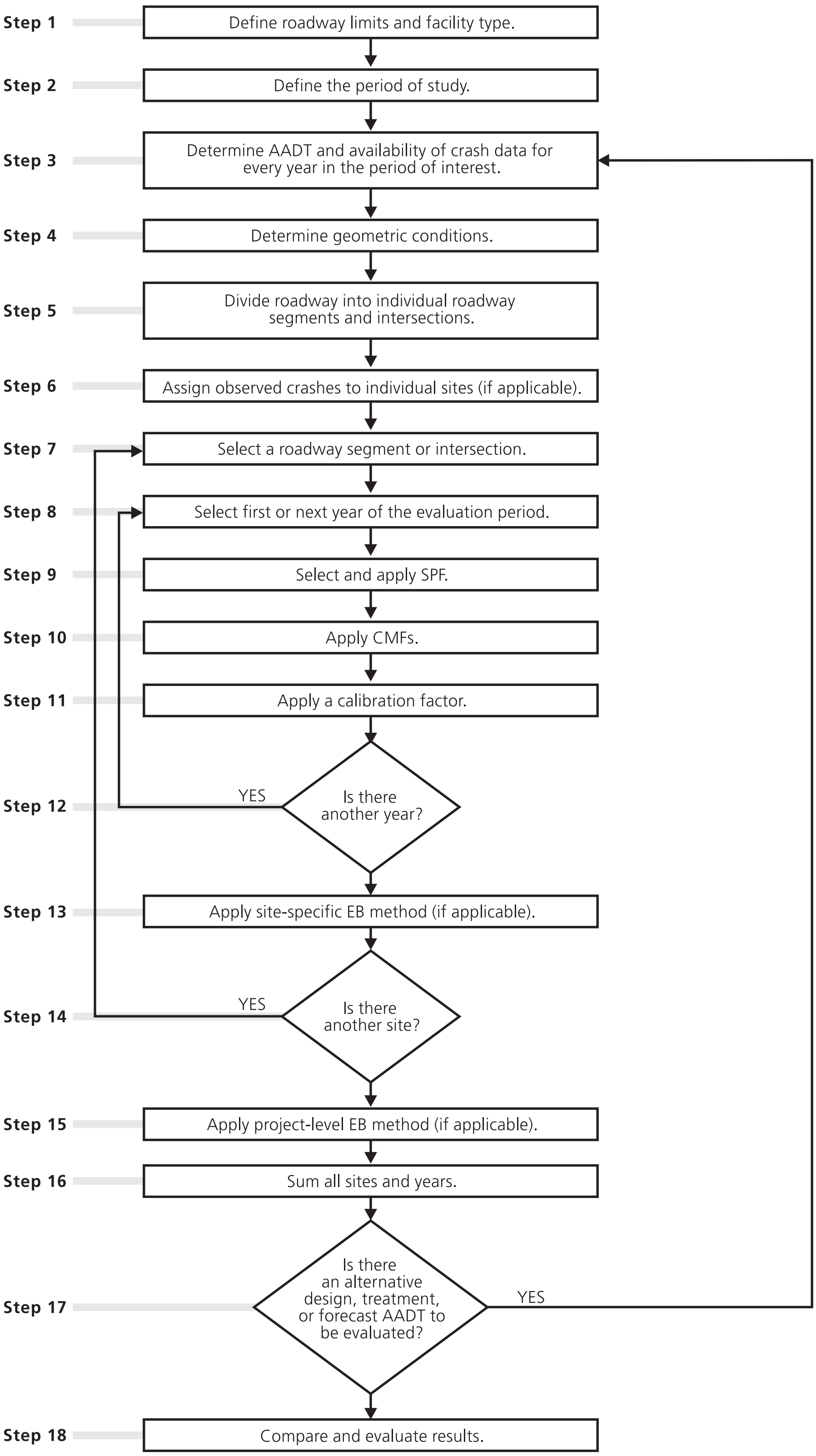

Figure 12-1. The HSM Predictive Method

Step 1—Define the limits of the roadway and facility types in the study network, facility, or site for which the expected average crash frequency, severity, and collision types are to be estimated.
The predictive method can be undertaken for a roadway network, a facility, or an individual site. A site is either an intersection or a homogeneous roadway segment. Sites may consist of a number of types, such as signalized and unsignalized intersections. The definitions of urban and suburban arterials, intersections, and roadway segments and the specific site types included in Chapter 12 are provided in Section 12.3.

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

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

Step 2—Define the period of interest.
The predictive method can be undertaken for either a past period or a future period. All periods are measured in years. Years of interest will be determined by the availability of observed or forecast average annual daily traffic (AADT) volumes, observed crash data, and geometric design data. Whether the predictive method is used for a past or future period depends upon the purpose of the study. The period of study may be:

- A past period (based on observed AADTs) for:
  - An existing roadway network, facility, or site. If observed crash data are available, the period of study is the period of time for which the observed crash data are available and for which (during that period) the site geometric design features, traffic control features and traffic volumes are known.
  - An existing roadway network, facility, or site for which alternative geometric design features or traffic control features are proposed (for near term conditions).
- A future period (based on forecast AADTs) for:
  - An existing roadway network, facility, or site for a future period where forecast traffic volumes are available.
  - An existing roadway network, facility, or site for which alternative geometric design or traffic control features are proposed for implementation in the future.
  - A new roadway network, facility, or site that does not currently exist but is proposed for construction during some future period.

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

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

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

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

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

In many cases, it is expected that AADT data will not be available for all years of the evaluation period. In that case, an estimate of AADT for each year of the evaluation period is interpolated or extrapolated, as appropriate. If there is not an established procedure for doing this, the following may be applied within the predictive method to estimate the AADTs for years for which data are not available.

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

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

For signalized intersections, the pedestrian volumes crossing each intersection leg are determined for each year of the period to be evaluated. The pedestrian crossing volumes for each leg of the intersection are then summed to determine the total pedestrian crossing volume for the intersection. Where pedestrian volume counts are not available, they may be estimated using the guidance presented in Table 12-15. Where pedestrian volume counts are not available for each year, they may be interpolated or extrapolated in the same manner as explained above for AADT data.

Determining Availability of Observed Crash Data

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

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

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

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

In order to determine the relevant data needs and avoid unnecessary collection of data, it is necessary to understand the base conditions and CMFs in Step 9 and Step 10. The base conditions are defined in Section 12.6.1 for roadway segments and in Section 12.6.2 for intersections.

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

- Length of roadway segment (miles)
- AADT (vehicles per day)
- Number of through lanes
- Presence/type of median (undivided, divided by raised or depressed median, center TWLTL)
- Presence/type of on-street parking (parallel vs. angle; one side vs. both sides of street)
- Number of driveways for each driveway type (major commercial, minor commercial; major industrial/institutional; minor industrial/institutional; major residential; minor residential; other)
- Roadside fixed object density (fixed objects/mile, only obstacles 4-in or more in diameter that do not have a break-away design are counted)
- Average offset to roadside fixed objects from edge of traveled way (feet)
- Presence/absence of roadway lighting
- Speed category (based on actual traffic speed or posted speed limit)
- Presence of automated speed enforcement
- For all intersections within the study area, the following geometric and traffic control features are identified:
- Number of intersection legs (3 or 4)
- Type of traffic control (minor-road stop or signal)
- Number of approaches with intersection left-turn lane (all approaches, 0, 1, 2, 3, or 4 for signalized intersection; only major approaches, 0, 1, or 2, for stop-controlled intersections)
- Number of major-road approaches with left-turn signal phasing (0, 1, or 2) (signalized intersections only) and type of left-turn signal phasing (permissive, protected/permissive, permissive/protected, or protected)
- Number of approaches with intersection right turn lane (all approaches, 0, 1, 2, 3, or 4 for signalized intersection; only major approaches, 0, 1, or 2, for stop-controlled intersections)
- Number of approaches with right-turn-on-red operation prohibited (0, 1, 2, 3, or 4) (signalized intersections only)
- Presence/absence of intersection lighting
- Maximum number of traffic lanes to be crossed by a pedestrian in any crossing maneuver at the intersection considering the presence of refuge islands (for signalized intersections only)
- Proportions of nighttime crashes for unlighted intersections (by total, fatal, injury, and property damage only)

For signalized intersections, land use and demographic data used in the estimation of vehicle-pedestrian collisions include:

- Number of bus stops within 1,000 feet of the intersection
- Presence of schools within 1,000 feet of the intersection
- Number of alcohol sales establishments within 1,000 feet of the intersection
- Presence of red light camera
- Number of approaches on which right-turn-on-red is allowed

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

Using the information from Step 1 and Step 4, the roadway is divided into individual sites, consisting of individual homogenous roadway segments and intersections. The definitions and methodology for dividing the roadway into individual intersections and homogenous roadway segments for use with the Chapter 12 predictive models are provided in Section 12.5. When dividing roadway facilities into small homogenous roadway segments, limiting the segment length to a minimum of 0.10 miles will decrease data collection and management efforts.

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

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

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

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

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

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

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

Step 8—For the selected site, select the first or next year in the period of interest. If there are no more years to be evaluated for that site, proceed to Step 14

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

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

Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.

Steps 9 through 13, described below, are repeated for each year of the evaluation period as part of the evaluation of any particular roadway segment or intersection. The predictive models in Chapter 12 follow the general form shown in Equation 12-1. Each predictive model consists of a SPF, which is adjusted to site specific conditions using CMFs (in Step 10) and adjusted to local jurisdiction conditions (in Step 11) using a calibration factor (C). The SPFs, CMFs, and calibration factor obtained in Steps 9, 10, and 11 are applied to calculate the predicted average crash frequency for the selected year of the selected site. The SPFs available for urban and suburban arterials are presented in Section 12.6.

The SPF (which is a regression model based on observed crash data for a set of similar sites) determines the predicted average crash frequency for a site with the same base conditions (i.e., a specific set of geometric design and traffic control features). The base conditions for each SPF are specified in Section 12.6. A detailed explanation and overview of the SPFs are provided in Section C.6.3.

The SPFs developed for Chapter 12 are summarized in Table 12-2. For the selected site, determine the appropriate SPF for the site type (intersection or roadway segment) and the geometric and traffic control features (undivided roadway, divided roadway, stop-controlled intersection, signalized intersection). The SPF for the selected site is calculated using the AADT determined in Step 3 (AADTmaj and AADTmin for intersections) for the selected year.

Each SPF determined in Step 9 is provided with default distributions of crash severity and collision type (presented in Section 12.6). These default distributions can benefit from being updated based on local data as part of the calibration process presented in Part C, Appendix A.1.1.

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.
In order to account for differences between the base conditions (Section 12.6) and the specific conditions of the site, CMFs are used to adjust the SPF estimate. An overview of CMFs and guidance for their use is provided in Section C.6.4, including the limitations of current knowledge related to the effects of simultaneous application of multiple CMFs. In using multiple CMFs, engineering judgment is required to assess the interrelationships and/or independence of individual elements or treatments being considered for implementation within the same project.

All CMFs used in Chapter 12 have the same base conditions as the SPFs used in Chapter 12 (i.e., when the specific site has the same condition as the SPF base condition, the CMF value for that condition is 1.00). Only the CMFs presented in Section 12.7 may be used as part of the Chapter 12 predictive method. Table 12-18 indicates which CMFs are applicable to the SPFs in Section 12.6.

The CMFs for roadway segments are those described in Section 12.7.1. These CMFs are applied as shown in Equation 12-3.

The CMFs for intersections are those described in Section 12.7.2, which apply to both signalized and stop-controlled intersections, and in Section 12.7.3, which apply to signalized intersections only. These CMFs are applied as shown in Equations 12-6 and 12-28.

In Chapter 12, the multiple- and single-vehicle base crashes determined in Step 9 and the CMFs values calculated in Step 10 are then used to estimate the vehicle-pedestrian and vehicle-bicycle base crashes for roadway segments and intersections (present in Sections 12.6.1 and 12.6.2 respectively).

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
The SPFs used in the predictive method have each been developed with data from specific jurisdictions and time periods. Calibration to local conditions will account for these differences. A calibration factor (Cr for roadway segments or Ci for intersections) is applied to each SPF in the predictive method. An overview of the use of calibration factors is provided in Section C.6.5. Detailed guidance for the development of calibration factors is included in Part C, Appendix A.1.1.

Steps 9, 10, and 11 together implement the predictive models in Equations 12-2 through 12-7 to determine predicted average crash frequency.

Step 12—If there is another year to be evaluated in the study period for the selected site, return to Step 8. Otherwise, proceed to Step 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 12 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 also used. This is in addition to the material in Part C, Appendix A.2.4. The overdispersion parameter provides an indication of the statistical reliability of the SPF. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. This parameter is used in the site-specific EB Method to provide a weighting to $N_{predicted}$ and $N_{observed}$. Overdispersion parameters are provided for each SPF in Section 12.6.

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

The estimated expected average crash frequency obtained above applies to the time period in the past for which the observed crash data were obtained. Part C, Appendix A.2.6 provides a method to convert the estimate of expected average crash frequency for a past time period to a future time period. In doing this, consideration is given to significant changes in geometric or roadway characteristics cause by the treatments considered for future time period.

Step 14—If there is another site to be evaluated, return to 7, otherwise, proceed to Step 15.
This step creates a loop through Steps 7 to 13 that is repeated for each roadway segment or intersection within the facility.

Step 15—Apply the project level EB Method (if the site-specific EB Method is not applicable).
This step is only applicable to existing conditions when observed crash data are available, but cannot be accurately assigned to specific sites (e.g., the crash report may identify crashes as occurring between two intersections, but is not accurate to determine a precise location on the segment). Detailed description of the project level EB Method is provided in Part C, Appendix A.2.5.

Step 16—Sum all sites and years in the study to estimate total crash frequency.
The total estimated number of crashes within the network or facility limits during a study period of *n* years is calculated using Equation 12-8:

$$N_{\text{total}} = \sum_{\substack{\text{all} \\ \text{roadway} \\ \text{segments}}} N_{rs} + \sum_{\substack{\text{all} \\ \text{intersections}}} N_{int} \tag{12-8}$$

Where:

N_{total} = total expected number of crashes within the limits of an urban or suburban arterial for the period of interest. Or, the sum of the expected average crash frequency for each year for each site within the defined roadway limits within the study period;

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

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

Equation 12-8 represents the total expected number of crashes estimated to occur during the study period. Equation 12-9 is used to estimate the total expected average crash frequency within the network or facility limits during the study period.

$$N_{\text{total aveage}} = \frac{N_{\text{total}}}{n} \tag{12-9}$$

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 12.6. These default distributions can benefit from being updated based on local data as part of the calibration process presented in Part C, Appendix A.1.1.

12.5. ROADWAY SEGMENTS AND INTERSECTIONS

Section 12.4 provides an explanation of the predictive method. Sections 12.5 through 12.8 provide the specific detail necessary to apply the predictive method steps. Detail regarding the procedure for determining a calibration factor to apply in Step 11 is provided in Part C, Appendix A.1. Detail regarding the EB Method, which is applied in Steps 6, 13, and 15, is provided in Part C, Appendix A.2.

In Step 5 of the predictive method, the roadway within the defined limits is divided into individual sites, which are homogenous roadway segments and intersections. A facility consists of a contiguous set of individual intersections and roadway segments, referred to as "sites." A roadway network consists of a number of contiguous facilities. Predictive models have been developed to estimate crash frequencies separately for roadway segments and intersections. The definitions of roadway segments and intersections presented below are the same as those used in the FHWA *Interactive Highway Safety Design Model* (IHSDM) (4).

Roadway segments begin at the center of an intersection and end at either the center of the next intersection or where there is a change from one homogeneous roadway segment to another homogenous segment. The roadway segment model estimates the frequency of roadway-segment-related crashes which occur in Region B in Figure 12-2. When a roadway segment begins or ends at an intersection, the length of the roadway segment is measured from the center of the intersection.

Chapter 12 provides predictive models for stop-controlled (three- and four-leg) and signalized (three- and four-leg) intersections. The intersection models estimate the predicted average frequency of crashes that occur within the limits of an intersection (Region A of Figure 12-2) and intersection-related crashes that occur on the intersection legs (Region B in Figure 12-2).

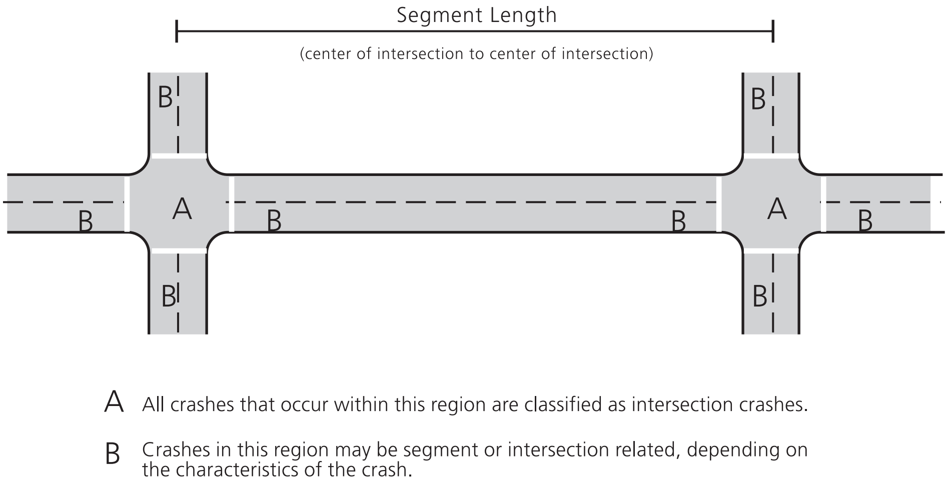

Figure 12-2. Definition of Roadway Segments and Intersections

The segmentation process produces a set of roadway segments of varying length, each of which is homogeneous with respect to characteristics such as traffic volumes and key roadway design characteristics and traffic control features. Figure 12-2 shows the segment length, L, for a single homogenous roadway segment occurring between two intersections. However, several homogenous roadway segments can occur between two intersections. A new (unique) homogeneous segment begins at the center of each intersection and where there is a change in at least one of the following characteristics of the roadway:

- Annual average daily traffic volume (AADT) (vehicles/day)
- Number of through lanes
- Presence/type of median

The following rounded widths for medians without barriers are recommended before determining "homogeneous" segments:

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

- Presence/type of on-street parking
- Roadside fixed object density
- Presence of lighting
- Speed category (based on actual traffic speed or posted speed limit)

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

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

In order to apply the site-specific EB Method, observed crashes are assigned to the individual roadway segments and intersections. Observed crashes that occur between intersections are classified as either intersection-related or roadway-segment related. The methodology for assigning crashes to roadway segments and intersections for use in the site-specific EB Method is presented in Part C, Appendix A.2.3. In applying the EB Method for urban and suburban arterials, whenever the predicted average crash frequency for a specific roadway segment during the multiyear study period is less than 1/k (the inverse of the overdispersion parameter for the relevant SPF), consideration should be given to combining adjacent roadway segments and applying the project-level EB Method. This guideline for the minimum crash frequency for a roadway segment applies only to Chapter 12 which uses fixed-value overdispersion parameters. It is not needed in Chapters 10 or 11, which use length-dependent overdispersion parameters.

12.6. SAFETY PERFORMANCE FUNCTIONS

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

The predicted crash frequencies for base conditions obtained with the SPFs are used in the predictive models in Equations 12-2 through 12-7. A detailed discussion of SPFs and their use in the HSM is presented in Sections 3.5.2 and C.6.3.

Each SPF also has an associated overdispersion parameter, k. The overdispersion parameter provides an indication of the statistical reliability of the SPF. The closer the overdispersion parameter is to zero, the more statistically reliable the SPF. This parameter is used in the EB Method discussed in Part C, Appendix A. The SPFs in Chapter 12 are summarized in Table 12-2.

Table 12-2. Safety Performance Functions included in Chapter 12

Chapter 12 SPFs for Urban and Suburban Arterials	SPF Components by Collision Type	SPF Equations, Tables, and Figures
Roadway segments	multiple-vehicle nondriveway collisions	Equations 12-10, 12-11, 12-12, Figure 12-3, Tables 12-3, 12-4
	single-vehicle crashes	Equations 12-13, 12-14, 12-15, Figure 12-4, Tables 12-5, 12-6
	multiple-vehicle driveway-related collisions	Equations 12-16, 12-17, 12-18, Figures 12-5, 12-6, 12-7, 12-8, 12-9, Table 12-7
	vehicle-pedestrian collisions	Equation 12-19, Table 12-8
	vehicle-bicycle collisions	Equation 12-20, Table 12-9
Intersections	multiple-vehicle collisions	Equations 12-21, 12-22, 12-23, Figures 12-10, 12-11, 12-12, 12-13, Tables 12-10, 12-11
	single-vehicle crashes	Equations 12-24, 12-25, 12-26, 12-27, Figures 12-14, 12-15, 12-16, 12-17, Tables 12-12, 12-13
	vehicle-pedestrian collisions	Equations 12-28, 12-29, 12-30, Tables 12-14, 12-15, 12-16
	vehicle-bicycle collisions	Equation 12-31, Table 12-17

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

12.6.1. Safety Performance Functions for Urban and Suburban Arterial Roadway Segments

The predictive model for predicting average crash frequency on a particular urban or suburban arterial roadway segment was presented in Equation 12-2. The effect of traffic volume (AADT) on crash frequency is incorporated through the SPF, while the effects of geometric design and traffic control features are incorporated through the CMFs. The SPF for urban and suburban arterial roadway segments is presented in this section. Urban and suburban arterial roadway segments are defined in Section 12.3.

SPFs and adjustment factors are provided for five types of roadway segments on urban and suburban arterials:

- Two-lane undivided arterials (2U)
- Three-lane arterials including a center two-way left-turn lane (TWLTL) (3T)
- Four-lane undivided arterials (4U)
- Four-lane divided arterials (i.e., including a raised or depressed median) (4D)
- Five-lane arterials including a center TWLTL (5T)

Guidance on the estimation of traffic volumes for roadway segments for use in the SPFs is presented in Step 3 of the predictive method described in Section 12.4. The SPFs for roadway segments on urban and suburban arterials are applicable to the following AADT ranges:

- 2U: 0 to 32,600 vehicles per day
- 3T : 0 to 32,900 vehicles per day
- 4U: 0 to 40,100 vehicles per day

- 4D: 0 to 66,000 vehicles per day
- 5T: 0 to 53,800 vehicles per day

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

Other types of roadway segments may be found on urban and suburban arterials but are not addressed by the predictive model in Chapter 12.

The procedure addresses five types of collisions. The corresponding equations, tables, and figures are indicated in Table 12-2 above:

- multiple-vehicle nondriveway collisions
- single-vehicle crashes
- multiple-vehicle driveway-related collisions
- vehicle-pedestrian collisions
- vehicle-bicycle collisions

The predictive model for estimating average crash frequency on roadway segments is shown in Equations 12-2 through 12-4. The effect of traffic volume on predicted crash frequency is incorporated through the SPFs, while the effects of geometric design and traffic control features are incorporated through the CMFs. SPFs are provided for multiple-vehicle nondriveway collisions and single-vehicle crashes. Adjustment factors are provided for multi-vehicle driveway-related, vehicle-pedestrian, and vehicle-bicycle collisions.

Multiple-Vehicle Nondriveway Collisions

The SPF for multiple-vehicle nondriveway collisions is applied as follows:

$$N_{brmv} = exp(a + b \times In(AADT) + In(L)) \tag{12-10}$$

Where:

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

L = length of roadway segment (mi); and

a, b = regression coefficients.

Table 12-3 presents the values of the coefficients a and b used in applying Equation 12-10. The overdispersion parameter, k, is also presented in Table 12-3.

Table 12-3. SPF Coefficients for Multiple-Vehicle Nondriveway Collisions on Roadway Segments

	Coefficients Used in Equation 12-10		
Road Type	**Intercept (a)**	**AADT (b)**	**Overdispersion Parameter (k)**
Total crashes			
2U	–15.22	1.68	0.84
3T	–12.40	1.41	0.66
4U	–11.63	1.33	1.01
4D	–12.34	1.36	1.32
5T	–9.70	1.17	0.81
Fatal-and-injury crashes			
2U	–16.22	1.66	0.65
3T	–16.45	1.69	0.59
4U	–12.08	1.25	0.99
4D	–12.76	1.28	1.31
5T	–10.47	1.12	0.62
Property-damage-only crashes			
2U	–15.62	1.69	0.87
3T	–11.95	1.33	0.59
4U	–12.53	1.38	1.08
4D	–12.81	1.38	1.34
5T	–9.97	1.17	0.88

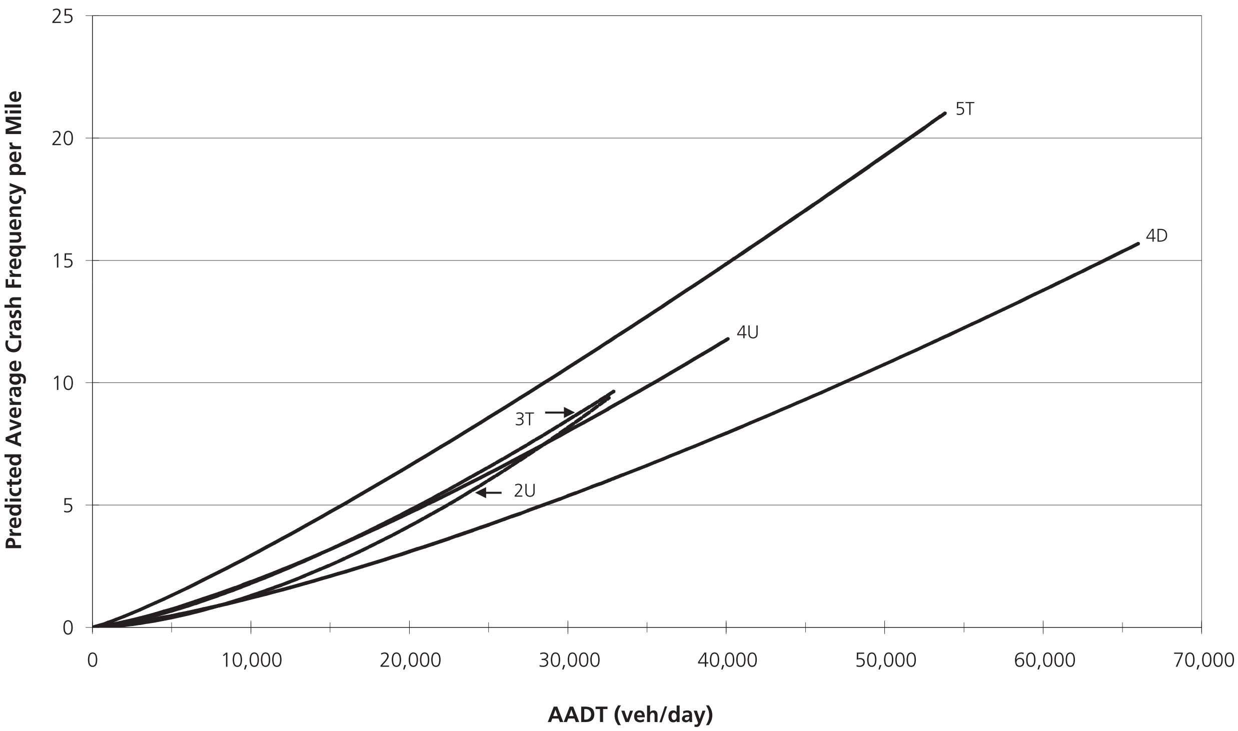

Figure 12-3. Graphical Form of the SPF for Multiple Vehicle Nondriveway collisions (from Equation 12-10 and Table 12-3)

Equation 12-10 is first applied to determine N_{brmv} using the coefficients for total crashes in Table 12-3. N_{brmv} is then divided into components by severity level, $N_{brmv(FI)}$ for fatal-and-injury crashes and $N_{brmv(PDO)}$ for property-damage-only crashes. These preliminary values of $N_{brmv(FI)}$ and $N_{brmv(PDO)}$, designated as $N'_{brmv(FI)}$ and $N'_{brmv(PDO)}$ in Equation 12-11, are determined with Equation 12-10 using the coefficients for fatal-and-injury and property-damage-only crashes, respectively, in Table 12-3. The following adjustments are then made to assure that $N_{brmv(FI)}$ and $N_{brmv(PDO)}$ sum to N_{brmv}:

$$N_{brmv(FI)} = N_{brmv(\text{total})}\left(\frac{N'_{brmv(FI)}}{N'_{brmv(FI)} + N'_{brmv(PDO)}}\right) \tag{12-11}$$

$$N_{brmv(PDO)} = N_{brmv(\text{total})} - N_{brmv(FI)} \tag{12-12}$$

The proportions in Table 12-4 are used to separate $N_{brmv(FI)}$ and $N_{brmv(PDO)}$ into components by collision type.

Table 12-4. Distribution of Multiple-Vehicle Nondriveway Collisions for Roadway Segments by Manner of Collision Type

	Proportion of Crashes by Severity Level for Specific Road Types									
	2U		3T		4U		4D		5T	
Collision Type	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Rear-end collision	0.730	0.778	0.845	0.842	0.511	0.506	0.832	0.662	0.846	0.651
Head-on collision	0.068	0.004	0.034	0.020	0.077	0.004	0.020	0.007	0.021	0.004
Angle collision	0.085	0.079	0.069	0.020	0.181	0.130	0.040	0.036	0.050	0.059
Sideswipe, same direction	0.015	0.031	0.001	0.078	0.093	0.249	0.050	0.223	0.061	0.248
Sideswipe, opposite direction	0.073	0.055	0.017	0.020	0.082	0.031	0.010	0.001	0.004	0.009
Other multiple-vehicle collisions	0.029	0.053	0.034	0.020	0.056	0.080	0.048	0.071	0.018	0.029

Source: HSIS data for Washington (2002–2006)

Single-Vehicle Crashes

SPFs for single-vehicle crashes for roadway segments are applied as follows:

$$Nbrsv = exp(a + b \times In(AADT) + In(L)) \tag{12-13}$$

Table 12-5 presents the values of the coefficients and factors used in Equation 12-13 for each roadway type. Equation 12-13 is first applied to determine N_{brsv} using the coefficients for total crashes in Table 12-5. N_{brsv} is then divided into components by severity level; $N_{brsv(FI)}$ for fatal-and-injury crashes and $N_{brsv(PDO)}$ for property-damage-only crashes. Preliminary values of $N_{brsv(FI)}$ and $N_{brsv(PDO)}$, designated as $N'_{brsv(FI)}$ and $N'_{brsv(PDO)}$ in Equation 12-14, are determined with Equation 12-13 using the coefficients for fatal-and-injury and property-damage-only crashes, respectively, in Table 12-5. The following adjustments are then made to assure that $N_{brsv(FI)}$ and $N_{brsv(PDO)}$ sum to N_{brsv}:

$$N_{brsv(FI)} = N_{brsv(\text{total})}\left(\frac{N'_{brsv(FI)}}{N'_{brsv(FI)} + N'_{brsv(PDO)}}\right) \quad (12\text{-}14)$$

$$N_{brsv(PDO)} = N_{brsv(\text{total})} - N_{brsv(FI)} \quad (12\text{-}15)$$

The proportions in Table 12-6 are used to separate $N_{brsv(FI)}$ and $N_{brsv(PDO)}$ into components by crash type.

Table 12-5. SPF Coefficients for Single-Vehicle Crashes on Roadway Segments

Road Type	Coefficients Used in Equation 12-11: Intercept (a)	Coefficients Used in Equation 12-11: AADT (b)	Overdispersion Parameter (k)
Total crashes			
2U	–5.47	0.56	0.81
3T	–5.74	0.54	1.37
4U	–7.99	0.81	0.91
4D	–5.05	0.47	0.86
5T	–4.82	0.54	0.52
Fatal-and-injury crashes			
2U	–3.96	0.23	0.50
3T	–6.37	0.47	1.06
4U	–7.37	0.61	0.54
4D	–8.71	0.66	0.28
5T	–4.43	0.35	0.36
Property-damage-only crashes			
2U	–6.51	0.64	0.87
3T	–6.29	0.56	1.93
4U	–8.50	0.84	0.97
4D	–5.04	0.45	1.06
5T	–5.83	0.61	0.55

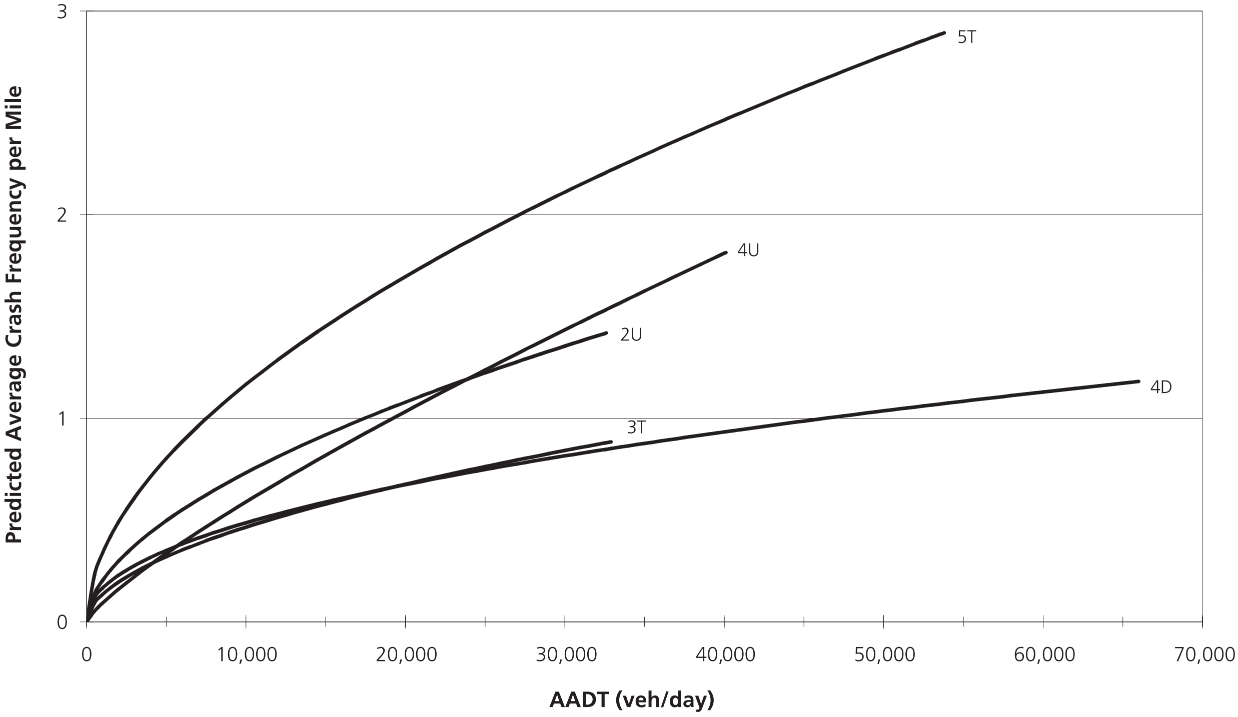

Figure 12-4. Graphical Form of the SPF for Single-Vehicle Crashes (from Equation 12-13 and Table 12-5)

Table 12-6. Distribution of Single-Vehicle Crashes for Roadway Segments by Collision Type

	Proportion of Crashes by Severity Level for Specific Road Types									
	2U		3T		4U		4D		5T	
Collision Type	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Collision with animal	0.026	0.066	0.001	0.001	0.001	0.001	0.001	0.063	0.016	0.049
Collision with fixed object	0.723	0.759	0.688	0.963	0.612	0.809	0.500	0.813	0.398	0.768
Collision with other object	0.010	0.013	0.001	0.001	0.020	0.029	0.028	0.016	0.005	0.061
Other single-vehicle collision	0.241	0.162	0.310	0.035	0.367	0.161	0.471	0.108	0.581	0.122

Source: HSIS data for Washington (2002–2006)

Multiple-Vehicle Driveway-Related Collisions

The model presented above for multiple-vehicle collisions addressed only collisions that are not related to driveways. Driveway-related collisions also generally involve multiple vehicles, but are addressed separately because the frequency of driveway-related collisions on a roadway segment depends on the number and type of driveways. Only unsignalized driveways are considered; signalized driveways are analyzed as signalized intersections.

The total number of multiple-vehicle driveway-related collisions within a roadway segment is determined as:

$$N_{brdwy} = \sum_{\substack{\text{all}\\ \text{driveway}\\ \text{types}}} n_j \times N_j \times \left(\frac{AADT}{15{,}000} \right)^{(t)} \tag{12-16}$$

Where:

N_j = Number of driveway-related collisions per driveway per year for driveway type *j* from Table 12-7;

n_j = number of driveways within roadway segment of driveway type j including all driveways on both sides of the road; and

t = coefficient for traffic volume adjustment from Table 12-7.

The number of driveways of a specific type, n_j, is the sum of the number of driveways of that type for both sides of the road combined. The number of driveways is determined separately for each side of the road and then added together.

Seven specific driveway types have been considered in modeling. These are:

- Major commercial driveways
- Minor commercial driveways
- Major industrial/institutional driveways
- Minor industrial/institutional driveways
- Major residential driveways
- Minor residential driveways
- Other driveways

Major driveways are those that serve sites with 50 or more parking spaces. Minor driveways are those that serve sites with less than 50 parking spaces. It is not intended that an exact count of the number of parking spaces be made for each site. Driveways can be readily classified as major or minor from a quick review of aerial photographs that show parking areas or through user judgment based on the character of the establishment served by the driveway. Commercial driveways provide access to establishments that serve retail customers. Residential driveways serve single- and multiple-family dwellings. Industrial/institutional driveways serve factories, warehouses, schools, hospitals, churches, offices, public facilities, and other places of employment. Commercial sites with no restriction on access along an entire property frontage are generally counted as two driveways.

Table 12-7. SPF Coefficients for Multiple-Vehicle Driveway Related Collisions

	Coefficients for Specific Roadway Types				
Driveway Type (j)	**2U**	**3T**	**4U**	**4D**	**5T**
Number of Driveway-Related Collisions per Driveway per Year (N_j)					
Major commercial	0.158	0.102	0.182	0.033	0.165
Minor commercial	0.050	0.032	0.058	0.011	0.053
Major industrial/institutional	0.172	0.110	0.198	0.036	0.181
Minor industrial/institutional	0.023	0.015	0.026	0.005	0.024
Major residential	0.083	0.053	0.096	0.018	0.087
Minor residential	0.016	0.010	0.018	0.003	0.016
Other	0.025	0.016	0.029	0.005	0.027
Regression Coefficient for AADT (t)					
All driveways	1.000	1.000	1.172	1.106	1.172
Overdispersion Parameter (k)					
All driveways	0.81	1.10	0.81	1.39	0.10
Proportion of Fatal-and-Injury Crashes (f_{dwy})					
All driveways	0.323	0.243	0.342	0.284	0.269
Proportion of Property-Damage-Only Crashes					
All driveways	0.677	0.757	0.658	0.716	0.731

Note: Includes only unsignalized driveways; signalized driveways are analyzed as signalized intersections. Major driveways serve 50 or more parking spaces; minor driveways serve less than 50 parking spaces.

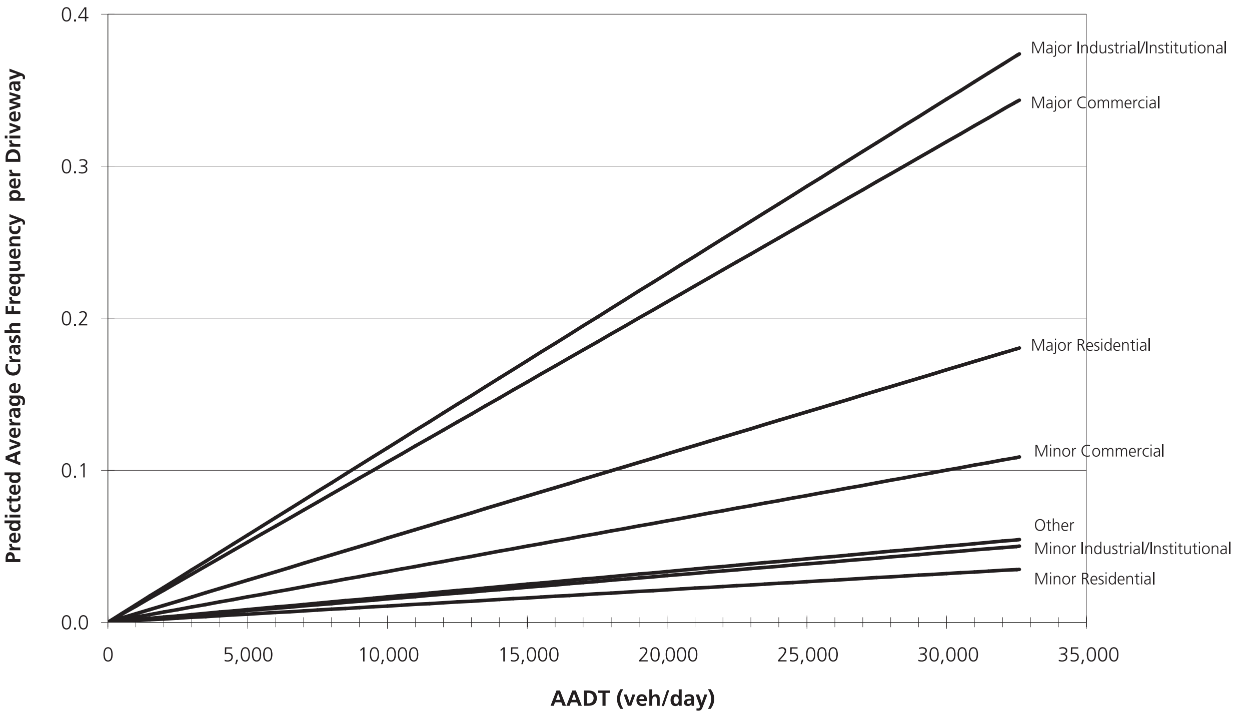

Figure 12-5. Graphical Form of the SPF for Multiple Vehicle Driveway Related Collisions on Two-Lane Undivided Arterials (2U) (from Equation 12-16 and Table 12-7)

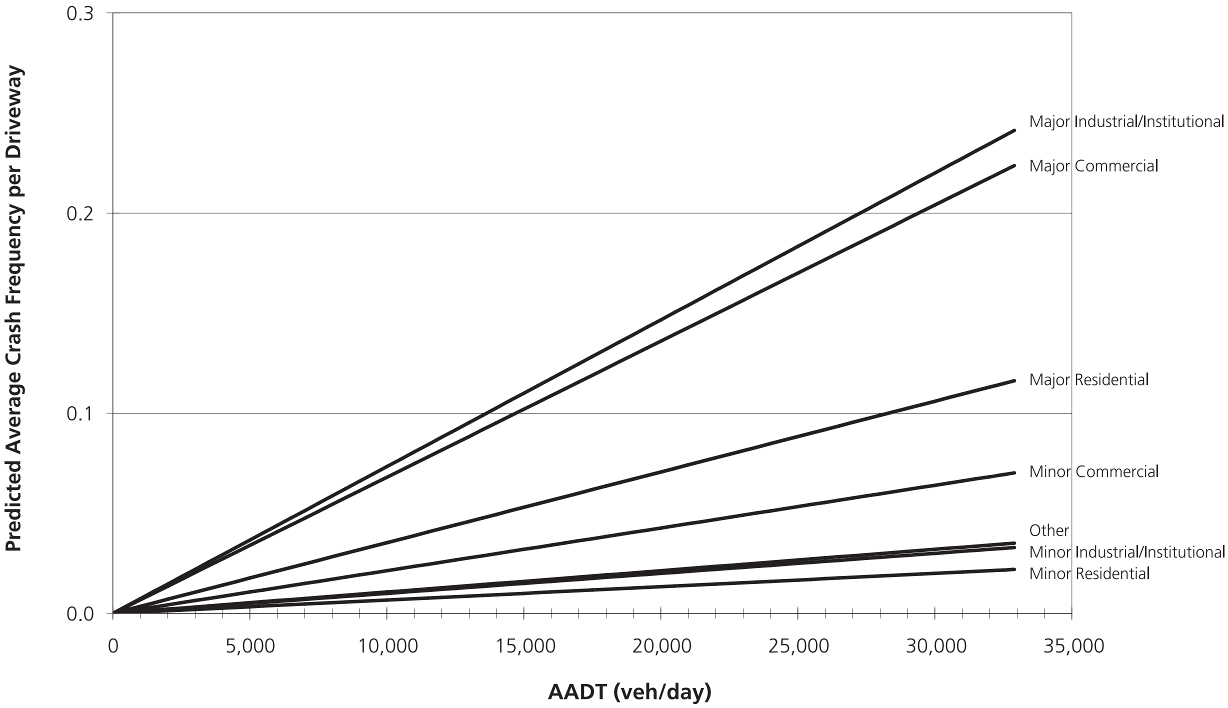

Figure 12-6. Graphical Form of the SPF for Multiple Vehicle Driveway Related Collisions on Three-Lane Undivided Arterials (3T) (from Equation 12-16 and Table 12-7)

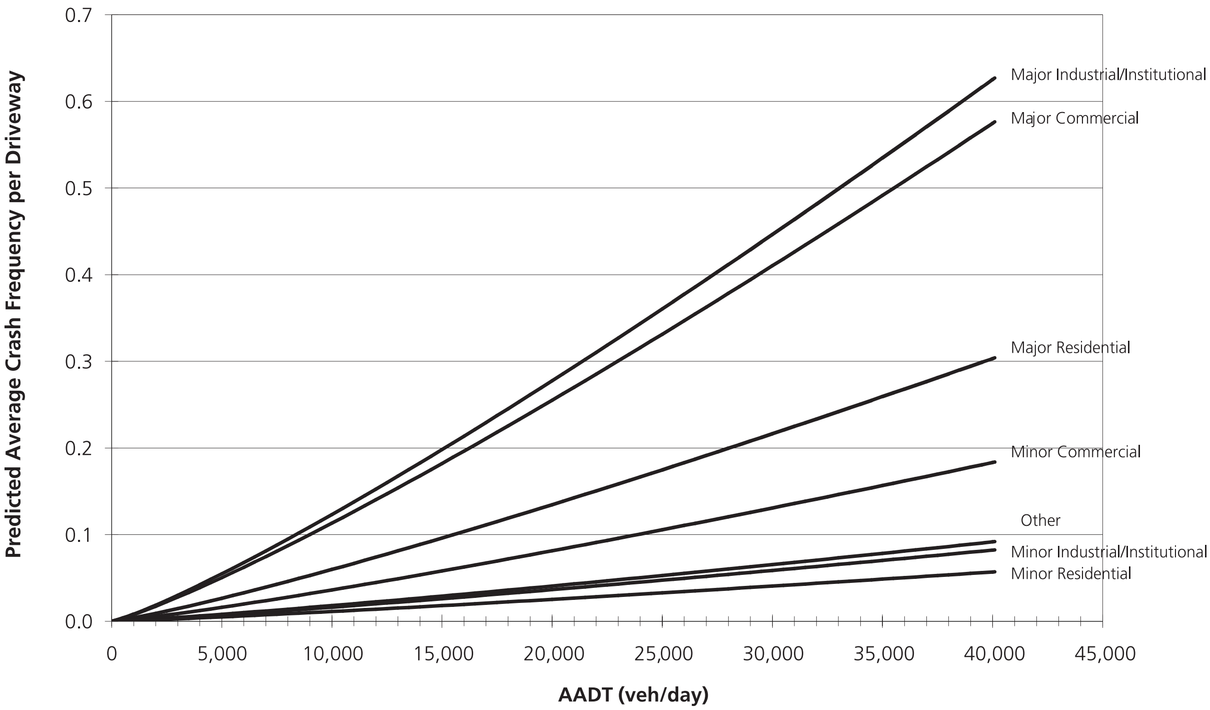

Figure 12-7. Graphical Form of the SPF for Multiple Vehicle Driveway Related Collisions on Four-Lane Undivided Arterials (4U) (from Equation 12-16 and Table 12-7)

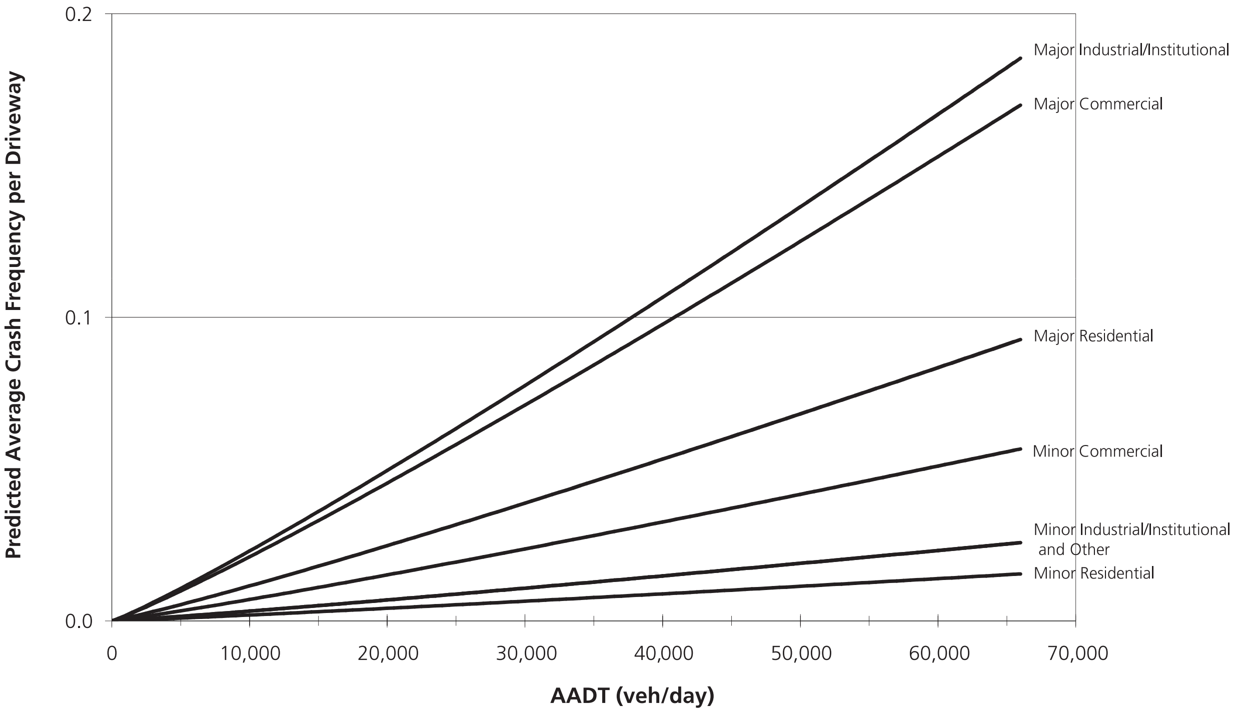

Figure 12-8. Graphical Form of the SPF for Multiple Vehicle Driveway Related Collisions on Four-Lane Divided Arterials (4D) (from Equation 12-16 and Table 12-7)

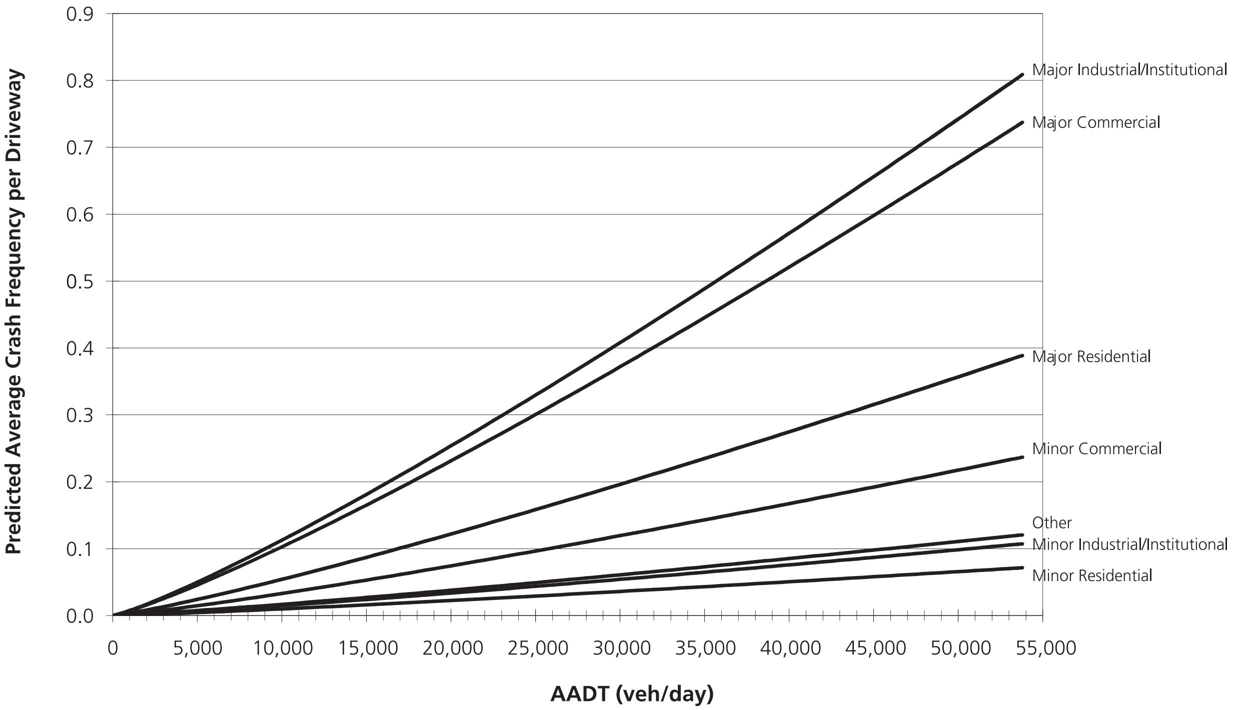

Figure 12-9. Graphical Form of the SPF for Multiple Vehicle Driveway Related Collisions on Five-Lane Arterials Including a Center Two-Way Left-Turn Lane (from Equation 12-16 and Table 12-7)

Driveway-related collisions can be separated into components by severity level as follows:

$$N_{brdwy(FI)} = N_{brdwy(\text{total})} \times f_{dwy} \tag{12-17}$$

$$N_{brdwy(PDO)} = N_{brdwy(\text{total})} - N_{brdwy(FI)} \tag{12-18}$$

Where:

f_{dwy} = proportion of driveway-related collisions that involve fatalities or injuries

The values of N_j and f_{dwy} are shown in Table 12-7.

Vehicle-Pedestrian Collisions

The number of vehicle-pedestrian collisions per year for a roadway segment is estimated as:

$$N_{pedr} = N_{br} \times f_{pedr} \tag{12-19}$$

Where:

f_{pedr} = pedestrian crash adjustment factor.

The value N_{br} used in Equation 12-19 is that determined with Equation 12-3.

Table 12-8 presents the values of f_{pedr} for use in Equation 12-19. All vehicle-pedestrian collisions are considered to be fatal-and-injury crashes. The values of f_{pedr} are likely to depend on the climate and the walking environment in particular states or communities. HSM users are encouraged to replace the values in Table 12-8 with suitable values for their own state or community through the calibration process (see Part C, Appendix A).

Table 12-8. Pedestrian Crash Adjustment Factor for Roadway Segments

	Pedestrian Crash Adjustment Factor (fpedr)	
Road Type	**Posted Speed 30 mph or Lower**	**Posted Speed Greater than 30 mph**
2U	0.036	0.005
3T	0.041	0.013
4U	0.022	0.009
4D	0.067	0.019
5T	0.030	0.023

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All pedestrian collisions resulting from this adjustment factor are treated as fatal-and-injury crashes and none as property-damage-only crashes.
Source: HSIS data for Washington (2002–2006)

Vehicle-Bicycle Collisions

The number of vehicle-bicycle collisions per year for a roadway segment is estimated as:

$$N_{biker} = N_{br} \times f_{biker} \tag{12-20}$$

Where:

f_{biker} = bicycle crash adjustment factor.

The value of N_{br} used in Equation 12-20 is determined with Equation 12-3.

Table 12-9 presents the values of fbiker for use in Equation 12-18. All vehicle-bicycle collisions are considered to be fatal-and-injury crashes. The values of fbiker are likely to depend on the climate and bicycling environment in particular states or communities. HSM users are encouraged to replace the values in Table 12-9 with suitable values for their own state or community through the calibration process (see Part C, Appendix A).

Table 12-9. Bicycle Crash Adjustment Factors for Roadway Segments

	Bicycle Crash Adjustment Factor (f_{biker})	
Road type	**Posted Speed 30 mph or Lower**	**Posted Speed Greater than 30 mph**
2U	0.018	0.004
3T	0.027	0.007
4U	0.011	0.002
4D	0.013	0.005
5T	0.050	0.012

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined).
All bicycle collisions resulting from this adjustment factor are treated as fatal-and-injury crashes and none as property-damage-only crashes.
Source: HSIS data for Washington (2002–2006)

12.6.2. Safety Performance Functions for Urban and Suburban Arterial Intersections

The predictive models for predicting the frequency of crashes related to an intersection is presented in Equations 12-5 through 12-7. The structure of the predictive models for intersections is similar to the predictive models for roadway segments.

The effect of traffic volume on predicted crash frequency for intersections is incorporated through SPFs, while the effect of geometric and traffic control features are incorporated through CMFs. Each of the SPFs for intersections incorporates separate effects for the AADTs on the major- and minor-road legs, respectively.

SPFs and adjustment factors have been developed for four types of intersections on urban and suburban arterials. These are:

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

Other types of intersections may be found on urban and suburban arterials but are not addressed by the Chapter 12 SPFs.

The SPFs for each of the four intersection types identified above predict total crash frequency per year for crashes that occur within the limits of the intersection. The SPFs and adjustment factors address the following four types of collisions, (the corresponding equations, tables, and figures are indicated in Table 12-2):

- multiple-vehicle collisions
- single-vehicle crashes
- vehicle-pedestrian collisions
- vehicle-bicycle collisions

Guidance on the estimation of traffic volumes for the major and minor road legs for use in the SPFs is presented in Step 3. The AADT(s) used in the SPF are the AADT(s) for the selected year of the evaluation period. The SPFs for intersections are applicable to the following AADT ranges:

3ST Intersections	$AADT_{maj}$: 0 to 45,700 vehicles per day and	$AADT_{min}$: 0 to 9,300 vehicles per day
4ST Intersections	$AADT_{maj}$: 0 to 46,800 vehicles per day and	$AADT_{min}$: 0 to 5,900 vehicles per day
3SG Intersections	$AADT_{maj}$: 0 to 58,100 vehicles per day and	$AADT_{min}$: 0 to 16,400 vehicles per day
4SG Intersections	$AADT_{maj}$: 0 to 67,700 vehicles per day and	$AADT_{min}$: 0 to 33,400 vehicles per day

4SG Intersections Pedestrian Models:

- $AADT_{maj}$: 80,200 vehicles per day
- $AADT_{min}$: 49,100 vehicles per day
- PedVol: 34,200 pedestrians per day crossing all four legs combined

Application to sites with AADTs substantially outside this range may not provide reliable results.

Multiple-Vehicle Collisions
SPFs for multiple-vehicle intersection-related collisions are applied as follows:

$$N_{bimv} = exp(a + b \times In(AADT_{maj}) + c \times In(AADT_{min})) \tag{12-21}$$

Where:

$AADT_{maj}$ = average daily traffic volume (vehicles/day) for major road (both directions of travel combined);

$AADT_{min}$ = average daily traffic volume (vehicles/day) for minor road (both directions of travel combined); and

a, b, c = regression coefficients.

Table 12-10 presents the values of the coefficients *a*, *b*, and *c* used in applying Equation 12-21. The SPF overdispersion parameter, *k*, is also presented in Table 12-10.

Equation 12-21 is first applied to determine N_{bimv} using the coefficients for total crashes in Table 12-10. N_{bimv} is then divided into components by crash severity level, $N_{bimv(FI)}$ for fatal-and-injury crashes and $N_{bimv(PDO)}$ for property-damage-only crashes. Preliminary values of $N_{bimv(FI)}$ and $N_{bimv(PDO)}$, designated as $N'_{bimv(FI)}$ and $N'_{bimv(PDO)}$ in Equation 12-22, are determined with Equation 12-21 using the coefficients for fatal-and-injury and property-damage-only crashes, respectively, in Table 12-10. The following adjustments are then made to assure that $N_{bimv(FI)}$ and $N_{bimv(PDO)}$ sum to N_{bimv}:

$$N_{bimv(FI)} = N_{bimv(\text{total})} \times \left(\frac{N'_{bimv(FI)}}{N'_{bimv(FI)} + N'_{bimv(PDO)}} \right) \tag{12-22}$$

$$N_{bimv(PDO)} = N_{bimv(\text{total})} - N_{bimv(FI)} \tag{12-23}$$

The proportions in Table 12-11 are used to separate $N_{bimv(FI)}$ and $N_{bimv(PDO)}$ into components by manner of collision.

Table 12-10. SPF Coefficients for Multiple-Vehicle Collisions at Intersections

Intersection Type	Coefficients Used in Equation 12-21 Intercept (a)	$AADT_{maj}$ (b)	$AADT_{min}$ (c)	Overdispersion Parameter (k)
Total Crashes				
3ST	−13.36	1.11	0.41	0.80
3SG	−12.13	1.11	0.26	0.33
4ST	−8.90	0.82	0.25	0.40
4SG	−10.99	1.07	0.23	0.39
Fatal-and-Injury Crashes				
3ST	−14.01	1.16	0.30	0.69
3SG	−11.58	1.02	0.17	0.30
4ST	−11.13	0.93	0.28	0.48
4SG	−13.14	1.18	0.22	0.33
Property-Damage-Only Crashes				
3ST	−15.38	1.20	0.51	0.77
3SG	−13.24	1.14	0.30	0.36
4ST	−8.74	0.77	0.23	0.40
4SG	−11.02	1.02	0.24	0.44

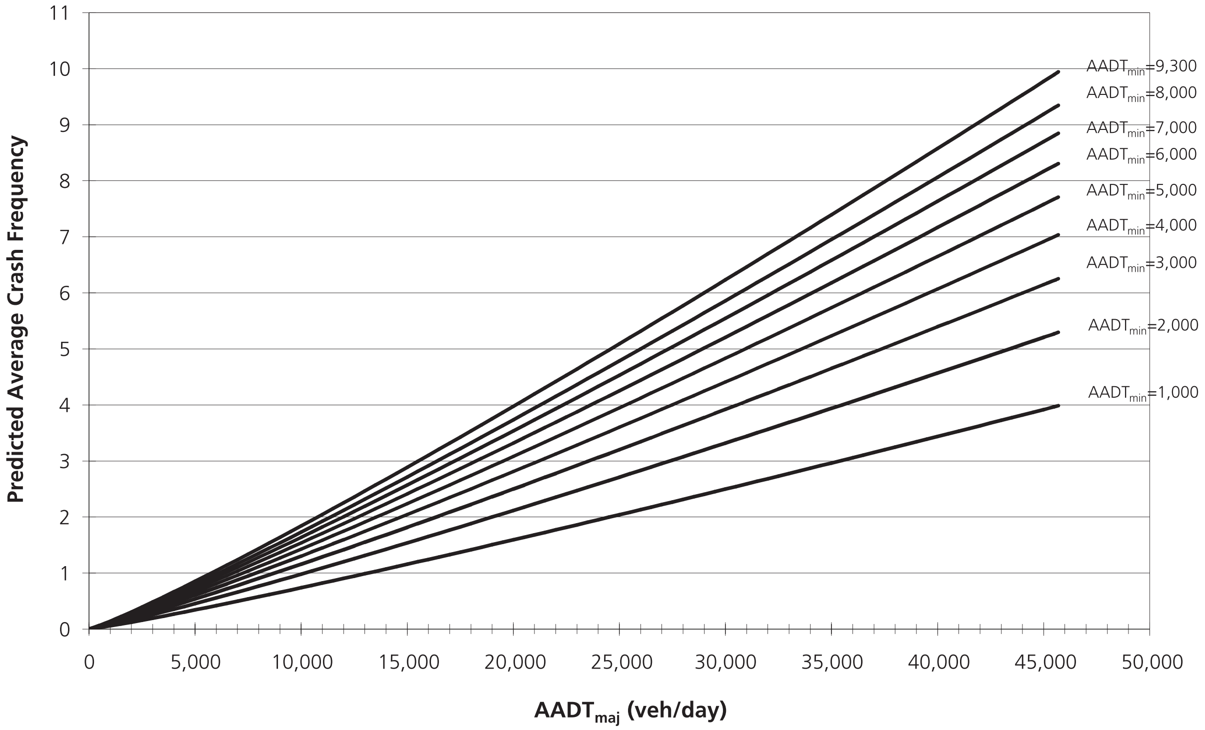

Figure 12-10. Graphical Form of the Intersection SPF for Multiple Vehicle Collisions on Three-Leg Intersections with Minor-Road Stop Control (3ST) (from Equation 12-21 and Table 12-10)

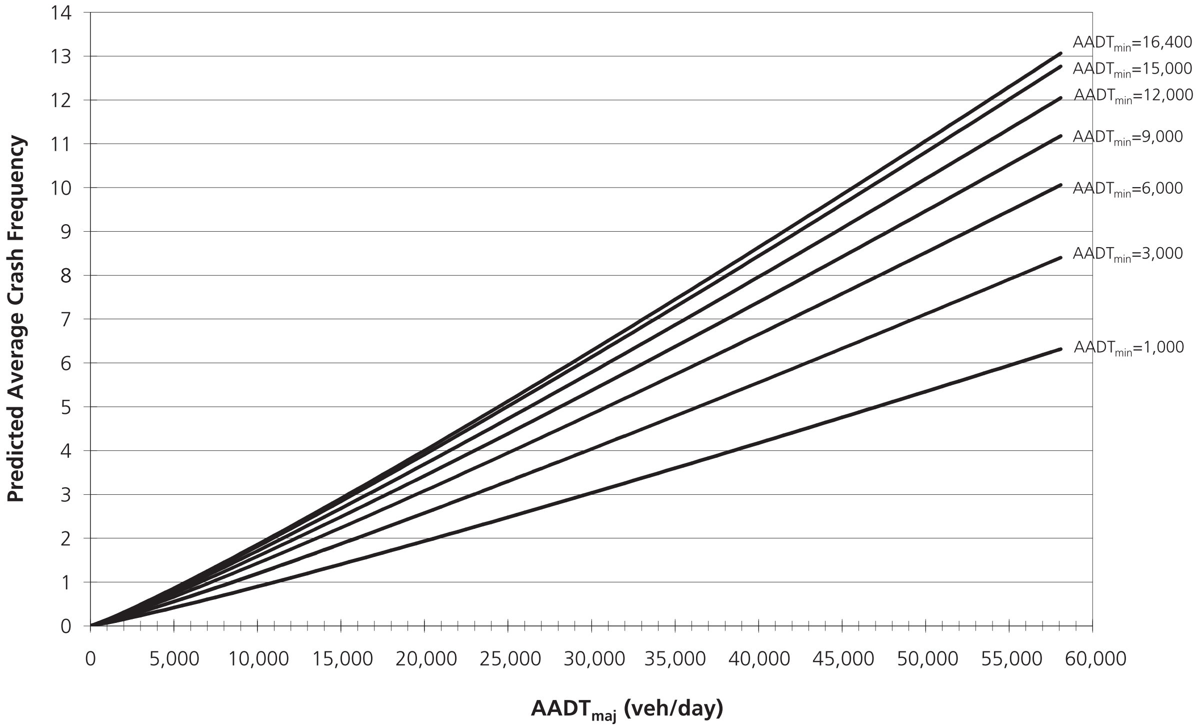

Figure 12-11. Graphical Form of the Intersection SPF for Multiple Vehicle Collisions on Three-Leg Signalized Intersections (3SG) (from Equation 12-21 and Table 12-10)

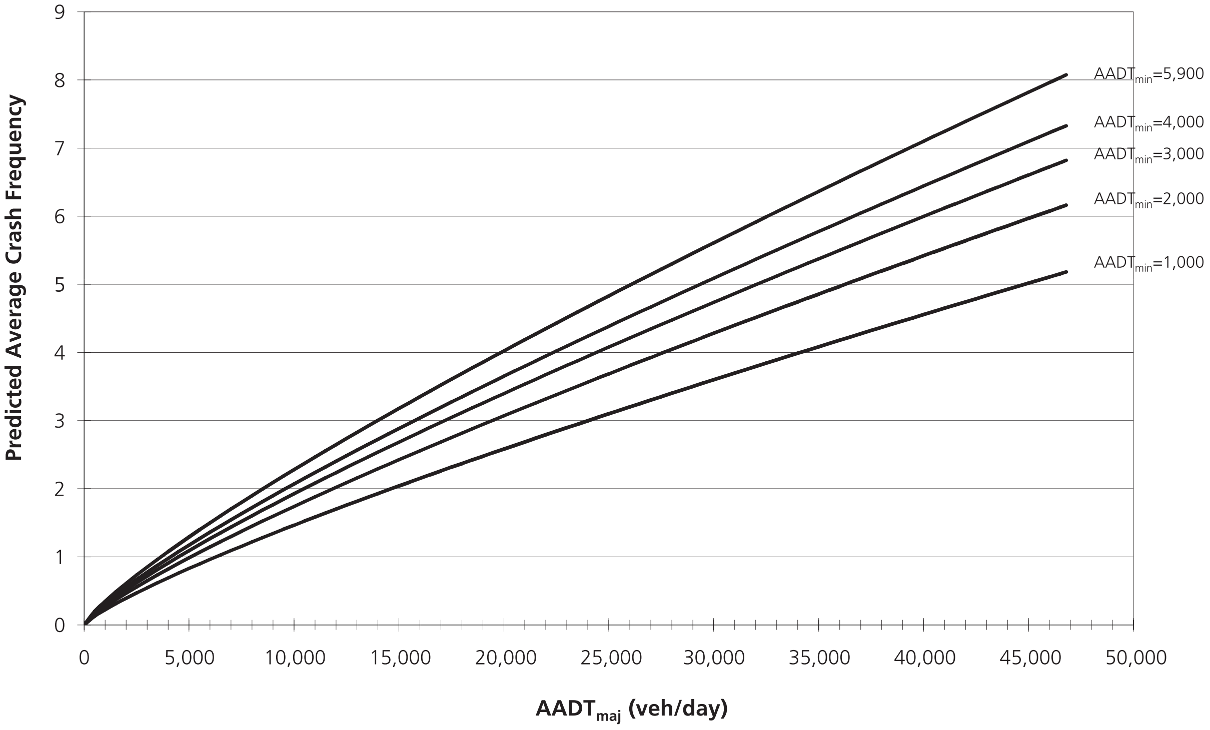

Figure 12-12. Graphical Form of the Intersection SPF for Multiple Vehicle Collisions on Four-Leg Intersections with Minor-Road Stop Control (4ST) (from Equation 12-21 and Table 12-10)

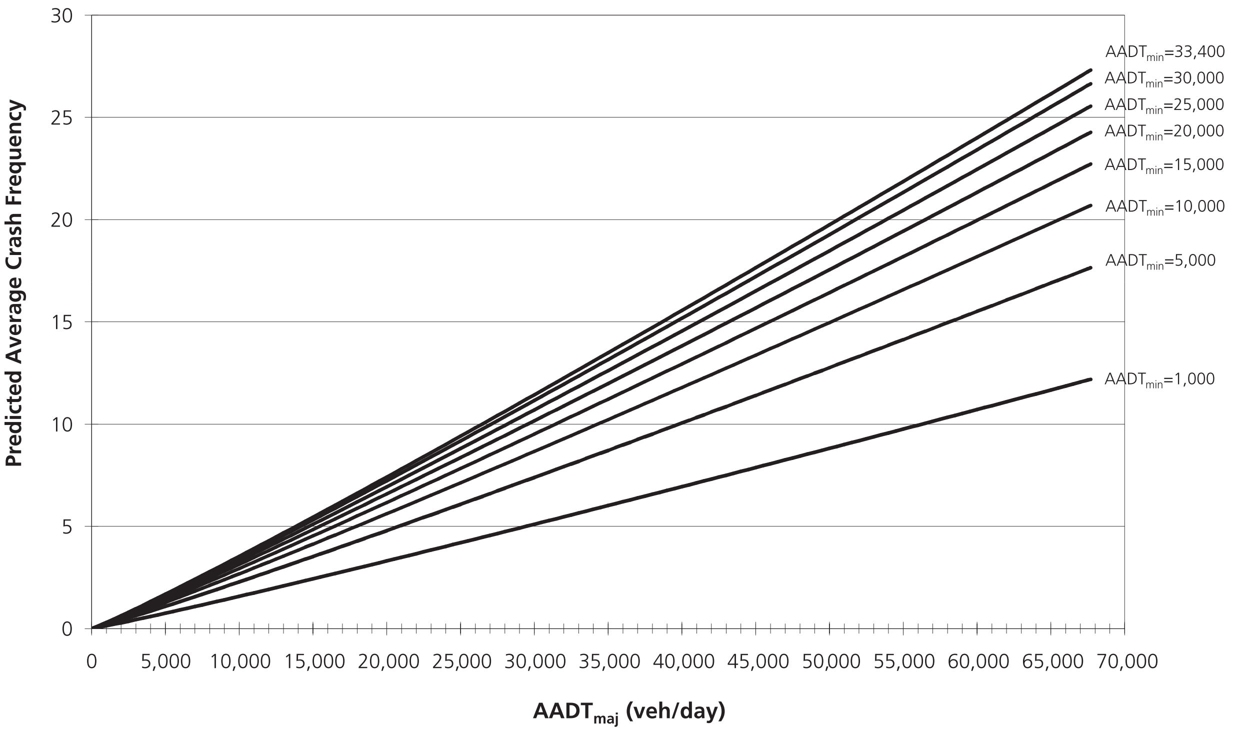

Figure 12-13. Graphical Form of the Intersection SPF for Multiple Vehicle Collisions on Four-Leg Signalized Intersections (4SG) (from Equation 12-21 and Table 12-10)

Table 12-11. Distribution of Multiple-Vehicle Collisions for Intersections by Collision Type

	Proportion of Crashes by Severity Level for Specific Intersections Types							
	3ST		3SG		4ST		4SG	
Manner of Collision	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Rear-end collision	0.421	0.440	0.549	0.546	0.338	0.374	0.450	0.483
Head-on collision	0.045	0.023	0.038	0.020	0.041	0.030	0.049	0.030
Angle collision	0.343	0.262	0.280	0.204	0.440	0.335	0.347	0.244
Sideswipe	0.126	0.040	0.076	0.032	0.121	0.044	0.099	0.032
Other multiple-vehicle collisions	0.065	0.235	0.057	0.198	0.060	0.217	0.055	0.211

Source: HSIS data for California (2002–2006)

Single-Vehicle Crashes

SPFs for single-vehicle crashes are applied as follows:

$$N_{bisv} = exp(a + b \times In(AADT_{maj}) + c \times In(AADT_{min})) \quad (12\text{-}24)$$

Table 12-12 presents the values of the coefficients and factors used in Equation 12-24 for each roadway type. Equation 12-24 is first applied to determine N_{bisv} using the coefficients for total crashes in Table 12-12. N_{bisv} is then divided into components by severity level, $N_{bisv(FI)}$ for fatal-and-injury crashes and $N_{bisv(PDO)}$ for property-damage-only crashes. Preliminary values of $N_{bisv(FI)}$ and $N_{bisv(PDO)}$, designated as $N'_{bisv(FI)}$ and $N'_{bisv(PDO)}$ in Equation 12-25, are determined with Equation 12-24 using the coefficients for fatal-and-injury and property-damage-only crashes, respectively, in Table 12-12. The following adjustments are then made to assure that $N_{bisv(FI)}$ and $N_{bisv(PDO)}$ sum to N_{bisv}.

$$N_{bisv(FI)} = N_{bisv(\text{total})} \times \left(\frac{N'_{bisv(FI)}}{N'_{bisv(FI)} + N'_{bisv(PDO)}} \right) \quad (12\text{-}25)$$

$$N_{bisv(PDO)} = N_{bisv(\text{total})} - N_{bisv(FI)} \quad (12\text{-}26)$$

Table 12-12. SPF Coefficients for Single-Vehicle Crashes at Intersections

	Coefficients Used in Equation 12-24			
Intersection Type	**Intercept (a)**	**$AADT_{maj}$ (b)**	**$AADT_{min}$ (c)**	**Overdispersion Parameter (k)**
Total Crashes				
3ST	–6.81	0.16	0.51	1.14
3SG	–9.02	0.42	0.40	0.36
4ST	–5.33	0.33	0.12	0.65
4SG	–10.21	0.68	0.27	0.36
Fatal-and-Injury Crashes				
3ST				
3SG	–9.75	0.27	0.51	0.24
4ST				
4SG	–9.25	0.43	0.29	0.09
Property-Damage-Only Crashes				
3ST	–8.36	0.25	0.55	1.29
3SG	–9.08	0.45	0.33	0.53
4ST	–7.04	0.36	0.25	0.54
4SG	–11.34	0.78	0.25	0.44

Note: Where no models are available, Equation 12-27 is used.

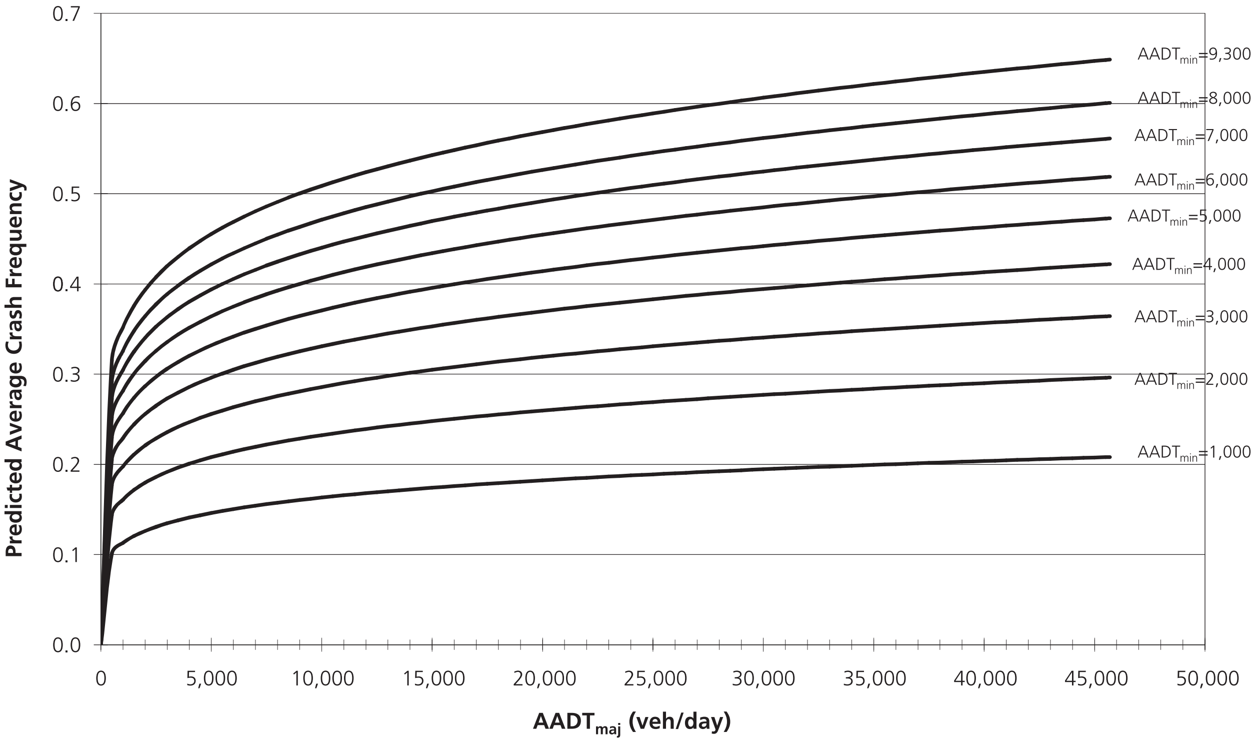

Figure 12-14. Graphical Form of the Intersection SPF for Single-Vehicle Crashes on Three-Leg Intersections with Minor-Road Stop Control (3ST) (from Equation 12-24 and Table 12-12)

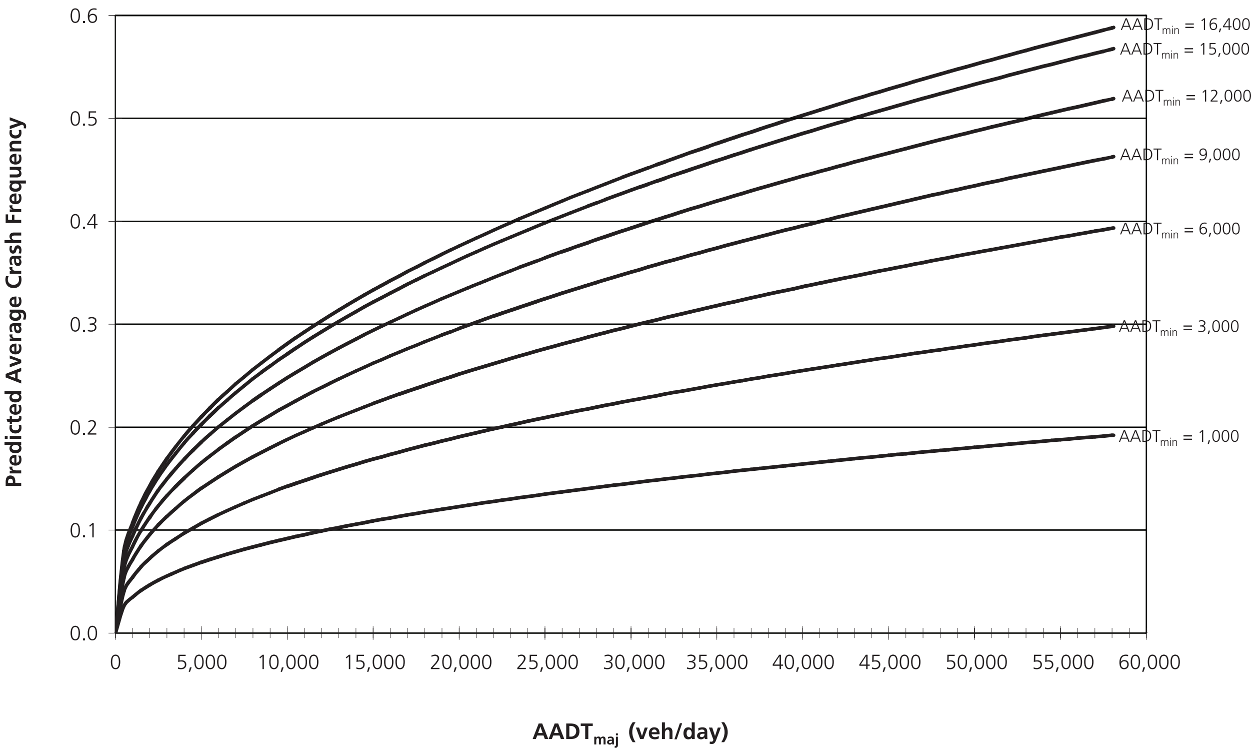

Figure 12-15. Graphical Form of the Intersection SPF for Single-Vehicle Crashes on Three-Leg Signalized Intersections (3SG) (from Equation 12-24 and Table 12-12)

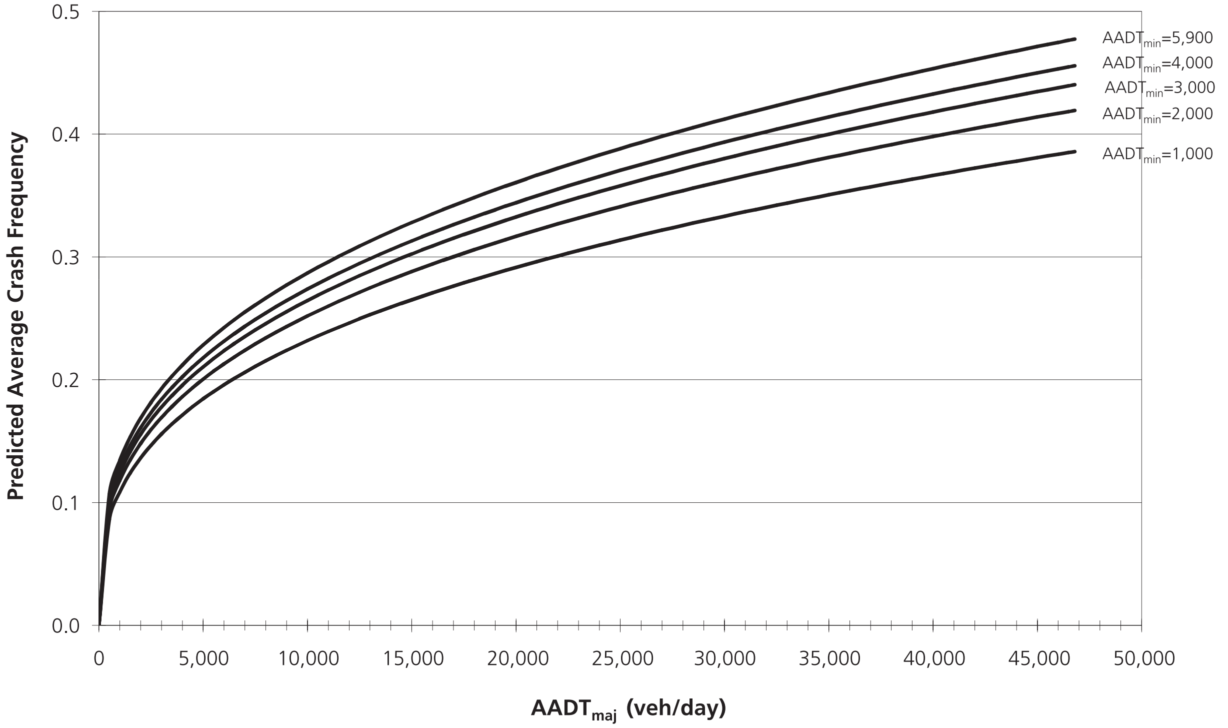

Figure 12-16. Graphical Form of the Intersection SPF for Single-Vehicle Crashes on Four-Leg Stop Controlled Intersections (4ST) (from Equation 12-24 and Table 12-12)

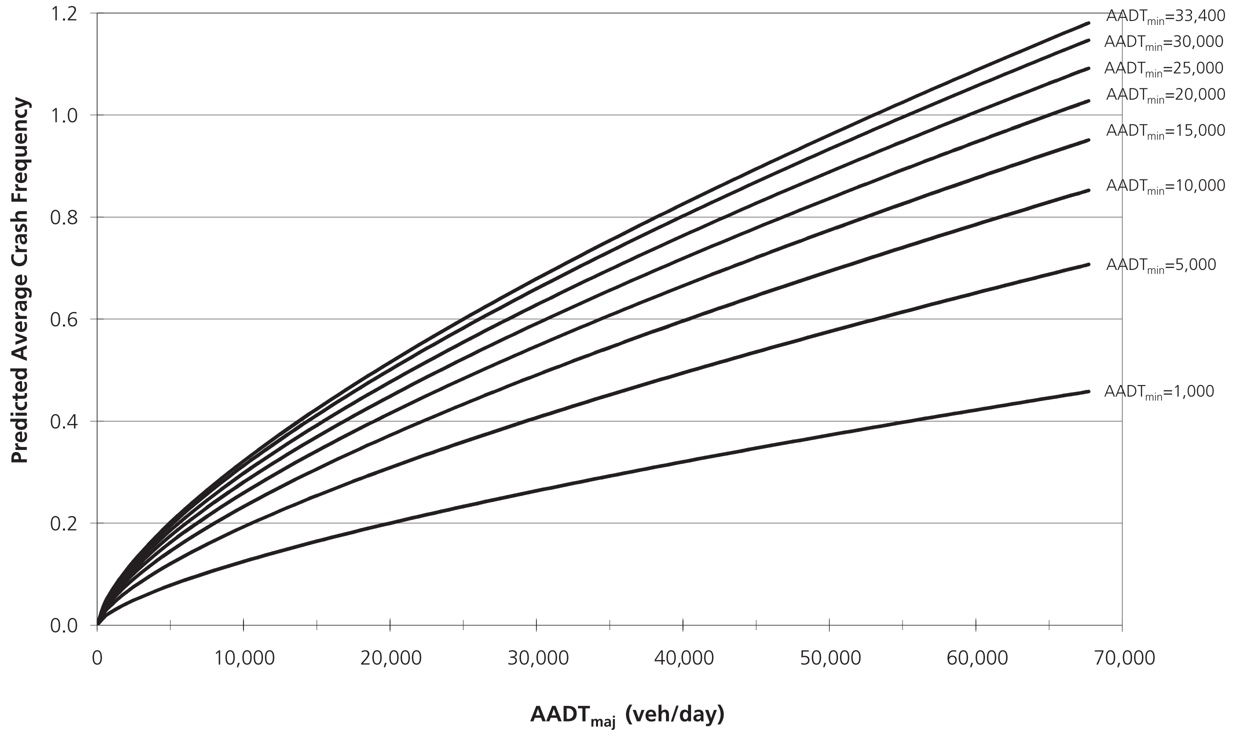

Figure 12-17. Graphical Form of the Intersection SPF for Single-Vehicle Crashes on Four-Leg Signalized Intersections (4SG) (from Equation 12-24 and Table 12-12)

The proportions in Table 12-13 are used to separate $N_{bisv(FI)}$ and $N_{bisv(PDO)}$ into components by crash type.

Table 12-13. Distribution of Single-Vehicle Crashes for Intersection by Collision Type

	Proportion of Crashes by Severity Level for Specific Road Types							
	3ST		3SG		4ST		4SG	
Crash Type	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**	**FI**	**PDO**
Collision with parked vehicle	0.001	0.003	0.001	0.001	0.001	0.001	0.001	0.001
Collision with animal	0.003	0.018	0.001	0.003	0.001	0.026	0.002	0.002
Collision with fixed object	0.762	0.834	0.653	0.895	0.679	0.847	0.744	0.870
Collision with other object	0.090	0.092	0.091	0.069	0.089	0.070	0.072	0.070
Other single-vehicle collision	0.039	0.023	0.045	0.018	0.051	0.007	0.040	0.023
Noncollision	0.105	0.030	0.209	0.014	0.179	0.049	0.141	0.034

Source: HSIS data for California (2002–2006)

Since there are no models for fatal-and-injury crashes at three- and four-leg stop-controlled intersections in Table 12-12, Equation 12-25 is replaced with the following equation in these cases:

$$N_{bisv(FI)} = N_{bisv(\text{total})} \times f_{bisv} \tag{12-27}$$

Where:

f_{bisv} = proportion of fatal-and-injury crashes for combined sites.

The default value of f_{bisv} in Equation 12-27 is 0.31 for 3ST and 0.28 for 4ST intersections. It is recommended that these default values be updated based on locally available data.

SPFs for Vehicle-Pedestrian Collisions

Separate SPFs are provided for estimation of the number of vehicle-pedestrian collisions at signalized and unsignalized intersections.

SPFs for Signalized Intersections

The number of vehicle-pedestrian collisions per year at a signalized intersection is estimated with a SPF and a set of CMFs that apply specifically to vehicle-pedestrian collisions. The model for estimating vehicle-pedestrian collisions at signalized intersections is:

$$N_{pedi} = N_{pedbase} \times CMF_{1p} \times CMF_{2p} \times CMF_{3p} \tag{12-28}$$

Where:

$N_{pedbase}$ = predicted number of vehicle-pedestrian collisions per year for base conditions at signalized intersections; and

$CMF_{1p}...CMF_{3p}$ = crash modification factors for vehicle-pedestrian collisions at signalized intersections.

The SPF for vehicle-pedestrian collisions at signalized intersections is:

$$N_{pedbase} = \exp\left(a + b \times In(AADT_{total}) + c \times In\left(\frac{AADT_{min}}{AADT_{maj}}\right) + d \times In(PedVol) + e \times n_{lanesx}\right) \tag{12-29}$$

Where:

$AADT_{total}$ = sum of the average daily traffic volumes (vehicles per day) for the major and minor roads (= $AADT_{maj} + AADT_{min}$);

PedVol = sum of daily pedestrian volumes (pedestrians/day) crossing all intersection legs;

n_{lanesx} = maximum number of traffic lanes crossed by a pedestrian in any crossing maneuver at the intersection considering the presence of refuge islands; and

a, *b*, *c*, *d*, *e* = regression coefficients.

Determination of values for $AADT_{maj}$ and $AADT_{min}$ is addressed in the discussion of Step 3. Only pedestrian crossing maneuvers immediately adjacent to the intersection (e.g., at a marked crosswalk or along the extended path of any sidewalk present) are considered in determining the pedestrian volumes. Table 12-14 presents the values of the coefficients *a*, *b*, *c*, *d*, and *e* used in applying Equation 12-29.

The coefficient values in Table 12-14 are intended for estimating total vehicle-pedestrian collisions. All vehicle-pedestrian collisions are considered to be fatal-and-injury crashes.

The application of Equation 12-29 requires data on the total pedestrian volumes crossing the intersection legs. Reliable estimates will be obtained when the value of PedVol in Equation 12-29 is based on actual pedestrian volume counts. Where pedestrian volume counts are not available, they may be estimated using Table 12-15. Replacing the values in Table 12-15 with locally derived values is encouraged.

The value of n_{lanesx} in Equation 12-29 represents the maximum number of traffic lanes that a pedestrian must cross in any crossing maneuver at the intersection. Both through and turning lanes that are crossed by a pedestrian along the crossing path are considered. If the crossing path is broken by an island that provides a suitable refuge for the pedestrian so that the crossing may be accomplished in two (or more) stages, then the number of lanes crossed in each stage is considered separately. To be considered as a suitable refuge, an island must be raised or depressed; a flush or painted island is not treated as a refuge for purposes of determining the value of nlanesx.

Table 12-14. SPFs for Vehicle-Pedestrian Collisions at Signalized Intersections

	Coefficients used in Equation 12-29					
Intersection Type	**Intercept (a)**	**AADTtotal (b)**	**$AADT_{min}/AADT_{maj}$ (c)**	**PedVol (d)**	**n_{lanesx} (e)**	**Overdispersion Parameter (k)**
Total crashes						
3SG	–6.60	0.05	0.24	0.41	0.09	0.52
4SG	–9.53	0.40	0.26	0.45	0.04	0.24

Table 12-15. Estimates of Pedestrian Crossing Volumes Based on General Level of Pedestrian Activity

	Estimate of PedVol (pedestrians/day) for Use in Equation 12-29	
General Level of Pedestrian Activity	**3SG Intersections**	**4SG Intersections**
High	1,700	3,200
Medium-high	750	1,500
Medium	400	700
Medium-low	120	240
Low	20	50

SPFs for Stop-Controlled Intersections

The number of vehicle-pedestrian collisions per year for a stop-controlled intersection is estimated as:

$$N_{pedi} = N_{bi} \times f_{pedi} \tag{12-30}$$

Where:

f_{pedi} = pedestrian crash adjustment factor.

The value of N_{bi} used in Equation 12-30 is that determined with Equation 12-6.

Table 12-16 presents the values of fpedi for use in Equation 12-30. All vehicle-pedestrian collisions are considered to be fatal-and-injury crashes. The values of f_{pedi} are likely to depend on the climate and walking environment in particular states or communities. HSM users are encouraged to replace the values in Table 12-16 with suitable values for their own state or community through the calibration process (see Part C, Appendix A).

Table 12-16. Pedestrian Crash Adjustment Factors for Stop-Controlled Intersections

Intersection Type	Pedestrian Crash Adjustment Factor (f_{pedi})
3ST	0.021
4ST	0.022

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All pedestrian collisions resulting from this adjustment factor are treated as fatal-and-injury crashes and none as property-damage-only crashes.
Source: HSIS data for California (2002–2006)

Vehicle-Bicycle Collisions

The number of vehicle-bicycle collisions per year for an intersection is estimated as:

$$N_{bikei} = N_{bi} \times f_{bikei} \tag{12-31}$$

Where:

f_{bikei} = bicycle crash adjustment factor.

The value of N_{bi} used in Equation 12-31 is determined with Equation 12-6.

Table 12-17 presents the values of f_{bikei} for use in Equation 12-31. All vehicle-bicycle collisions are considered to be fatal-and-injury crashes. The values of f_{bikei} are likely to depend on the climate and bicycling environment in particular states or communities. HSM users are encouraged to replace the values in Table 12-17 with suitable values for their own state or community through the calibration process (see Part C, Appendix A).

Table 12-17. Bicycle Crash Adjustment Factors for Intersections

Intersection Type	Bicycle Crash Adjustment Factor (f_{bikei})
3ST	0.016
3SG	0.011
4ST	0.018
4SG	0.015

Note: These factors apply to the methodology for predicting total crashes (all severity levels combined). All bicycle collisions resulting from this adjustment factor are treated as fatal-and-injury crashes and none as property-damage-only crashes. Source: HSIS data for California (2002–2006)

12.7. CRASH MODIFICATION FACTORS

In Step 10 of the predictive method shown in Section 12.4, crash modification factors are applied to the selected safety performance function (SPF), which was selected in Step 9. SPFs provided in Chapter 12 are presented in Section 12.6. A general overview of crash modification factors (CMFs) is presented in Section 3.5.3. The Part C—Introduction and Applications Guidance provides further discussion on the relationship of CMFs to the predictive method. This section provides details of the specific CMFs applicable to the SPFs presented in Section 12.6.

Crash modification factors (CMFs) are used to adjust the SPF estimate of predicted average crash frequency for the effect of individual geometric design and traffic control features, as shown in the general predictive model for Chapter 12 shown in Equation 12-1. The CMF for the SPF base condition of each geometric design or traffic control feature has a value of 1.00. Any feature associated with higher crash frequency than the base condition has a CMF with a value greater than 1.00; any feature associated with lower crash frequency than the base condition has a CMF with a value less than 1.00.

The CMFs used in Chapter 12 are consistent with the CMFs in Part D, although they have, in some cases, been expressed in a different form to be applicable to the base conditions of the SPFs. The CMFs presented in Chapter 12 and the specific SPFs which they apply to are summarized in Table 12-18.

Table 12-18. Summary of CMFs in Chapter 12 and the Corresponding SPFs

Applicable SPF	CMF	CMF Description	CMF Equations and Tables
Roadway Segments	CMF_{1r}	On-Street Parking	Equation 12-32 and Table 12-19
	CMF_{2r}	Roadside Fixed Objects	Equation 12-33 and Tables 12-20 and 12-21
	CMF_{3r}	Median Width	Table 12-22
	CMF_{4r}	Lighting	Equation 12-34 and Table 12-23
	CMF_{5r}	Automated Speed Enforcement	See text
Multiple-Vehicle Collisions and Single-Vehicle Crashes at Intersections	CMF_{1i}	Intersection Left-Turn Lanes	Table 12-24
	CMF_{2i}	Intersection Left-Turn Signal Phasing	Table 12-25
	CMF_{3i}	Intersection Right-Turn Lanes	Table 12-26
	CMF_{4i}	Right-Turn-on-Red	Equation 12-35
	CMF_{5i}	Lighting	Equation 12-36 and Table 12-27
	CMF_{6i}	Red-Light Cameras	Equations 12-37, 12-38, 12-39
Vehicle-Pedestrian Collisions at Signalized Intersections	CMF_{1p}	Bus Stops	Table 12-28
	CMF_{2p}	Schools	Table 12-29
	CMF_{3p}	Alcohol Sales Establishments	Table 12-30

12.7.1. Crash Modification Factors for Roadway Segments

The CMFs for geometric design and traffic control features of urban and suburban arterial roadway segments are presented below. These CMFs are determined in Step 10 of the predictive method and used in Equation 12-3 to adjust the SPF for urban and suburban arterial roadway segments to account for differences between the base conditions and the local site conditions.

CMF_{1r}—On-Street Parking

The CMF for on-street parking, where present, is based on research by Bonneson (1). The base condition is the absence of on-street parking on a roadway segment. The CMF is determined as:

$$CMF_{1r} = 1 + p_{pk} \times (f_{pk} - 1.0) \tag{12-32}$$

Where:

CMF_{1r} = crash modification factor for the effect of on-street parking on total crashes;

f_{pk} = factor from Table 12-19;

p_{pk} = proportion of curb length with on-street parking = ($0.5\ L_{pk}/L$); and

L_{pk} = sum of curb length with on-street parking for both sides of the road combined (miles); and

L = length of roadway segment (miles).

This CMF applies to total roadway segment crashes.

The sum of curb length with on-street parking (L_{pk}) can be determined from field measurements or video log review to verify parking regulations. Estimates can be made by deducting from twice the roadway segment length allowances for intersection widths, crosswalks, and driveway widths.

Table 12-19. Values of f_{pk} Used in Determining the Crash Modification Factor for On-Street Parking

	Type of Parking and Land Use			
	Parallel Parking		Angle Parking	
Road Type	Residential/Other	Commercial or Industrial/Institutional	Residential/Other	Commercial or Industrial/Institutional
2U	1.465	2.074	3.428	4.853
3T	1.465	2.074	3.428	4.853
4U	1.100	1.709	2.574	3.999
4D	1.100	1.709	2.574	3.999
5T	1.100	1.709	2.574	3.999

CMF_{2r}—Roadside Fixed Objects

The base condition is the absence of roadside fixed objects on a roadway segment. The CMF for roadside fixed objects, where present, has been adapted from the work of Zegeer and Cynecki (15) on predicting utility pole crashes. The CMF is determined with the following equation:

$$CMF_{2r} = f_{\text{offset}} \times D_{fo} \times p_{fo} + (1.0 - p_{fo}) \tag{12-33}$$

Where:

CMF_{2r} = crash modification factor for the effect of roadside fixed objects on total crashes;

f_{offset} = fixed-object offset factor from Table 12-20;

D_{fo} = fixed-object density (fixed objects/mi) for both sides of the road combined; and

p_{fo} = fixed-object collisions as a proportion of total crashes from Table 12-21.

This CMF applies to total roadway segment crashes. If the computed value of CMF_{2r} is less than 1.00, it is set equal to 1.00. This can only occur for very low fixed object densities.

In estimating the density of fixed objects (D_{fo}), only point objects that are 4 inches or more in diameter and do not have breakaway design are considered. Point objects that are within 70 ft of one another longitudinally along the road are counted as a single object. Continuous objects that are not behind point objects are counted as one point object for each 70 ft of length. The offset distance (O_{fo}) shown in Table 12-20 is an estimate of the average distance from the edge of the traveled way to roadside objects over an extended roadway segment. If the average offset to fixed objects exceeds 30 ft, use the value of foffset for 30 ft. Only fixed objects on the roadside on the right side of the roadway in each direction of travel are considered; fixed objects in the roadway median on divided arterials are not considered.

Table 12-20. Fixed-Object Offset Factor

Offset to Fixed Objects (O_{fo}) (ft)	Fixed-Object Offset Factor (f_{offset})
2	0.232
5	0.133
10	0.087
15	0.068
20	0.057
25	0.049
30	0.044

Table 12-21. Proportion of Fixed-Object Collisions

Road Type	Proportion of Fixed-Object Collisions (p_{fo})
2U	0.059
3T	0.034
4U	0.037
4D	0.036
5T	0.016

CMF_{3r}—Median Width

A CMF for median widths on divided roadway segments of urban and suburban arterials is presented in Table 12-22 based on the work of Harkey et al. (6). The base condition for this CMF is a median width of 15 ft. The CMF applies to total crashes and represents the effect of median width in reducing cross-median collisions; the CMF assumes that nonintersection collision types other than cross-median collusions are not affected by median width. The CMF in Table 12-22 has been adapted from the CMF in Table 13-12 based on the estimate by Harkey et al. (6) that cross-median collisions represent 12.0 percent of crashes on divided arterials.

This CMF applies only to traversable medians without traffic barriers; it is not applicable to medians serving as TWLTLs (a CMF for TWLTLs is provided in Chapter 16). The effect of traffic barriers on safety would be expected to be a function of barrier type and offset, rather than the median width; however, the effects of these factors on safety have not been quantified. Until better information is available, a CMF value of 1.00 is used for medians with traffic barriers. The value of this CMF is 1.00 for undivided facilities.

Table 12-22. CMFs for Median Widths on Divided Roadway Segments without a Median Barrier (CMF_{3r})

Median Width (ft)	CMF
10	1.01
15	1.00
20	0.99
30	0.98
40	0.97
50	0.96
60	0.95
70	0.94
80	0.93
90	0.93
100	0.92

CMF_{4r}—Lighting

The base condition for lighting is the absence of roadway segment lighting (CMF_{4r} = 1.00). The CMF for lighted roadway segments is determined, based on the work of Elvik and Vaa (3), as:

$$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr})) \tag{12-34}$$

Where:

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

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

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

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

CMF_{4r} applies to total roadway segment crashes. Table 12-23 presents default values for the nighttime crash proportions p_{inr}, p_{pnr}, and p_{nr}. Replacement of the estimates in Table 12-23 with locally derived values is encouraged. If lighting installation increases the density of roadside fixed objects, the value of CMF_{2r} is adjusted accordingly.

Table 12-23. Nighttime Crash Proportions for Unlighted Roadway Segments

	Proportion of Total Nighttime Crashes by Severity Level		Proportion of Crashes that Occur at Night
Roadway Segment Type	Fatal and Injury p_{inr}	PDO p_{pnr}	p_{nr}
2U	0.424	0.576	0.316
3T	0.429	0.571	0.304
4U	0.517	0.483	0.365
4D	0.364	0.636	0.410
5T	0.432	0.568	0.274

CMF_{5r}—Automated Speed Enforcement

Automated speed enforcement systems use video or photographic identification in conjunction with radar or lasers to detect speeding drivers. These systems automatically record vehicle identification information without the need for police officers at the scene. The base condition for automated speed enforcement is that it is absent. Chapter 17 presents a CMF of 0.83 for the reduction of all types of fatal-and-injury crashes from implementation of automated speed enforcement. This CMF is assumed to apply to roadway segments between intersections with fixed camera sites where the camera is always present or where drivers have no way of knowing whether the camera is present or not. No information is available on the effect of automated speed enforcement on noninjury crashes. With the conservative assumption that automated speed enforcement has no effect on noninjury crashes, the value of the CMF for automated speed enforcement would be 0.95.

12.7.2. Crash Modification Factors for Intersections

The effects of individual geometric design and traffic control features of intersections are represented in the predictive models by CMFs. CMF_{1i} through CMF_{4i} are applied to multiple-vehicle collisions and single-vehicle crashes at intersections, but not to vehicle-pedestrian and vehicle-bicycle collisions. CMF_{1p} through CMF_{3p} are applied to vehicle-pedestrian collisions at four-leg signalized intersections (4SG), but not to multiple-vehicle collisions and single-vehicle crashes and not to other intersection types.

CMF_{1i}—Intersection Left-Turn Lanes

The base condition for intersection left-turn lanes is the absence of left-turn lanes on the intersection approaches. The CMFs for presence of left-turn lanes are presented in Table 12-24. These CMFs apply to installation of left-turn lanes on any approach to a signalized intersection but only on uncontrolled major-road approaches to stop-controlled intersections. The CMFs for installation of left-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF for installation of a left-turn lane on one approach raised to a power equal to the number of approaches with left-turn lanes. There is no indication of any change in crash frequency for providing a left-turn lane on an approach controlled by a stop sign, so the presence of a left-turn lane on a stop-controlled approach is not considered in applying Table 12-24. The CMFs in the table apply to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions). The CMFs for installation of left-turn lanes are based on research by Harwood et al. (7). A CMF of 1.00 is always used when no left-turn lanes are present.

Table 12-24. Crash Modification Factor (CMF_{1i}) for Installation of Left-Turn Lanes on Intersection Approaches

		Number of Approaches with Left-Turn Lanes[a]			
Intersection Type	**Intersection Traffic Control**	**One Approach**	**Two Approaches**	**Three Approaches**	**Four Approaches**
Three-leg intersection	Minor-road stop control[b]	0.67	0.45	—	—
	Traffic signal	0.93	0.86	0.80	—
Four-leg intersection	Minor-road stop control[b]	0.73	0.53	—	—
	Traffic signal	0.90	0.81	0.73	0.66

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

CMF_{2i}—Intersection Left-Turn Signal Phasing

The CMF for left-turn signal phasing is based on the results of work by Hauer (10), as modified in a study by Lyon et al. (11). Types of left-turn signal phasing considered include permissive, protected, protected/permissive, and permissive/protected. Protected/permissive operation is also referred to as a leading left-turn signal phase; permissive/protected operation is also referred to as a lagging left-turn signal phase. The CMF values are presented in Table 12-25. The base condition for this CMF is permissive left-turn signal phasing. This CMF applies to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions) and is applicable only to signalized intersections. A CMF value of 1.00 is always used for unsignalized intersections.

If several approaches to a signalized intersection have left-turn phasing, the values of CMF_{2i} for each approach are multiplied together.

Table 12-25. Crash Modification Factor (CMF_{2i}) for Type of Left-Turn Signal Phasing

Type of Left-Turn Signal Phasing	CMF_{2i}
Permissive	1.00
Protected/permissive or permissive/protected	0.99
Protected	0.94

Note: Use CMF_{2i} = 1.00 for all unsignalized intersections. If several approaches to a signalized intersection have left-turn phasing, the values of CMF2i for each approach are multiplied together.

CMF_{3i}—Intersection Right-Turn Lanes

The base condition for intersection right-turn lanes is the absence of right-turn lanes on the intersection approaches. The CMFs for presence of right-turn lanes based on research by Harwood et al. (7) are presented in Table 12-26. These CMFs apply to installation of right-turn lanes on any approach to a signalized intersection, but only on uncontrolled major-road approaches to stop-controlled intersections. The CMFs for installation of right-turn lanes on multiple approaches to an intersection are equal to the corresponding CMF for installation of a right-turn lane on one approach raised to a power equal to the number of approaches with right-turn lanes. There is no indication of any change in crash frequency for providing a right-turn lane on an approach controlled by a stop sign, so the presence of a right-turn lane on a stop-controlled approach is not considered in applying Table 12-26.

The CMFs in Table 12-26 apply to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions). A CMF value of 1.00 is always used when no right-turn lanes are present. This CMF applies only to right-turn lanes that are identified by marking or signing. The CMF is not applicable to long tapers, flares, or paved shoulders that may be used informally by right-turn traffic.

Table 12-26. Crash Modification Factor (CMF_{3i}) for Installation of Right-Turn Lanes on Intersection Approaches

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

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

CMF_{4i}—Right-Turn-on-Red

The CMF for prohibiting right-turn-on-red on one or more approaches to a signalized intersection has been derived from a study by Clark (2) and from the CMFs for right-turn-on-red operation shown in Chapter 14. The base condition for CMF_{4i} is permitting a right-turn-on-red at all approaches to a signalized intersection. The CMF is determined as:

$$CMF_{4i} = 0.98^{(n_{prohib})} \tag{12-35}$$

Where:

CMF_{4i} = crash modification factor for the effect of prohibiting right turns on red on total crashes; and

n_{prohib} = number of signalized intersection approaches for which right-turn-on-red is prohibited.

This CMF applies to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions) and is applicable only to signalized intersections. A CMF value of 1.00 is used for unsignalized intersections.

CMF_{5i}—Lighting

The base condition for lighting is the absence of intersection lighting. The CMF for lighted intersections is adapted from the work of Elvik and Vaa (3), as:

$$CMF_{5i} = 1 - 0.38 \times p_{ni} \tag{12-36}$$

Where:

CMF_{5i} = crash modification factor for the effect of intersection lighting on total crashes; and

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

This CMF applies to total intersection crashes (not including vehicle-pedestrian and vehicle-bicycle collisions). Table 12-27 presents default values for the nighttime crash proportion, p_{ni}. HSM users are encouraged to replace the estimates in Table 12-27 with locally derived values.

Table 12-27. Nighttime Crash Proportions for Unlighted Intersections

Intersection Type	Proportion of Crashes that Occur at Night p_{ni}
3ST	0.238
4ST	0.229
3SG and 4SG	0.235

CMF_{6i}—Red-Light Cameras

The base condition for red light cameras is their absence. The CMF for installation of a red light camera for enforcement of red signal violations at a signalized intersection is based on an evaluation by Persaud et al. (12). As shown in Chapter 14, this study indicates a CMF for red light camera installation of 0.74 for right-angle collisions and a CMF of 1.18 for rear-end collisions. In other words, red light cameras would typically be expected to reduce right-angle collisions and increase rear-end collisions. There is no evidence that red light camera installation affects other collision types. Therefore, a CMF for the effect of red light camera installation on total crashes can be computed with the following equations:

$$CMF_{6i} = 1 - p_{ra} \times (1 - 0.74) - p_{re} \times (1 - 1.18) \tag{12-37}$$

$$p_{ra} = \frac{p_{ramv(FI)} \times N_{bimv(FI)} + p_{ramv(PDO)} \times N_{bimv(PDO)}}{(N_{bimv(FI)} + N_{bimv(PDO)} + N_{bisv})} \tag{12-38}$$

$$p_{re} = \frac{p_{remv(FI)} \times N_{bimv(FI)} + p_{remv(PDO)} \times N_{bimv(PDO)}}{(N_{bimv(FI)} + N_{bimv(PDO)} + N_{bisv})} \tag{12-39}$$

Where:

CMF_{6i} = crash modification factor for installation of red light cameras at signalized intersections;

p_{ra} = proportion of crashes that are multiple-vehicle, right-angle collisions;

p_{re} = proportion of crashes that are multiple-vehicle, rear-end collisions;

$p_{ramv(FI)}$ = proportion of multiple-vehicle fatal-and-injury crashes represented by right-angle collisions;

$p_{ramv(PDO)}$ = proportion of multiple-vehicle property-damage-only crashes represented by right-angle collisions;

$p_{remv(FI)}$ = proportion of multiple-vehicle fatal-and-injury crashes represented by rear-end collisions; and

$p_{remv(PDO)}$ = proportion of multiple-vehicle property-damage-only crashes represented by rear-end collisions.

The values of $N_{bimv(FI)}$ is available from Equation 12-22, the value of $N_{bimv(PDO)}$ is available from Equation 12-23, and the value of N_{bisv} is available from Equation 12-24. The values of $p_{ramv(FI)}$, $p_{ramv(PDO)}$, $p_{remv(FI)}$, and $p_{remv(PDO)}$ can be determined from data for the applicable intersection type in Table 12-11. The values in Table 12-11 may be updated with data for a particular jurisdiction as part of the calibration process presented in Part C, Appendix A. The data in Table 12-11, by definition, represent average values for a broad range of signalized intersections. Because jurisdictions are likely to implement red-light cameras at intersections with higher than average proportions of right-angle collisions, it is acceptable to replace the values in Table 12-11 with estimate based on data for a specific intersection when determining the value of the red light camera CMF.

12.7.3. Crash Modification Factors for Vehicle-Pedestrian Collisions at Signalized Intersections

The CMFs for vehicle-pedestrian collisions at signalized intersections are presented below.

CMF_{1p}—Bus Stops

The CMFs for the number of bus stops within 1,000 ft of the center of the intersection are presented in Table 12-28. The base condition for bus stops is the absence of bus stops near the intersection. These CMFs apply to total vehicle-pedestrian collisions and are based on research by Harwood et al. (8).

Table 12-28. Crash Modification Factor (CMF_{1p}) for the Presence of Bus Stops near the Intersection

Number of Bus Stops within 1,000 ft of the Intersection	CMF_{1p}
0	1.00
1 or 2	2.78
3 or more	4.15

In applying Table 12-28, multiple bus stops at the same intersection (i.e., bus stops in different intersection quadrants or located some distance apart along the same intersection leg) are counted separately. Bus stops located at adjacent intersections would also be counted as long as any portion of the bus stop is located within 1,000 ft of the intersection being evaluated.

CMF_{2p}—Schools

The base condition for schools is the absence of a school near the intersection. The CMF for schools within 1,000 ft of the center of the intersection is presented in Table 12-29. A school may be counted if any portion of the school grounds is within 1,000 ft of the intersection. Where one or more schools are located near the intersection, the value of the CMF is independent of the number of schools present. This CMF applies to total vehicle-pedestrian collisions and is based on research by Harwood et al. (8).

This CMF indicates that an intersection with a school nearby is likely to experience more vehicle-pedestrian collisions than an intersection without schools even if the traffic and pedestrian volumes at the two intersections are identical. Such increased crash frequencies indicate that school children are at higher risk than other pedestrians.

Table 12-29. Crash Modification Factor (CMF_{2p}) for the Presence of Schools near the Intersection

Presence of Schools within 1,000 ft of the Intersection	CMF_{2p}
No school present	1.00
School present	1.35

CMF_{3p}—Alcohol Sales Establishments

The base condition for alcohol sales establishments is the absence of alcohol sales establishments near the intersection. The CMF for the number of alcohol sales establishments within 1,000 ft of the center of an intersection is presented in Table 12-30. Any alcohol sales establishment wholly or partly within 1,000 ft of the intersection may be counted. The CMF applies to total vehicle-pedestrian collisions and is based on research by Harwood et al. (8).

This CMF indicates that an intersection with alcohol sales establishments nearby is likely to experience more vehicle-pedestrian collisions than an intersection without alcohol sales establishments even if the traffic and pedestrian volumes at the two intersections are identical. This indicates the likelihood of higher risk behavior on the part of either pedestrians or drivers near alcohol sales establishments. The CMF includes any alcohol sales establishment which may include liquor stores, bars, restaurants, convenience stores, or grocery stores. Alcohol sales establishments are counted if they are on any intersection leg or even on another street, as long as they are within 1,000 ft of the intersection being evaluated.

Table 12-30. Crash Modification Factor (CMF_{3p}) for the Number of Alcohol Sales Establishments near the Intersection

Number of Alcohol Sales Establishments within 1,000 ft of the Intersection	CMF_{3p}
0	1.00
1–8	1.12
9 or more	1.56

12.8. CALIBRATION OF THE SPFS TO LOCAL CONDITIONS

In Step 10 of the predictive method, presented in Section 12.4, the predictive model is calibrated to local state or geographic conditions. Crash frequencies, even for nominally similar roadway segments or intersections, can vary widely from one jurisdiction to another. Geographic regions differ markedly in climate, animal population, driver populations, crash reporting threshold, and crash reporting practices. These variations may result in some jurisdictions experiencing a different number of reported traffic crashes on urban and suburban arterial highways than others. Calibration factors are included in the methodology to allow highway agencies to adjust the SPFs to match actual local conditions.

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

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

12.9. INTERIM PREDICTIVE METHOD FOR ROUNDABOUTS

Sufficient research has not yet been conducted to form the basis for development of a predictive method for roundabouts. Since many jurisdictions are planning projects to convert existing intersections into modern roundabouts, an interim predictive method is presented here. This interim procedure is applicable to a location at which a modern roundabout has been constructed or is being planned to replace an existing intersection with minor-road stop control or an existing signalized intersection. The interim procedure is:

1. Apply the predictive method from Chapter 12 to estimate the crash frequency, N_{int}, for the existing intersection.

2. Multiply N_{int} by the appropriate CMF from Chapter 12 for conversion on an existing intersection to a modern roundabout. The applicable CMFs are:
   - 0.56 for conversion of a two-way stop-controlled intersection to a modern roundabout.
   - 0.52 for conversion of a signalized intersection to a modern roundabout.

These CMFs are applicable to all crash severities and collision types for both one- and two-lane roundabouts in all settings.

At present, there are no available SPFs to determine predicted average crash frequency of an existing or newly constructed roundabout where no intersection currently exists.

12.10. LIMITATIONS OF PREDICTIVE METHOD IN CHAPTER 12

The limitations of the predictive method which apply generally across all of the Part C chapters are discussed in Section C.8. This section discusses limitations of the specific predictive models and the application of the predictive method in Chapter 12.

Where urban and suburban arterials intersect access-controlled facilities (i.e., freeways), the grade-separated interchange facility, including the arterial facility within the interchange area, cannot be addressed with the predictive method for urban and suburban arterials.

12.11. APPLICATION OF CHAPTER 12 PREDICTIVE METHOD

The predictive method presented in Chapter 12 applies to urban and suburban arterials. The predictive method is applied to by following the 18 steps presented in Section 12.4. Appendix 12A provides a series of worksheets for applying the predictive method and the predictive models detailed in this chapter. All computations within these worksheets are conducted with values expressed to three decimal places. This level of precision is needed for consistency in computations. In the last stage of computation, rounding the final estimate expected average crash frequency to one decimal place.

12.12. SUMMARY

The predictive method is used to estimate the expected average crash frequency for a series of contiguous sites (entire urban or suburban arterial facility), or a single individual site. An urban or suburban facility is defined in Section 12.3.

The predictive method for urban and suburban arterial highways is applied by following the 18 steps of the predictive method presented in Section 12.4. Predictive models, developed for urban and suburban arterial facilities, are applied in Steps 9, 10, and 11 of the method. These models have been developed to estimate the predicted average crash frequency of an individual intersection or homogenous roadway segment. The facility is divided into these individual sites in Step 5 of the predictive method.

Where observed data are available, the EB Method may be applied in Step 13 or 15 of the predictive method to improve the reliability of the estimate. The EB Method can be applied at the site-specific level or at the project specific level. It may also be applied to a future time period if site conditions will not change in the future period. The EB Method is described in Part C, Appendix A.2.

Each predictive model in Chapter 12 consists of a safety performance function (SPF), crash modification factors (CMFs), a calibration factor, and pedestrian and bicyclist factors. The SPF is selected in Step 9 and is used to estimate the predicted average crash frequency for a site with base conditions. This estimate can be for either total crashes or organized by crash-severity or collision-type distribution. In order to account for differences between the base conditions of the SPF and the actual conditions of the local site, CMFs are applied in Step 10 which adjust the predicted number of crashes according the geometric conditions of the site.

In order to account for the differences in state or regional crash frequencies, the SPF is calibrated to the specific state and or geographic region to which they apply. The process for determining calibration factors for the predictive models is described in Part C, Appendix A.1.

Section 12.13 presents six sample problems which detail the application of the predictive method. A series of template worksheets have been developed to assist with applying the predictive method in Chapter 12. These worksheets are utilized to solve the sample problems in Section 12.13, and Appendix 12A contains blank versions of the worksheets.

12.13. SAMPLE PROBLEMS

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

Table 12-31. List of Sample Problems in Chapter 12

Problem No.	Page No.	Description
1	12-49	Predicted average crash frequency for a three-lane TWLTL arterial roadway segment
2	12-63	Predicted average crash frequency for a four-lane divided arterial roadway segment
3	12-74	Predicted average crash frequency for a three-leg stop-controlled intersection
4	12-86	Predicted average crash frequency for a four-leg signalized intersection
5	12-97	Expected average crash frequency for a facility when site-specific observed crash data are available
6	12-101	Expected average crash frequency for a facility when site-specific observed crash data are not available

12.13.1. Sample Problem 1

The Site/Facility

A three-lane urban arterial roadway segment with a center two-way left-turn lane (TWLTL).

The Question

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

The Facts

- 1.5-mi length
- 11,000 veh/day
- 1.0 mi of parallel on-street commercial parking on each side of street
- 30 driveways (10 minor commercial, 2 major residential, 15 minor residential, 3 minor industrial/institutional)

- 10 roadside fixed objects per mile
- 6-ft offset to roadside fixed objects
- Lighting present
- 35-mph posted speed

Assumptions

Collision type distributions used are the default values presented in Tables 12-4 and 12-6 and Equations 12-19 and 12-20.

The calibration factor is assumed to be 1.00.

Results

Using the predictive method steps as outlined below, the predicted average crash frequency for the roadway segment in Sample Problem 1 is determined to be 7.0 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8

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

Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.

For a three-lane urban arterial roadway segment with TWLTL, SPF values for multiple-vehicle nondriveway, single-vehicle, multiple-vehicle driveway-related, vehicle-pedestrian, and vehicle-bicycle collisions are determined. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these models.

Multiple-Vehicle Nondriveway Collisions

The SPF for multiple-vehicle nondriveway collisions for the roadway segment is calculated from Equation 12-10 and Table 12-3 as follows:

$$N_{brmv} = exp(a + b \times In(AADT) + In(L))$$

$$N_{brmv(\text{total})} = exp(-12.40 + 1.41 \times In(11{,}000) + In(1.5))$$

$$= 3.805 \text{ crashes/year}$$

$$N_{brmv(FI)} = \exp(-16.45 + 1.69 \times In(11{,}000) + In(1.5))$$

$$= 0.728 \text{ crashes/year}$$

$$N_{brmv(PDO)} = exp(-11.95 + 1.33 \times In(11{,}000) + In(1.5))$$

$$= 2.298 \text{ crashes/year}$$

These initial values for fatal-and-injury (FI) and property-damage-only (PDO) crashes are then adjusted using Equations 12-11 and 12-12 to assure that they sum to the value for total crashes as follows:

$$N_{brmv(FI)} = N_{brmv(\text{total})}\left(\frac{N'_{brmv(FI)}}{N'_{brmv(FI)} + N'_{brmv(PDO)}}\right)$$

$$= 3.085\left(\frac{0.728}{0.728 + 2.298}\right)$$

$$= 0.742 \text{ crashes/year}$$

$$N_{brmv(PDO)} = N_{brmv(\text{total})} - N_{brmv(FI)}$$

$$= 3.085 - 0.742$$

$$= 2.343 \text{ crashes/year}$$

Single-Vehicle Crashes

The SFP for single-vehicle crashes for the roadway segments is calculated from Equation 12-13 and Table 12-5 as follows:

$$N_{brsv} = exp(a + b \times In(AADT) + In(L))$$

$$N_{brsv(\text{total})} = exp(-5.74 + 0.54 \times In(11{,}000) + In(1.5))$$

$$= 0.734 \text{ crashes/year}$$

$$N_{brsv(FI)} = exp(-6.37 + 0.47 \times In(11{,}000) + In(1.5))$$

$$= 0.204 \text{ crashes/year}$$

$$N_{brsv(PDO)} = exp(-6.29 + 0.56 \times In(11{,}000) + In(1.5))$$

$$= 0.510 \text{ crashes/year}$$

These initial values for fatal-and-injury (FI) and property-damage-only (PDO) crashes are then adjusted using Equations 12-14 and 12-15 to assure that they sum to the value for total crashes as follows:

$$N_{brsv(FI)} = N_{brsv(\text{total})}\left(\frac{N'_{brsv(FI)}}{N'_{brsv(FI)} + N'_{brsv(PDO)}}\right)$$

$$= 0.734 \times \left(\frac{0.204}{0.204 + 0.510}\right)$$

$$= 0.210 \text{ crashes/year}$$

$$N_{brsv(PDO)} = N_{brsv(\text{total})} - N_{brsv(FI)}$$

$$= 0.734 - 0.210$$

$$= 0.524 \text{ crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions

The SPF for multiple-vehicle driveway-related collisions for the roadway segment is calculated from Equation 12-16 as follows:

$$N_{brdwy(\text{total})} = \sum_{\substack{\text{all}\\ \text{driveway}\\ \text{types}}} n_j \times N_j \times \left(\frac{AADT}{15{,}000}\right)^{(t)}$$

The number of driveways within the roadway segment, n_j, for Sample Problem 1 is 10 minor commercial, two major residential, 15 minor residential, and three minor industrial/institutional.

The number of driveway-related collisions, N_j, and the regression coefficient for AADT, t, for a three-lane arterial are provided in Table 12-7.

$$\begin{aligned} N_{brdwy(\text{total})} &= 10 \times 0.032 \times \left(\frac{11{,}000}{15{,}000}\right)^{(1.0)} + 2 \times 0.053 \times \left(\frac{11{,}000}{15{,}000}\right)^{(1.0)} \\ &\quad + 15 \times 0.010 \times \left(\frac{11{,}000}{15{,}000}\right)^{(1.0)} + 3 \times 0.015 \times \left(\frac{11{,}000}{15{,}000}\right)^{(1.0)} \\ &= 0.455 \text{ crashes/year} \end{aligned}$$

Driveway-related collisions can be separated into components by severity level using Equations 12-17 and 12-18 as follows:

From Table 12-7, for a three-lane arterial the proportion of driveway-related collisions that involve fatalities and injuries, $f_{dwy} = 0.243$

$$\begin{aligned} N_{brdwy(FI)} &= N_{brdwy(\text{total})} \times f_{dwy} \\ &= 0.455 \times 0.243 \\ &= 0.111 \text{ crashes/year} \end{aligned}$$

$$\begin{aligned} N_{brdwy(PDO)} &= N_{brdwy(\text{total})} - N_{brdwy(FI)} \\ &= 0.455 - 0.111 \\ &= 0.344 \text{ crashes/year} \end{aligned}$$

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

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

On-Street Parking (CMF_{1r})

CMF_{1r} is calculated from Equation 12-32 as follows:

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

The proportion of curb length with on-street parking, p_{pk}, is determined as follows:

$$p_{pk} = 0.5 \times \frac{L_{pk}}{L}$$

Since 1.0 mile of on-street parking on each side of the road is provided, the sum of curb length with on-street parking for both sides of the road combined, $L_{pk} = 2$.

$$p_{pk} = 0.5 \times \frac{2}{1.5} = 0.66$$

From Table 12-19, $f_{pk} = 2.074$.

$$\begin{aligned} CMF_{1r} &= 1 + 0.66 \times (2.074 - 1.0) \\ &= 1.71 \end{aligned}$$

Roadside Fixed Objects (CMF_{2r})

CMF_{2r} is calculated from Equation 12-33 as follows:

$$CMF_{2r} = f_{\text{offset}} \times D_{fo} \times p_{fo} + (1.0 - p_{fo})$$

From Table 12-20, for a roadside fixed object with a 6-ft offset, the fixed-object offset factor, f_{offset}, is interpolated as 0.124.

From Table 12-21, for a three-lane arterial the proportion of total crashes, p_{fo} = 0.034.

$$CMF_{2r} = 0.124 \times 10 \times 0.034 + (1.0 - 0.034)$$

$$= 1.01$$

Median Width (CMF_{3r})

The value of CMF_{3r} is 1.00 for undivided facilities (see Section 12.7.1). It is assumed that a roadway with TWLTL is undivided.

Lighting (CMF_{4r})

CMF_{4r} is calculated from Equation 12-34 as follows:

$$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr}))$$

For a three-lane arterial, p_{inr} = 0.429, p_{pnr} = 0.571, and p_{nr} = 0.304 (see Table 12-23).

$$CMF_{4r} = 1.0 - (0.304 \times (1.0 - 0.72 \times 0.429 - 0.83 \times 0.571))$$

$$= 0.93$$

Automated Speed Enforcement (CMF_{5r})

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

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

$$CMF_{comb} = 1.71 \times 1.01 \times 0.93$$

$$= 1.61$$

Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions) for SPF base conditions, N_{br}, is calculated first in order to determine vehicle-pedestrian and vehicle-bicycle crashes. N_{br} is determined from Equation 12-3 as follows:

$$N_{br} = N_{spf\,rs} \times (CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{nr})$$

From Equation 12-4, $N_{spf\,rs}$ can be calculated as follows:

$$N_{spf\,rs} = N_{brmv} + N_{brsv} + N_{brdwy}$$

$$= 3.085 + 0.734 + 0.455$$

$$= 4.274 \text{ crashes/year}$$

The combined CMF value for Sample Problem 1 is 1.61.

$$N_{br} = 4.274 \times (1.61)$$
$$= 6.881 \text{ crashes/year}$$

The SPF for vehicle-pedestrian collisions for the roadway segment is calculated from Equation 12-19 as follows:

$$N_{pedr} = N_{br} \times f_{pedr}$$

From Table 12-8, for a posted speed greater than 30 mph on three-lane arterials the pedestrian crash adjustment factor, $f_{pedr} = 0.013$.

$$N_{pedr} = 6.881 \times 0.013$$
$$= 0.089 \text{ crashes/year}$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-20 as follows:

$$N_{biker} = N_{br} \times f_{biker}$$

From Table 12-9, for a posted speed greater than 30 mph on three-lane arterials the bicycle crash adjustment factor, $f_{biker} = 0.007$.

$$N_{biker} = 6.881 \times 0.007$$
$$= 0.048 \text{ crashes/year}$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed in that a calibration factor, C_r, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 12-2 based on the results obtained in Steps 9 through 11 as follows:

$$N_{\text{predicted } rs} = C_r \times (N_{br} + N_{pedr} + N_{biker})$$
$$= 1.00 \times (6.881 + 0.089 + 0.048)$$
$$= 7.018 \text{ crashes/year}$$

WORKSHEETS

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for a roadway segment. To apply the predictive method steps to multiple segments, a series of 12 worksheets are provided for determining the predicted average crash frequency. The 12 worksheets include:

- *Worksheet SP1A (Corresponds to Worksheet 1A)*—General Information and Input Data for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1B (Corresponds to Worksheet 1B)*—Crash Modification Factors for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1C (Corresponds to Worksheet 1C)*—Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1D (Corresponds to Worksheet 1D)*—Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Arterial Roadway Segments

- *Worksheet SP1E (Corresponds to Worksheet 1E)*—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1F (Corresponds to Worksheet 1F)*—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1G (Corresponds to Worksheet 1G)*—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1H (Corresponds to Worksheet 1H)*—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1I (Corresponds to Worksheet 1I)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1J (Corresponds to Worksheet 1J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1K (Corresponds to Worksheet 1K)*—Crash Severity Distribution for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP1L (Corresponds to Worksheet 1L)*—Summary Results for Urban and Suburban Arterial Roadway Segments

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheet SP1A—General Information and Input Data for Urban and Suburban Roadway Segments

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

Worksheet SP1A. General Information and Input Data for Urban and Suburban Roadway Segments

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

Input Data	Base Conditions	Site Conditions
Road type (2U, 3T, 4U, 4D, 5T)	—	3T
Length of segment, L (mi)	—	1.5
AADT (veh/day)	—	11,000
Type of on-street parking (none/parallel/angle)	none	parallel-commercial
Proportion of curb length with on-street parking	—	0.66
Median width (ft)	15	not present
Lighting (present/not present)	not present	present
Auto speed enforcement (present/not present)	not present	not present
Major commercial driveways (number)	—	0
Minor commercial driveways (number)	—	10
Major industrial/institutional driveways (number)	—	0
Minor industrial/institutional driveways (number)	—	3
Major residential driveways (number)	—	2
Minor residential driveways (number)	—	15
Other driveways (number)	—	0
Speed Category	—	intermediate or high speed (>30 mph)
Roadside fixed object density (fixed objects/mi)	not present	10
Offset to roadside fixed objects (ft)	not present	6
Calibration Factor, C_r	1.0	1.0

Worksheet SP1B. Crash Modification Factors for Urban and Suburban Roadway Segments

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 6 of Worksheet SP1B which indicates the combined CMF value.

Worksheet SP1B. Crash Modification Factors for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
CMF for On-Street Parking	CMF for Roadside Fixed Objects	CMF for Median Width	CMF for Lighting	CMF for Auto Speed Enforcement	Combined CMF
CMF_{1r}	CMF_{2r}	CMF_{3r}	CMF_{4r}	CMF_{5r}	CMF_{comb}
from Equation 12-32	from Equation 12-33	from Table 12-22	from Equation 12-34	from Section 12.7.1	(1)*(2)*(3)*(4)*(5)
1.71	1.01	1.00	0.93	1.00	1.61

Worksheet SP1C—Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Roadway Segments

The SPF for multiple-vehicle nondriveway collisions along the roadway segment in Sample Problem 1 is calculated using Equation 12-10 and entered into Column 4 of Worksheet SP1C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 6 in Worksheet SP1B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle nondriveway crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP1C. Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)
	SPF Coefficients		Overdispersion Parameter, k	Initial N_{brmv}
	from Table 12-3			
Crash Severity Level	a	b	from Table 12-3	from Equation 12-10
Total	−12.40	1.41	0.66	3.085
Fatal and injury (FI)	−16.45	1.69	0.59	0.728
Property damage only (PDO)	−11.95	1.33	0.59	2.298

Worksheet SP1C. continued

(1)	(5)	(6)	(7)	(8)	(9)
		Adjusted N_{brmv}	Combined CMFs	Calibration Factor	Predicted N_{brmv}
Crash Severity Level	Proportion of Total Crashes	$(4)_{total}*(5)$	(6) from Worksheet SP1B	C_r	(6)*(7)*(8)
Total	1.000	3.085	1.61	1.00	4.967
Fatal and injury (FI)	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$	0.743	1.61	1.00	1.196
	0.241				
Property damage only (PDO)	$(5)_{total}-(5)_{FI}$	2.342	1.61	1.00	3.771
	0.759				

Worksheet SP1D—Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Roadway Segments

Worksheet SP1D presents the default proportions for collision type (from Table 12-4) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for multiple-vehicle nondriveway crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle nondriveway crashes (from Column 9, Worksheet SP1C) into components by crash severity and collision type.

Worksheet SP1D. Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{brmv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{brmv\ (PDO)}$ (crashes/year)	Predicted $N_{brmv\ (total)}$ (crashes/year)
Collision Type	from Table 12-4	$(9)_{FI}$ from Worksheet SP1C	from Table 12-4	$(9)_{PDO}$ from Worksheet SP1C	$(9)_{total}$ from Worksheet SP1C
Total	1.000	1.196	1.000	3.771	4.967
		$(2)*(3)_{FI}$		$(4)*(5)_{PDO}$	(3)+(5)
Rear-end collision	0.845	1.011	0.842	3.175	4.186
Head-on collision	0.034	0.041	0.020	0.075	0.116
Angle collision	0.069	0.083	0.020	0.075	0.158
Sideswipe, same direction	0.001	0.001	0.078	0.294	0.295
Sideswipe, opposite direction	0.017	0.020	0.020	0.075	0.095
Other multiple-vehicle collision	0.034	0.041	0.020	0.075	0.116

Worksheet SP1E—Single-Vehicle Crashes by Severity Level for Urban and Suburban Roadway Segments

The SPF for single-vehicle crashes along the roadway segment in Sample Problem 1 is calculated using Equation 12-13 and entered into Column 4 of Worksheet SP1E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 6 in Worksheet SP1B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle nondriveway crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP1E. Single-Vehicle Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
	SPF Coefficients		Overdispersion Parameter, k	Initial N_{brsv}		Adjusted N_{brsv}	Combined CMFs	Calibration Factor	Predicted N_{brsv}
	from Table 12-5								
Crash Severity Level	a	b	from Table 12-5	from Equation 12-13	Proportion of Total Crashes	$(4)_{total}*(5)$	(6) from Worksheet SP1B	C_r	(6)*(7)*(8)
Total	−5.74	0.54	1.37	0.734	1.000	0.734	1.61	1.00	1.182
Fatal and injury (FI)	−6.37	0.47	1.06	0.204	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$ 0.286	0.210	1.61	1.00	0.338
Property damage only (PDO)	−6.29	0.56	1.93	0.510	$(5)_{total}-(5)_{FI}$ 0.714	0.524	1.61	1.00	0.844

Worksheet SP1F—Single-Vehicle Crashes by Collision Type for Urban and Suburban Roadway Segments

Worksheet SP1F presents the default proportions for collision type (from Table 12-5) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by collision type is presented in 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and Columns 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 9, Worksheet SP1E) into components by crash severity and collision type.

Worksheet SP1F. Single-Vehicle Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	**Predicted $N_{brsv\ (FI)}$ (crashes/year)**	**Proportion of Collision Type $_{(PDO)}$**	**Predicted $N_{brsv\ (PDO)}$ (crashes/year)**	**Predicted $N_{brsv\ (total)}$ (crashes/year)**
Collision Type	**from Table 12-6**	**$(9)_{FI}$ from Worksheet SP1E**	**from Table 12-6**	**$(9)_{PDO}$ from Worksheet SP1E**	**$(9)_{total}$ from Worksheet SP1E**
Total	1.000	0.338	1.000	0.844	1.182
		$(2)*(3)_{FI}$		$(4)*(5)_{PDO}$	(3)+(5)
Collision with animal	0.001	0.000	0.001	0.001	0.001
Collision with fixed object	0.688	0.233	0.963	0.813	1.046
Collision with other object	0.001	0.000	0.001	0.001	0.001
Other single-vehicle collision	0.310	0.105	0.035	0.030	0.135

Worksheet SP1G—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Roadway Segments

Worksheet SP1G determines and presents the number of driveway-related multiple-vehicle collisions. The number of driveways along both sides of the road is entered in Column 2 by driveway type (Column 1). The associated number of crashes per driveway per year by driveway type as found in Table 12-7 is entered in Column 3. Column 4 contains the regression coefficient for AADT also found in Table 12-7. The initial average crash frequency of multiple-vehicle driveway-related crashes is calculated from Equation 12-16 and entered into Column 5. The overdispersion parameter from Table 12-7 is entered into Column 6; however, the overdispersion parameter is not needed for Sample Problem 1 (as the EB Method is not utilized).

Worksheet SP1G. Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
		Crashes per Driveway per Year, N_j	Coefficient for Traffic Adjustment, t	Initial N_{brdwy}	Overdispersion Parameter, k
Driveway Type	Number of Driveways, n_j	from Table 12-7	from Table 12-7	Equation 12-16 n_j*N_j*(AADT/15,000)t	from Table 12-7
Major commercial	0	0.102	1.000	0.000	—
Minor commercial	10	0.032	1.000	0.235	
Major industrial/institutional	0	0.110	1.000	0.000	
Minor industrial/institutional	3	0.015	1.000	0.033	
Major residential	2	0.053	1.000	0.078	
Minor residential	15	0.010	1.000	0.110	
Other	0	0.016	1.000	0.000	
Total	—	—	—	0.456	1.10

Worksheet SP1H—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Roadway Segments

The initial average crash frequency of multiple-vehicle driveway-related crashes from Column 5 of Worksheet SP1G is entered in Column 2. This value is multiplied by the proportion of crashes by severity (Column 3) found in Table 12-7 and the adjusted value is entered into Column 4. Column 5 represents the combined CMF (from Column 6 in Worksheet SP1B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of multiple-vehicle driveway-related crashes using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SP1H. Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Initial N_{brdwy}	Proportion of Total Crashes (f_{dwy})	Adjusted N_{brdwy}	Combined CMFs		Predicted N_{brdwy}
Crash Severity Level	$(5)_{total}$ from Worksheet SP1G	from Table 12-7	$(2)_{total}$ *(3)	(6) from Worksheet SP1B	Calibration Factor, C_r	(4)*(5)*(6)
Total	0.456	1.000	0.456	1.61	1.00	0.734
Fatal and injury (FI)	—	0.243	0.111	1.61	1.00	0.179
Property damage only (PDO)	—	0.757	0.345	1.61	1.00	0.555

Worksheet SP1I—Vehicle-Pedestrian Collisions for Urban and Suburban Roadway Segments

The predicted average crash frequency of multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related predicted crashes from Worksheets SP1C, SP1E, and SP1H are entered into Columns 2, 3, and 4, respectively. These values are summed in Column 5. Column 6 contains the pedestrian crash adjustment factor (see Table 12-8). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP1I. Vehicle-Pedestrian Collisions for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted N_{brmv}	Predicted N_{brsv}	Predicted N_{brdwy}	Predicted N_{br}	f_{pedr}		Predicted N_{pedr}
Crash Severity Level	(9) from Worksheet SP1C	(9) from Worksheet SP1E	(7) from Worksheet SP1H	(2)+(3)+(4)	from Table 12-8	Calibration Factor, C_r	(5)*(6)*(7)
Total	4.967	1.182	0.734	6.883	0.013	1.00	0.089
Fatal and injury (FI)	—	—	—	—	—	1.00	0.089

Worksheet SP1J—Vehicle-Bicycle Collisions for Urban and Suburban Roadway Segments

The predicted average crash frequency of multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related predicted crashes from Worksheets SP1C, SP1E, and SP1H are entered into Columns 2, 3, and 4, respectively. These values are summed in Column 5. Column 6 contains the bicycle crash adjustment factor (see Table 12-9). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-bicycle collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-bicycle collisions are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP1J. Vehicle-Bicycle Collisions for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted N_{brmv}	Predicted N_{brsv}	Predicted N_{brdwy}	Predicted N_{br}	f_{biker}		Predicted N_{biker}
Crash Severity Level	(9) from Worksheet SP1C	(9) from Worksheet SP1E	(7) from Worksheet SP1H	(2)+(3)+(4)	from Table 12-9	Calibration Factor, C_r	(5)*(6)*(7)
Total	4.967	1.182	0.734	6.883	0.007	1.00	0.048
Fatal and injury	—	—	—	—	—	1.00	0.048

Worksheet SP1K—Crash Severity Distribution for Urban and Suburban Roadway Segments

Worksheet SP1K provides a summary of all collision types by severity level. Values from Worksheets SP1C, SP1E, SP1H, SP1I, and SP1J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP1K. Crash Severity Distribution for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	**Property Damage Only (PDO)**	**Total**
Collision Type	**(3) from Worksheets SP1D and SP1F; (7) from Worksheet SP1H; and (8) from Worksheets SP1I and SP1J**	**(5) from Worksheets SP1D and SP1F; and (7) from Worksheet SP1H**	**(6) from Worksheets SP1D and SP1F; (7) from Worksheet SP1H; and (8) from Worksheets SP1I and SP1J**
MULTIPLE-VEHICLE			
Rear-end collisions (from Worksheet SP1D)	1.011	3.175	4.186
Head-on collisions (from Worksheet SP1D)	0.041	0.075	0.116
Angle collisions (from Worksheet SP1D)	0.083	0.075	0.158
Sideswipe, same direction (from Worksheet SP1D)	0.001	0.294	0.295
Sideswipe, opposite direction (from Worksheet SP1D)	0.020	0.075	0.095
Driveway-related collisions (from Worksheet SP1H)	0.179	0.555	0.734
Other multiple-vehicle collision (from Worksheet SP1D)	0.041	0.075	0.116
Subtotal	1.376	4.324	5.700
SINGLE-VEHICLE			
Collision with animal (from Worksheet SP1F)	0.000	0.001	0.001
Collision with fixed object (from Worksheet SP1F)	0.233	0.813	1.046
Collision with other object (from Worksheet SP1F)	0.000	0.001	0.001
Other single-vehicle collision (from Worksheet SP1F)	0.105	0.030	0.135
Collision with pedestrian (from Worksheet SP1I)	0.089	0.000	0.089
Collision with bicycle (from Worksheet SP1J)	0.048	0.000	0.048
Subtotal	0.475	0.845	1.320
Total	1.851	5.169	7.020

Worksheet SP1L—Summary Results for Urban and Suburban Roadway Segments

Worksheet SP1L presents a summary of the results. Using the roadway segment length and the AADT, the worksheet presents the crash rate in miles per year (Column 4) and in million vehicle miles (Column 6).

Worksheet SP1L. Summary Results for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
	Predicted Average Crash Frequency, $N_{predicted\ rs}$ (crashes/year)		**Crash Rate (crashes/mi/year)**
Crash Severity Level	**(Total) from Worksheet SP1K**	**Roadway Segment Length, L (mi)**	**(2)/(3)**
Total	7.020	1.5	4.7
Fatal and injury (FI)	1.851	1.5	1.2
Property damage only (PDO)	5.169	1.5	3.4

12.13.2. Sample Problem 2

The Highway
A four-lane divided urban arterial roadway segment.

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

The Facts
- 0.75-mi length
- 23,000 veh/day
- On-street parking not permitted
- 8 driveways (1 major commercial, 4 minor commercial, 1 major residential, 1 minor residential, 1 minor industrial/institutional)
- 20 roadside fixed objects per mile
- 12-ft offset to roadside fixed objects
- 40-ft median
- Lighting present
- 30-mph posted speed

Assumptions
Collision type distributions used are the default values presented in Tables 12-4 and 12-6 and Equations 12-19 and 12-20.

The calibration factor is assumed to be 1.00.

Results
Using the predictive method steps as outlined below, the predicted average crash frequency for the roadway segment in Sample Problem 2 is determined to be 3.4 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the roadway segment in Sample Problem 2, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year, and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.
For a four-lane divided urban arterial roadway segment, SPF values for multiple-vehicle nondriveway, single-vehicle, multiple-vehicle driveway-related, vehicle-pedestrian, and vehicle-bicycle collisions are determined. The calculations for total multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related collisions are presented below. Detailed steps for calculating SPFs for fatal-and-injury (FI) and property-damage-only (PDO) crashes are presented in Sample Problem 1. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these two models.

Multiple-Vehicle Nondriveway Collisions
The SPF for multiple-vehicle nondriveway collisions for the roadway segment is calculated from Equation 12-10 and Table 12-3 as follows:

$$N_{brmv} = exp(a + b \times In(AADT) + In(L))$$

$$N_{brmv(\text{total})} = exp(-12.34 + 1.36 \times In(23{,}000) + In(0.75))$$

$$= 2.804 \text{ crashes/year}$$

Single-Vehicle Crashes
The SFP for single-vehicle crashes for the roadway segments is calculated from Equation 12-13 and Table 12-5 as follows:

$$N_{brsv} = exp(a + b \times In(AADT) + In(L))$$

$$N_{brsv(\text{total})} = exp(-5.05 + 0.47 \times In(23{,}000) + In(0.75))$$

$$= 0.539 \text{ crashes/year}$$

Multiple-Vehicle Driveway-Related Collisions
The SPF for multiple-vehicle driveway-related collisions for the roadway segment is calculated from Equation 12-16 as follows:

$$N_{brdwy(\text{total})} = \sum_{\substack{\text{all}\\ \text{driveway}\\ \text{types}}} n_j \times N_j \times \left(\frac{AADT}{15{,}000}\right)^{(t)}$$

The number of driveways within the roadway segment, n_j, for Sample Problem 1 is one major commercial, four minor commercial, one major residential, one minor residential, and one minor industrial/institutional.

The number of driveway-related collisions, N_j, and the regression coefficient for AADT, t, for a four-lane divided arterial, are provided in Table 12-7.

$$N_{brdwy(\text{total})} = 1 \times 0.033 \times \left(\frac{23{,}000}{15{,}000}\right)^{(1.106)} + 4 \times 0.011 \times \left(\frac{23{,}000}{15{,}000}\right)^{(1.106)} + 1 \times 0.018 \times \left(\frac{23{,}000}{15{,}000}\right)^{(1.106)}$$

$$+ 1 \times 0.003 \times \left(\frac{23{,}000}{15{,}000}\right)^{(1.106)} + 1 \times 0.005 \times \left(\frac{23{,}000}{15{,}000}\right)^{(1.106)}$$

$$= 0.165 \text{ crashes/year}$$

The fatal-and-injury (FI) and property-damage-only (PDO) SPF values for multiple-vehicle nondriveway collisions, single-vehicle crashes and multiple-vehicle driveway-related collisions can be determined by using the same procedure presented in Sample Problem 1.

Step 10—Multiply the result obtained in Step 9 by the appropriate CMFs to adjust base conditions to site specific geometric design and traffic control features.
Each CMF used in the calculation of the predicted average crash frequency of the roadway segment is calculated below:

On-Street Parking (CMF_{1r})
Since on-street parking is not permitted, CMF_{1r} = 1.00 (i.e., the base condition for CMF_{1r} is the absence of on-street parking).

Roadside Fixed Objects (CMF_{2r})
CMF_{2r} is calculated from Equation 12-33 as follows:

$$CMF_{2r} = f_{\text{offset}} \times D_{fo} \times p_{fo} + (1.0 - p_{fo})$$

From Table 12-20, for a roadside fixed object with a 12-ft offset, the fixed-object offset factor, f_{offset}, is interpolated as 0.079.

From Table 12-21, for a four-lane divided arterial the proportion of total crashes, $p_{fo} = 0.036$.

$$CMF_{2r} = 0.079 \times 20 \times 0.036 + (1.0 - 0.036)$$

$$= 1.02$$

Median Width (CMF_{3r})

From Table 12-22, for a four-lane divided arterial with a 40-ft median, $CMF_{3r} = 0.97$.

Lighting (CMF_{4r})

CMF_{4r} can be calculated from Equation 12-34 as follows:

$$CMF_{4r} = 1.0 - (p_{nr} \times (1.0 - 0.72 \times p_{inr} - 0.83 \times p_{pnr}))$$

For a four-lane divided arterial, $p_{inr} = 0.364$, $p_{pnr} = 0.636$, and $p_{nr} = 0.410$ (see Table 12-23).

$$CMF_{4r} = 1.0 - (0.410 \times (1.0 - 0.72 \times 0.364 - 0.83 \times 0.636))$$

$$= 0.91$$

Automated Speed Enforcement (CMF_{5r})

Since there is no automated speed enforcement in Sample Problem 2, $CMF_{5r} = 1.00$ (i.e., the base condition for CMF_{5r} is the absent of automated speed enforcement).

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

$$CMF_{comb} = 1.02 \times 0.97 \times 0.91$$

$$= 0.90$$

Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The predicted average crash frequency of an individual roadway segment (excluding vehicle-pedestrian and vehicle-bicycle collisions) for SPF base conditions, N_{br}, is calculated first in order to determine vehicle-pedestrian and vehicle-bicycle crashes. N_{br} is determined from Equation 12-3 as follows:

$$N_{br} = N_{spf\,rs} \times (CMF_{1r} \times CMF_{2r} \times \ldots \times CMF_{nr})$$

From Equation 12-4, $N_{spf\,rs}$ can be calculated as follows:

$$N_{spf\,rs} = N_{brmv} + N_{brsv} + N_{brdwy}$$

$$= 2.804 + 0.539 + 0.165$$

$$= 3.508 \text{ crashes/year}$$

The combined CMF value for Sample Problem 2 is 0.90.

$$N_{br} = 3.508 \times (0.90)$$

$$= 3.157 \text{ crashes/year}$$

The SPF for vehicle-pedestrian collisions for the roadway segment is calculated from Equation 12-19 as follows:

$$N_{pedr} = N_{br} \times f_{pedr}$$

From Table 12-8, for a posted speed of 30 mph on four-lane divided arterials, the pedestrian crash adjustment factor $f_{pedr} = 0.067$.

$$N_{pedr} = 3.157 \times 0.067$$
$$= 0.212 \text{ crashes/year}$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-20 as follows:

$$N_{biker} = N_{br} \times f_{biker}$$

From Table 12-9, for a posted speed of 30 mph on four-lane divided arterials, the bicycle crash adjustment factor $f_{biker} = 0.013$.

$$N_{biker} = 3.157 \times 0.013$$
$$= 0.041 \text{ crashes/year}$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed in that a calibration factor, C_r, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 12-2 based on the results obtained in Steps 9 through 11 as follows:

$$N_{\text{predicted } rs} = C_r \times (N_{br} + N_{pedr} + N_{biker})$$
$$= 1.00 \times (3.157 + 0.212 + 0.041)$$
$$= 3.410$$

WORKSHEETS

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for a roadway segment. To apply the predictive method steps to multiple segments, a series of 12 worksheets are provided for determining the predicted average crash frequency. The 12 worksheets include:

- *Worksheet SP2A (Corresponds to Worksheet 1A)*—General Information and Input Data for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2B (Corresponds to Worksheet 1B)*—Crash Modification Factors for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2C (Corresponds to Worksheet 1C)*—Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2D (Corresponds to Worksheet 1D)*—Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2E (Corresponds to Worksheet 1E)*—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2F (Corresponds to Worksheet 1F)*—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2G (Corresponds to Worksheet 1G)*—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2H (Corresponds to Worksheet 1H)*—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Arterial Roadway Segments

- *Worksheet SP2I (Corresponds to Worksheet 1I)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2J (Corresponds to Worksheet 1J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2K (Corresponds to Worksheet 1K)*—Crash Severity Distribution for Urban and Suburban Arterial Roadway Segments
- *Worksheet SP2L (Corresponds to Worksheet 1L)*—Summary Results for Urban and Suburban Arterial Roadway Segments

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheet SP2A—General Information and Input Data for Urban and Suburban Roadway Segments

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

Worksheet SP2A. General Information and Input Data for Urban and Suburban Roadway Segments

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

Input Data	**Base Conditions**	**Site Conditions**
Road type (2U, 3T, 4U, 4D, 5T)	—	4D
Length of segment, L (mi)	—	0.75
AADT (veh/day)	—	23,000
Type of on-street parking (none/parallel/angle)	none	None
Proportion of curb length with on-street parking	—	N/A
Median width (ft)	15	40
Lighting (present/not present)	not present	present
Auto speed enforcement (present/not present)	not present	not present
Major commercial driveways (number)	—	1
Minor commercial driveways (number)	—	4
Major industrial/institutional driveways (number)	—	—
Minor industrial/institutional driveways (number)	—	1
Major residential driveways (number)	—	1
Minor residential driveways (number)	—	1
Other driveways (number)	—	—
Speed Category	—	Low (30mph)
Roadside fixed object density (fixed objects/mi)	not present	20
Offset to roadside fixed objects (ft)	not present	12
Calibration Factor, C_r	1.0	1.0

Worksheet SP2B—Crash Modification Factors for Urban and Suburban Roadway Segments

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 6 of Worksheet SP2B which indicates the combined CMF value.

Worksheet SP2B. Crash Modification Factors for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
CMF for On-Street Parking	**CMF for Roadside Fixed Objects**	**CMF for Median Width**	**CMF for Lighting**	**CMF for Auto Speed Enforcement**	**Combined CMF**
CMF_{1r}	CMF_{2r}	CMF_{3r}	CMF_{4r}	CMF_{5r}	CMF_{comb}
from Equation 12-32	from Equation 12-33	from Table 12-22	from Equation 12-34	from Section 12.7.1	(1)*(2)*(3)*(4)*(5)
1.00	1.02	0.97	0.91	1.00	0.90

Worksheet SP2C—Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Roadway Segments

The SPF for multiple-vehicle nondriveway collisions along the roadway segment in Sample Problem 2 is calculated using Equation 12-10 and entered into Column 4 of Worksheet SP2C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 2 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values(from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 6 in Worksheet SP2B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle nondriveway crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP2C. Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
	SPF Coefficients		**Overdispersion Parameter, k**	**Initial N_{brmv}**		**Adjusted N_{brmv}**	**Combined CMFs**	**Calibration Factor**	**Predicted N_{brmv}**
	from Table 12-3								
Crash Severity Level	**a**	**b**	**from Table 12-3**	**from Equation 12-10**	**Proportion of Total Crashes**	$(4)_{total}*(5)$	**(6) from Worksheet SP2B**	C_r	**(6)*(7)*(8)**
Total	−12.34	1.36	1.32	2.804	1.000	2.804	0.90	1.00	2.524
Fatal and injury (FI)	−12.76	1.28	1.31	0.825	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$ 0.278	0.780	0.90	1.00	0.702
Property damage only (PDO)	−12.81	1.38	1.34	2.143	$(5)_{total}-(5)_{FI}$ 0.722	2.024	0.90	1.00	1.822

Worksheet SP2D—Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Roadway Segments

Worksheet SP2D presents the default proportions for collision type (from Table 12-4) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for multiple-vehicle nondriveway crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle nondriveway crashes (from Column 9, Worksheet SP2C) into components by crash severity and collision type.

Worksheet SP2D. Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{brmv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{brmv\ (PDO)}$ (crashes/year)	Predicted $N_{brmv\ (total)}$ (crashes/year)
Collision Type	from Table 12-4	$(9)_{FI}$ from Worksheet SP2C	from Table 12-4	$(9)_{PDO}$ from Worksheet SP2C	(9)total from Worksheet SP2C
Total	1.000	0.702 $(2)*(3)_{FI}$	1.000	1.822 $(4)*(5)_{PDO}$	2.524 (3)+(5)
Rear-end collision	0.832	0.584	0.662	1.206	1.790
Head-on collision	0.020	0.014	0.007	0.013	0.027
Angle collision	0.040	0.028	0.036	0.066	0.094
Sideswipe, same direction	0.050	0.035	0.223	0.406	0.441
Sideswipe, opposite direction	0.010	0.007	0.001	0.002	0.009
Other multiple-vehicle collision	0.048	0.034	0.071	0.129	0.163

Worksheet SP2E—Single-Vehicle Crashes by Severity Level for Urban and Suburban Roadway Segments

The SPF for single-vehicle crashes along the roadway segment in Sample Problem 2 is calculated using Equation 12-13 and entered into Column 4 of Worksheet SP2E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 2 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 6 in Worksheet SP2B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle nondriveway crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP2E. Single-Vehicle Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
	SPF Coefficients		Overdispersion Parameter, k	Initial N_{brsv}		Adjusted N_{brsv}	Combined CMFs	Calibration Factor	Predicted N_{brsv}
Crash Severity Level	from Table 12-5		from Table 12-5	from Equation 12-13	Proportion of Total Crashes	$(4)_{total}$*(5)	(6) from Worksheet SP2B	C_r	(6)*(7)*(8)
	a	b							
Total	−5.05	0.47	0.86	0.539	1.000	0.539	0.90	1.00	0.485
Fatal and injury (FI)	−8.71	0.66	0.28	0.094	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$ 0.174	0.094	0.90	1.00	0.085
Property damage only (PDO)	−5.04	0.45	1.06	0.446	$(5)_{total}-(5)_{FI}$ 0.826	0.445	0.90	1.00	0.401

Worksheet SP2F—Single-Vehicle Crashes by Collision Type for Urban and Suburban Roadway Segments

Worksheet SP2F presents the default proportions for collision type (from Table 12-5) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by collision type is presented in 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and Columns 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 9, Worksheet SP2E) into components by crash severity and collision type.

Worksheet SP2F. Single-Vehicle Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{brsv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{brsv\ (PDO)}$ (crashes/year)	Predicted $N_{brsv\ (total)}$ (crashes/year)
Collision Type	from Table 12-6	$(9)_{FI}$ from Worksheet SP2E	from Table 12-6	$(9)_{PDO}$ from Worksheet SP2E	$(9)_{total}$ from Worksheet SP2E
Total	1.000	0.085	1.000	0.401	0.485
		$(2)*(3)_{FI}$		$(4)*(5)_{PDO}$	(3)+(5)
Collision with animal	0.001	0.000	0.063	0.025	0.025
Collision with fixed object	0.500	0.043	0.813	0.326	0.369
Collision with other object	0.028	0.002	0.016	0.006	0.008
Other single-vehicle collision	0.471	0.040	0.108	0.043	0.083

Worksheet SP2G—Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Roadway Segments

Worksheet SP2G determines and presents the number of multiple-vehicle driveway-related collisions. The number of driveways along both sides of the road is entered in Column 2 by driveway type (Column 1). The associated number of crashes per driveway per year by driveway type as found in Table 12-7 is entered in Column 3. Column 4 contains the regression coefficient for AADT also found in Table 12-7. The initial average crash frequency of multiple-vehicle driveway-related crashes is calculated from Equation 12-16 and entered into Column 5. The overdispersion parameter from Table 12-7 is entered into Column 6; however, the overdispersion parameter is not needed for Sample Problem 2 (as the EB Method is not utilized).

Worksheet SP2G. Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
		Crashes per Driveway per Year, N_j	**Coefficient for Traffic Adjustment, t**	**Initial N_{brdwy}**	**Overdispersion Parameter, k**
Driveway Type	**Number of Driveways, n_j**	**from Table 12-7**	**from Table 12-7**	**Equation 12-16 n_j*N_j*$(AADT/15{,}000)_t$**	**from Table 12-7**
Major commercial	1	0.033	1.106	0.053	—
Minor commercial	4	0.011	1.106	0.071	
Major industrial/institutional	0	0.036	1.106	0.000	
Minor industrial/institutional	1	0.005	1.106	0.008	
Major residential	1	0.018	1.106	0.029	
Minor residential	1	0.003	1.106	0.005	
Other	0	0.005	1.106	0.000	
Total	—	—	—	0.166	1.39

Worksheet SP2H—Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Roadway Segments

The initial average crash frequency of multiple-vehicle driveway-related crashes from Column 5 of Worksheet SP2G is entered in Column 2. This value is multiplied by the proportion of crashes by severity (Column 3) found in Table 12-7, and the adjusted value is entered into Column 4. Column 5 represents the combined CMF (from Column 6 in Worksheet SP2B), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of multiple-vehicle driveway-related crashes using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6.

Worksheet SP2H. Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Initial N_{brdwy}	Proportion of Total Crashes (f_{dwy})	Adjusted N_{brdwy}	Combined CMFs		Predicted N_{brdwy}
Crash Severity Level	$(5)_{total}$ from Worksheet SP2G	from Table 12-7	$(2)_{total}$ *(3)	(6) from Worksheet SP2B	Calibration Factor, C_r	(4)*(5)*(6)
Total	0.166	1.000	0.166	0.90	1.00	0.149
Fatal and injury (FI)	—	0.284	0.047	0.90	1.00	0.042
Property damage only (PDO)	—	0.716	0.119	0.90	1.00	0.107

Worksheet SP2I—Vehicle-Pedestrian Collisions for Urban and Suburban Roadway Segments

The predicted average crash frequency of multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related predicted crashes from Worksheets SP2C, SP2E, and SP2H are entered into Columns 2, 3, and 4, respectively. These values are summed in Column 5. Column 6 contains the pedestrian crash adjustment factor (see Table 12-8). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP2I. Vehicle-Pedestrian Collisions

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted N_{brmv}	Predicted N_{brsv}	Predicted N_{brdwy}	Predicted N_{br}	f_{pedr}		Predicted N_{pedr}
Crash Severity Level	(9) from Worksheet SP2C	(9) from Worksheet SP2E	(7) from Worksheet SP2H	(2)+(3)+(4)	from Table 12-8	Calibration Factor, C_r	(5)*(6)*(7)
Total	2.524	0.485	0.149	3.158	0.067	1.000	0.212
Fatal and injury (FI)	—	—	—	—	—	1.00	0.212

Worksheet SP2J—Vehicle-Bicycle Collisions for Urban and Suburban Roadway Segments

The predicted average crash frequency of multiple-vehicle nondriveway, single-vehicle, and multiple-vehicle driveway-related predicted crashes from Worksheets SP2C, SP2E, and SP2H are entered into Columns 2, 3, and 4, respectively. These values are summed in Column 5. Column 6 contains the bicycle crash adjustment factor (see Table 12-9). Column 7 represents the calibration factor. The predicted average crash frequency of vehicle-bicycle collisions (Column 8) is the product of Columns 5, 6, and 7. Since all vehicle-bicycle collisions are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP2J. Vehicle-Bicycle Collisions for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted N_{brmv}	Predicted N_{brsv}	Predicted N_{brdwy}	Predicted N_{br}	f_{biker}		Predicted N_{biker}
Crash Severity Level	(9) from Worksheet SP2C	(9) from Worksheet SP2E	(7) from Worksheet SP2H	(2)+(3)+(4)	from Table 12-9	Calibration Factor, C_r	(5)*(6)*(7)
Total	2.524	0.485	0.149	3.158	0.013	1.00	0.041
Fatal and injury	—	—	—	—	—	1.00	0.041

Worksheet SP2K—Crash Severity Distribution for Urban and Suburban Roadway Segments

Worksheet SP2K provides a summary of all collision types by severity level. Values from Worksheets SP2C, SP2E, SP2H, SP2I, and SP2J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP2K. Crash Severity Distribution for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	**Property Damage Only (PDO)**	**Total**
Collision Type	**(3) from Worksheet SP2D and SP2F; (7) from Worksheet SP2H; and (8) from Worksheet SP2I and SP2J**	**(5) from Worksheet SP2D and SP2F; and (7) from Worksheet SP2H**	**(6) from Worksheet SP2D and SP2F; (7) from Worksheet SP2H; and (8) from Worksheet SP2I and SP2J**
MULTIPLE-VEHICLE			
Rear-end collisions (from Worksheet SP2D)	0.584	1.206	1.790
Head-on collisions (from Worksheet SP2D)	0.014	0.013	0.027
Angle collisions (from Worksheet SP2D)	0.028	0.066	0.094
Sideswipe, same direction (from Worksheet SP2D)	0.035	0.406	0.441
Sideswipe, opposite direction (from Worksheet SP2D)	0.007	0.002	0.009
Driveway-related collisions (from Worksheet SP2H)	0.042	0.107	0.149
Other multiple-vehicle collision (from Worksheet SP2D)	0.034	0.129	0.163
Subtotal	0.744	1.929	2.673
SINGLE-VEHICLE			
Collision with animal (from Worksheet SP2F)	0.000	0.025	0.025
Collision with fixed object (from Worksheet SP2F)	0.043	0.326	0.369
Collision with other object (from Worksheet SP2F)	0.002	0.006	0.008
Other single-vehicle collision (from Worksheet SP2F)	0.040	0.043	0.083
Collision with pedestrian (from Worksheet SP2I)	0.212	0.000	0.212
Collision with bicycle (from Worksheet SP2J)	0.041	0.000	0.041
Subtotal	0.338	0.400	0.738
Total	1.082	2.329	3.411

Worksheet SP2L—Summary Results for Urban and Suburban Roadway Segments

Worksheet SP2L presents a summary of the results. Using the roadway segment length and the AADT, the worksheet presents the crash rate in miles per year (Column 4) and in million vehicle miles (Column 6).

Worksheet SP2L. Summary Results for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
	Predicted Average Crash Frequency, $N_{predicted\ rs}$ (crashes/year)		Crash Rate (crashes/mi/year)
Crash Severity Level	(Total) from Worksheet SP2K	Roadway Segment Length, L (mi)	(2)/(3)
Total	3.411	0.75	4.5
Fatal and injury (FI)	1.082	0.75	1.4
Property damage only (PDO)	2.329	0.75	3.1

12.13.3. Sample Problem 3

The Site/Facility

A three-leg stop-controlled intersection located on an urban arterial.

The Question

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

The Facts

- 1 left-turn lane on one major road approach
- No right-turn lanes on any approach
- AADT of major road is 14,000 veh/day
- AADT of minor road is 4,000 veh/day

Assumptions

Collision type distributions used are the default values from Tables 12-11 and 12-13 and Equations 12-30 and 12-31.

The calibration factor is assumed to be 1.00.

Results

Using the predictive method steps as outlined below, the predicted average crash frequency for the unsignalized intersection in Sample Problem 3 is determined to be 1.6 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8

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

Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.

For a three-leg stop-controlled intersection, SPF values for multiple-vehicle, single-vehicle, vehicle-pedestrian, and vehicle-bicycle collisions are determined. The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these two models.

Multiple-Vehicle Crashes

The SPF for multiple-vehicle collisions for a single three-leg stop-controlled intersection is calculated from Equation 12-21 and Table 12-10 as follows:

$$N_{bimv} = exp(a + b \times In(AADT_{maj}) + c \times In(AADT_{min}))$$

$$N_{bimv(\text{total})} = exp(-13.63 + 1.11 \times In(14{,}000) + 0.41 \times In(4{,}000))$$

$$= 1.892 \text{ crashes/year}$$

$$N_{bimv(FI)} = exp(-14.01 + 1.16 \times In(14{,}000) + 0.30 \times In(4{,}000))$$

$$= 0.639 \text{ crashes/year}$$

$$N_{bimv(PDO)} = exp(-15.38 + 1.20 \times In(14{,}000) + 0.51 \times In(4{,}000))$$

$$= 1.358 \text{ crashes/year}$$

These initial values for fatal-and-injury (FI) and property-damage-only (PDO) crashes are then adjusted using Equations 12-22 and 12-23 to assure that they sum to the value for total crashes as follows:

$$N_{bimv(FI)} = N_{bimv(\text{total})}\left(\frac{N'_{bimv(FI)}}{N'_{bimv(FI)} + N'_{bimv(PDO)}}\right)$$

$$= 1.892 \times \left(\frac{0.639}{0.639 + 1.358}\right)$$

$$= 0.605 \text{ crashes/year}$$

$$N_{bimv(PDO)} = N_{bimv(\text{total})} - N_{bimv(FI)}$$

$$= 1.892 - 0.605$$

$$= 1.287 \text{ crashes/year}$$

Single-Vehicle Crashes

The SPF for single-vehicle crashes for a single three-leg stop-controlled intersection is calculated from Equation 12-24 and Table 12-12 as follows:

$$N_{bisv} = exp(a + b \times In(AADT_{maj}) + c \times In(AADT_{min}))$$

$$N_{bisv(\text{total})} = exp(-6.81 + 0.16 \times In(14{,}000) + 0.51 \times In(4{,}000))$$

$$= 0.349 \text{ crashes/year}$$

$$N_{bisv(PDO)} = exp(-8.36 + 0.25 \times In(14{,}000) + 0.55 \times In(4{,}000))$$

$$= 0.244 \text{ crashes/year}$$

Since there are no models for fatal-and-injury crashes at a three-leg stop-controlled intersections, $N_{bisv(FI)}$ is calculated using Equation 12-27 (in place of Equation 12-25), and the initial value for $N_{bisv(PDO)}$ calculated above is then adjusted using Equation 12-26 to assure that fatal-and-injury and property-damage-only crashes sum to the value for total crashes as follows:

$$N_{bisv(FI)} = N_{bisv(\text{total})} \times f_{bisv}$$

For a three-leg stop-controlled intersection, the default proportion of fatal-and-injury crashes, f_{bisv}= 0.31 (see Section 12.6.2, Single-Vehicle Crashes)

$$\begin{aligned} N_{bisv(FI)} &= 0.349 \times 0.31 \\ &= 0.108 \text{ crashes/year} \end{aligned}$$

$$\begin{aligned} N_{bisv(PDO)} &= N_{bisv(\text{total})} - N_{bisv(FI)} \\ &= 0.349 - 0.108 \\ &= 0.241 \text{ crashes/year} \end{aligned}$$

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

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

Intersection Left-Turn Lanes (CMF_{1i})

From Table 12-24, for a three-leg stop-controlled intersection with one left-turn lane on the major road, CMF_{1i} = 0.67.

Intersection Left-Turn Signal Phasing (CMF_{2i})

For unsignalized intersections, CMF_{2i} = 1.00.

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

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

Right-Turn-on-Red (CMF_{4i})

For unsignalized intersections, CMF_{4i} = 1.00.

Lighting (CMF_{5i})

Since there is no lighting at this intersection, CMF_{5i} is 1.00 (i.e., the base condition for CMF_{5i} is the absence of intersection lighting).

Red-Light Cameras (CMF_{6i})

For unsignalized intersections, CMF_{6i} is always 1.00.

The combined CMF value for Sample Problem 3 is 0.67.

Vehicle-Pedestrian and Vehicle-Bicycle Collisions

The predicted average crash frequency of an intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions) for SPF base conditions, N_{bi}, must be calculated in order to determine vehicle-pedestrian and vehicle-bicycle crashes. N_{bi} is determined from Equation 12-6 as follows:

$$N_{bi} = N_{spf\ int} \times (CMF_{1i} \times CMF_{2i} \times \ldots \times CMF_{6i})$$

From Equation 12-7, $N_{spf\ int}$ can be calculated as follows:

$$\begin{aligned} N_{spf\ int} &= N_{bimv} + N_{bisv} \\ &= 1.892 + 0.349 \\ &= 2.241 \text{ crashes/year} \end{aligned}$$

The combined CMF value for Sample Problem 3 is 0.67.

N_{bi} = 2.241 × (0.67)

= 1.501 crashes/year

The SPF for vehicle-pedestrian collisions for a three-leg stop-controlled intersection is calculated from Equation 12-30 as follows:

$N_{pedi} = N_{bi} \times f_{pedi}$

From Table 12-16, for a three-leg stop-controlled intersection the pedestrian crash adjustment factor, f_{pedi} = 0.211.

N_{pedi} = 1.501 × 0.021

= 0.032 crashes/year

The SPF for vehicle-bicycle collisions is calculated from Equation 12-31 as follows:

$N_{bikei} = N_{pedi} \times f_{bikei}$

From Table 12-17, for a three-leg stop-controlled intersection, the bicycle crash adjustment factor f_{bikei} = 0.016.

N_{bikei} = 1.501 × 0.016

= 0.024 crashes/year

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed in Sample Problem 3 that a calibration factor, C_i, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated using Equation 12-5 based on results obtained in Steps 9 through 11 as follows:

$N_{\text{predicted } int} = C_i \times (N_{bi} + N_{pedi} + N_{bikei})$

= 1.00 × (1.501 + 0.032 + 0.024)

= 1.557 crashes/year

WORKSHEETS

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for an intersection. To apply the predictive method steps to multiple intersections, a series of 12 worksheets are provided for determining the predicted average crash frequency at intersections. The 12 worksheets include:

- *Worksheet SP3A (Corresponds to Worksheet 2A)*—General Information and Input Data for Urban and Suburban Arterial Intersections
- *Worksheet SP3B (Corresponds to Worksheet 2B)*—Crash Modification Factors for Urban and Suburban Arterial Intersections
- *Worksheet SP3C (Corresponds to Worksheet 2C)*—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SP3D (Corresponds to Worksheet 2D)*—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

- *Worksheet SP3E (Corresponds to Worksheet 2E)*—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SP3F (Corresponds to Worksheet 2F)*—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SP3G (Corresponds to Worksheet 2G)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Stop-Controlled Intersections
- *Worksheet SP3J (Corresponds to Worksheet 2J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections
- *Worksheet SP3K (Corresponds to Worksheet 2K)*—Crash Severity Distribution for Urban and Suburban Arterial Intersections
- *Worksheet SP3L (Corresponds to Worksheet 2L)*—Summary Results for Urban and Suburban Arterial Intersections

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheet SP3A—General Information and Input Data for Urban and Suburban Arterial Intersections

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

Worksheet SP3A. General Information and Input Data for Urban and Suburban Arterial Intersections

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

Input Data	**Base Conditions**	**Site Conditions**
Intersection type (3ST, 3SG, 4ST, 4SG)	—	3ST
$AADT_{maj}$ (veh/day)	—	14,000
$AADT_{min}$ (veh/day)	—	4,000
Intersection lighting (present/not present)	not present	not present
Calibration factor, C_i	1.00	1.00
Data for unsignalized intersections only:	—	—
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	1
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	0
Data for signalized intersections only:	—	—
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)	0	N/A
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)	0	N/A
Number of approaches with left-turn signal phasing	—	N/A
Number of approaches with right-turn-on-red prohibited	0	N/A
Type of left-turn signal phasing	permissive	N/A
Intersection red light cameras (present/not present)	not present	N/A
Sum of all pedestrian crossing volumes (PedVol)	—	N/A
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	N/A
Number of bus stops within 300 m (1,000 ft) of the intersection	0	N/A
Schools within 300 m (1,000 ft) of the intersection (present/not present)	not present	N/A
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection	0	N/A

Worksheet SP3B—Crash Modification Factors for Urban and Suburban Arterial Intersections

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 7 of Worksheet SP3B which indicates the combined CMF value.

Worksheet SP3B. Crash Modification Factors for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CMF for Left-Turn Lanes	**CMF for Left-Turn Signal Phasing**	**CMF for Right-Turn Lanes**	**CMF for Right-Turn-on-Red**	**CMF for Lighting**	**CMF for Red-Light Cameras**	**Combined CMF**
CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{5i}	CMF_{6i}	CMF_{comb}
from Table 12-24	from Table 12-25	from Table 12-26	from Equation 12-35	from Equation 12-36	from Equation 12-37	(1)*(2)*(3)*(4)*(5)*(6)
0.67	1.00	1.00	1.00	1.00	1.00	0.67

Worksheet SP3C—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

The SPF for multiple-vehicle collisions at the intersection in Sample Problem 3 is calculated using Equation 12-22 and entered into Column 4 of Worksheet SP3C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 3 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 7 in Worksheet SP3B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP3C. Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

(1)	(2)			(3)	(4)
	SPF Coefficients			**Overdispersion Parameter, k**	**Initial N_{bimv}**
	from Table 12-10				
Crash Severity Level	**a**	**b**	**c**	**from Table 12-10**	**from Equation 12-22**
Total	−13.36	1.11	0.41	0.80	1.892
Fatal and injury (FI)	−14.01	1.16	0.30	0.69	0.639
Property damage only (PDO)	−15.38	1.20	0.51	0.77	1.358

Worksheet SP3C. Continued

(1)	(5)	(6)	(7)	(8)	(9)
		Adjusted N_{bimv}	**Combined CMFs**		**Predicted N_{bimv}**
Crash Severity Level	**Proportion of Total Crashes**	**$(4)_{total}$*(5)**	**(7) from Worksheet SP3B**	**Calibration Factor, C_i**	**(6)*(7)*(8)**
Total	1.000	1.892	0.67	1.00	1.268
Fatal and injury (FI)	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$ 0.320	0.605	0.67	1.00	0.405
Property damage only (PDO)	$(5)_{total}-(5)_{FI}$ 0.680	1.287	0.67	1.00	0.862

Worksheet SP3D—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

Worksheet SP3D presents the default proportions for collision type (from Table 12-11) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for multiple-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle crashes (from Column 9, Worksheet SP3C) into components by crash severity and collision type.

Worksheet SP3D. Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	**Predicted $N_{bimv\ (FI)}$ (crashes/year)**	**Proportion of Collision Type $_{(PDO)}$**	**Predicted $N_{bimv\ (PDO)}$ (crashes/year)**	**Predicted $N_{bimv\ (total)}$ (crashes/year)**
Collision Type	**from Table 12-11**	**$(9)_{FI}$ from Worksheet SP3C**	**from Table 12-11**	**$(9)_{PDO}$ from Worksheet SP3C**	**$(9)_{PDO}$ from Worksheet SP3C**
Total	1.000	0.405 $(2)*(3)_{FI}$	1.000	0.862 $(4)*(5)_{PDO}$	1.268 (3)+(5)
Rear-end collision	0.421	0.171	0.440	0.379	0.550
Head-on collision	0.045	0.018	0.023	0.020	0.038
Angle collision	0.343	0.139	0.262	0.226	0.365
Sideswipe	0.126	0.051	0.040	0.034	0.085
Other multiple-vehicle collision	0.065	0.026	0.235	0.203	0.229

Worksheet SP3E—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections

The SPF for single-vehicle crashes at the intersection in Sample Problem 3 is calculated using Equation 12-25 for total and property-damage-only (PDO) crashes and entered into Column 4 of Worksheet SP3E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 3 (as the EB Method is not utilized). Since there are no models for fatal-and-injury crashes at a three-leg stop-controlled intersections, $N_{bisv(FI)}$ is calculated using Equation 12-27 (in place of Equation 12-25), and the value is entered into Column 4 and 6 since no further adjustment is required. Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 7 in Worksheet SP3B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of single-vehicle crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP3E. Single-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

(1)	(2)			(3)	(4)
	SPF Coefficients			Overdispersion Parameter, k	Initial N_{bisv}
	from Table 12-12				from Equation 12-25; (*FI*) from Equation 12-25 or 12-27
Crash Severity Level	a	b	c	from Table 12-12	
Total	−6.81	0.16	0.51	1.14	0.349
Fatal and injury (FI)	N/A	N/A	N/A	N/A	0.108
Property damage only (PDO)	−8.36	0.25	0.55	1.29	0.244

Worksheet SP3E. Continued

(1)	(5)	(6)	(7)	(8)	(9)
		Adjusted N_{bisv}	Combined CMFs		Predicted N_{bisv}
Crash Severity Level	Proportion of Total Crashes	$(4)_{total}$*(5)	(7) from Worksheet SP3B	Calibration Factor, C_i	(6)*(7)*(8)
Total	1.000	0.349	0.67	1.00	0.234
Fatal and injury (FI)	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$ N/A	0.108	0.67	1.00	0.072
Property damage only (PDO)	$(5)_{total}-(5)_{FI}$ 0.693	0.242	0.67	1.00	0.162

Worksheet SP3F—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections

Worksheet SP3F presents the default proportions for collision type (from Table 12-13) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 9, Worksheet SP3E) into components by crash severity and collision type.

Worksheet SP3F. Single-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type (FI)	Predicted $N_{bisv\,(FI)}$ (crashes/year)	Proportion of Collision Type (PDO)	Predicted $N_{bisv\,(PDO)}$ (crashes/year)	Predicted $N_{bisv\,(total)}$ (crashes/year)
Collision Type	Table 12-13	$(9)_{FI}$ from Worksheet SP3E	Table 12-13	$(9)_{PDO}$ from Worksheet SP3E	$(9)_{PDO}$ from Worksheet SP3E
Total	1.000	0.072 $(2)*(3)_{FI}$	1.000	0.162 $(4)*(5)_{PDO}$	0.234 (3)+(5)
Collision with parked vehicle	0.001	0.000	0.003	0.000	0.000
Collision with animal	0.003	0.000	0.018	0.003	0.003
Collision with fixed object	0.762	0.055	0.834	0.135	0.190
Collision with other object	0.090	0.006	0.092	0.015	0.021
Other single-vehicle collision	0.039	0.003	0.023	0.004	0.007
Single-vehicle noncollision	0.105	0.008	0.030	0.005	0.013

Worksheet SP3G—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Stop-Controlled Intersections

The predicted average crash frequency of multiple-vehicle predicted crashes and single-vehicle predicted crashes from Worksheets SP3C and SP3E are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the pedestrian crash adjustment factor (see Table 12-16). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-pedestrian collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP3G. Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Stop-Controlled Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv}	Predicted N_{bisv}	Predicted N_{bi}	f_{pedi}		Predicted N_{pedi}
Crash Severity Level	(9) from Worksheet SP3C	(9) from Worksheet SP3E	(2)+(3)	from Table 12-16	Calibration Factor, C_i	(4)*(5)*(6)
Total	1.268	0.234	1.502	0.021	1.00	0.032
Fatal and injury (FI)	—	—	—	—	1.00	0.032

Worksheet SP3J—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

The predicted average crash frequency of multiple-vehicle predicted crashes and single-vehicle predicted crashes from Worksheets SP3C and SP3E are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the bicycle crash adjustment factor (see Table 12-17). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-bicycle collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP3J. Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv}	**Predicted N_{bisv}**	**Predicted N_{bi}**	**f_{bikei}**		**Predicted N_{pedi}**
Crash Severity Level	**(9) from Worksheet SP3C**	**(9) from Worksheet SP3E**	**(2)+(3)**	**from Table 12-17**	**Calibration Factor, C_i**	**(4)*(5)*(6)**
Total	1.268	0.234	1.502	0.016	1.000	0.024
Fatal and injury (FI)	—	—	—	—	1.000	0.024

Worksheet SP3K—Crash Severity Distribution for Urban and Suburban Arterial Intersections

Worksheet SP3K provides a summary of all collision types by severity level. Values from Worksheets SP3D, SP3F, SP3G, and SP3J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP3K. Crash Severity Distribution for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	Property Damage Only (PDO)	Total
Collision Type	(3) from Worksheets SP3D and SP3F; (7) from SP3G and SP3J	(5) from Worksheets SP3D and SP3F	(6) from Worksheets SP3D and SP3F; (7) from SP3G and SP3J
MULTIPLE-VEHICLE COLLISIONS			
Rear-end collisions (from Worksheet SP3D)	0.171	0.379	0.550
Head-on collisions (from Worksheet SP3D)	0.018	0.020	0.038
Angle collisions (from Worksheet SP3D)	0.139	0.226	0.365
Sideswipe (from Worksheet SP3D)	0.051	0.034	0.085
Other multiple-vehicle collision (from Worksheet SP3D)	0.026	0.203	0.229
Subtotal	0.405	0.862	1.267
SINGLE-VEHICLE COLLISIONS			
Collision with parked vehicle (from Worksheet SP3F)	0.000	0.000	0.000
Collision with animal (from Worksheet SP3F)	0.000	0.003	0.003
Collision with fixed object (from Worksheet SP3F)	0.055	0.135	0.190
Collision with other object (from Worksheet SP3F)	0.006	0.015	0.021
Other single-vehicle collision (from Worksheet SP3F)	0.003	0.004	0.007
Single-vehicle noncollision (from Worksheet SP3F)	0.008	0.005	0.013
Collision with pedestrian (from Worksheet SP3G)	0.032	0.000	0.032
Collision with bicycle (from Worksheet SP3J)	0.024	0.000	0.024
Subtotal	0.128	0.162	0.290
Total	0.533	1.024	1.557

Worksheet SP3L—Summary Results for Urban and Suburban Arterial Intersections

Worksheet SP3L presents a summary of the results.

Worksheet SP3L. Summary Results for Urban and Suburban Arterial Intersections

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	(Total) from Worksheet SP3K
Total	1.557
Fatal and injury (FI)	0.533
Property damage only (PDO)	1.024

12.13.4. Sample Problem 4

The Intersection
A four-leg signalized intersection located on an urban arterial.

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

The Facts

- 1 left-turn lane on each of the two major road approaches
- 1 right-turn lane on each of the two major road approaches
- Protected/permissive left-turn signal phasing on major road
- AADT of major road is 15,000 veh/day
- AADT of minor road is 9,000 veh/day
- Lighting is present
- No approaches with prohibited right-turn-on-red
- Four-lane divided major road
- Two-lane undivided minor road
- Pedestrian volume is 1,500 peds/day
- The number of bus stops within 1,000 ft of intersection is 2
- A school is present within 1,000 ft of intersection
- The number of alcohol establishments within 1,000 ft of intersection is 6

Assumptions
Collision type distributions used are the default values from Tables 12-11 and 12-13 and Equations 12-28 and 12-31.

The calibration factor is assumed to be 1.00.

The maximum number of lanes crossed by a pedestrian is assumed to be four (crossing two through lanes, one left-turn lane, and one right-turn lane across one side of the divided major road).

Results
Using the predictive method steps as outlined below, the predicted average crash frequency for the unsignalized intersection in Sample Problem 4 is determined to be 3.4 crashes per year (rounded to one decimal place).

Steps

Step 1 through 8
To determine the predicted average crash frequency of the roadway segment in Sample Problem 4, only Steps 9 through 11 are conducted. No other steps are necessary because only one roadway segment is analyzed for one year and the EB Method is not applied.

Step 9—For the selected site, determine and apply the appropriate safety performance function (SPF) for the site's facility type and traffic control features.

For a four-leg signalized intersection, SPF values for multiple-vehicle, single-vehicle, vehicle-pedestrian, and vehicle-bicycle collisions are determined. The calculations for total multiple- and single-vehicle collisions are presented below. Detailed steps for calculating SPFs for fatal-and-injury (FI) and property-damage-only (PDO) crashes are presented in Sample Problem 3 (for fatal-and-injury base crashes at a four-leg signalized intersection, Equation 12-25 in place of Equation 12-27 is used). The calculations for vehicle-pedestrian and vehicle-bicycle collisions are shown in Step 10 since the CMF values are needed for these two models.

Multiple-Vehicle Collisions

The SPF for multiple-vehicle collisions for a single four-leg signalized intersection is calculated from Equation 12-21 and Table 12-10 as follows:

$$N_{bimv} = exp(a + b \times In(AADT_{maj}) + c \times In(AADT_{min}))$$

$$N_{bimv(\text{total})} = exp(-10.99 + 1.07 \times In(15{,}000) + c \times In(9{,}000))$$

$$= 4.027 \text{ crashes/year}$$

Single-Vehicle Crashes

The SPF for single-vehicle crashes for a single four-leg signalized intersection is calculated from Equation 12-24 and Table 12-12 as follows:

$$N_{bisv} = exp(a + b \times In(AADT_{maj}) + c \times In(AADT_{min}))$$

$$N_{bisv(\text{total})} = exp(-10.21 + 0.68 \times In(15{,}000) + 0.27 \times In(9{,}000))$$

$$= 0.297 \text{ crashes/year}$$

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

Each CMF used in the calculation of the predicted average crash frequency of the intersection is calculated below. CMF_{1i} through CMF_{2i} are applied to multiple-vehicle collisions and single-vehicle crashes, while CMF_{1p} through CMF_{3p} are applied to vehicle-pedestrian collisions.

Intersection Left-Turn Lanes (CMF_{1i})

From Table 12-24, for a four-leg signalized intersection with one left-turn lane on each of two approaches, CMF_{1i} = 0.81.

Intersection Left-Turn Signal Phasing (CMF_{2i})

From Table 12-25, for a four-leg signalized intersection with protected/permissive left-turn signal phasing for two approaches, CMF_{2i} = 0.98 (0.99*0.99).

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

From Table 12-26, for a four-leg signalized intersection with one right-turn lane on each of two approaches, CMF_{3i} = 0.92.

Right-Turn-on-Red (CMF_{4i})

Since right-turn-on-red (RTOR) is not prohibited on any of the intersection legs, CMF_{4i} = 1.00 (i.e., the base condition for CMF_{4i} is permitting a RTOR at all approaches to a signalized intersection).

Lighting (CMF_{5i})

CMF_{5i} is calculated from Equation 12-36.

$$CMF_{5i} = 1 - 0.38 \times p_{ni}$$

From Table 12-27, the proportion of crashes that occur at night, p_{ni} = 0.235.

$$CMF_{5i} = 1 - 0.38 \times 0.235$$

$$= 0.91$$

Red-Light Cameras (CMF_{6i})
Since no red light cameras are present at this intersection, CMF_{6i} = 1.00 (i.e., the base condition for CMF_{6i} is the absence of red light cameras).

The combined CMF value applied to multiple- and single-vehicle crashes in Sample Problem 4 is calculated below.

$$CMF_{comb} = 0.81 \times 0.98 \times 0.92 \times 0.91$$
$$= 0.66$$

Bus Stop (CMF_{1p})
From Table 12-28, for two bus stops within 1,000 ft of the center of the intersection, CMF_{1p} = 2.78.

Schools (CMF_{2p})
From Table 12-29, for one school within 1,000 ft of the center of the intersection, CMF_{2p} = 1.35.

Alcohol Sales Establishments (CMF_{3p})
From Table 12-30, for six alcohol establishments within 1,000 ft of the center of the intersection, CMF_{3p} = 1.12.

Vehicle-Pedestrian and Vehicle-Bicycle Collisions
The SPF for vehicle-pedestrian collisions for a four-leg signalized intersection is calculated from Equation 12-28 as follows:

$$N_{pedi} = N_{pedbase} \times CMF_{1p} \times CMF_{2p} \times CMF_{3p}$$

Npedbase is calculated from Equation 12-29 using the coefficients from Table 12-14.

$$N_{pedbase} = exp\left(a + b \times In(AADT_{\text{total}}) + c \times In\left(\frac{AADT_{min}}{AADT_{maj}}\right) + d \times In(PedVol) + e \times n_{lanesx}\right)$$
$$= exp\left(-9.53 + 0.40 \times In(24,000) + 0.26 \times In\left(\frac{9,000}{15,000}\right) + 0.45 \times In(1,500) + 0.04 \times 4\right)$$
$$= 0.113 \text{ crashes/year}$$

The CMF vehicle-pedestrian collision values calculated above are CMF_{1p} =2.78, CMF_{2p} = 1.35, and CMF_{3p} = 1.12.

$$N_{pedi} = 0.113 \times 2.78 \times 1.35 \times 1.12$$
$$= 0.475 \text{ crashes/year}$$

The predicted average crash frequency of an intersection (excluding vehicle-pedestrian and vehicle-bicycle collisions) for SPF base conditions, N_{bi}, must be calculated in order to determine vehicle-bicycle crashes. N_{bi} is determined from Equation 12-6 as follows:

$$N_{bi} = N_{spf\,int} \times (CMF_{1i} \times CMF_{2i} \times \ldots \times CMF_{6i})$$

From Equation 12-7, $N_{spf\,int}$ can be calculated as follows:

$$N_{spf\,int} = N_{bimv} + N_{bisv}$$
$$= 4.027 + 0.297$$
$$= 4.324 \text{ crashes/year}$$

The combined CMF value for Sample Problem 4 is 0.66.

$$N_{bi} = 4.324 \times (0.66)$$
$$= 2.854 \text{ crashes/year}$$

The SPF for vehicle-bicycle collisions is calculated from Equation 12-31 as follows:

$$N_{bikei} = N_{bi} \times f_{bikei}$$

From Table 12-17, for a four-leg signalized intersection the bicycle crash adjustment factor, $f_{bikei} = 0.015$.

$$\begin{aligned} N_{bikei} &= 2.854 \times 0.015 \\ &= 0.043 \text{ crashes/year} \end{aligned}$$

Step 11—Multiply the result obtained in Step 10 by the appropriate calibration factor.
It is assumed in Sample Problem 4 that a calibration factor, C_i, of 1.00 has been determined for local conditions. See Part C, Appendix A.1 for further discussion on calibration of the predicted models.

Calculation of Predicted Average Crash Frequency
The predicted average crash frequency is calculated from Equation 12-5 based on the results obtained in Steps 9 through 11 as follows:

$$\begin{aligned} N_{\text{predicted } int} &= C_i \times (N_{bi} + N_{pedi} + N_{bikei}) \\ &= 1.00 \times (2.854 + 0.475 + 0.043) \\ &= 3.372 \text{ crashes/year} \end{aligned}$$

WORKSHEETS

The step-by-step instructions above are provided to illustrate the predictive method for calculating the predicted average crash frequency for an intersection. To apply the predictive method steps to multiple intersections, a series of 12 worksheets are provided for determining the predicted average crash frequency at intersections. The 12 worksheets include:

- *Worksheet SP4A (Corresponds to Worksheet 2A)*—General Information and Input Data for Urban and Suburban Arterial Intersections
- *Worksheet SP4B (Corresponds to Worksheet 2B)*—Crash Modification Factors for Urban and Suburban Arterial Intersections
- *Worksheet SP4C (Corresponds to Worksheet 2C)*—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SP4D (Corresponds to Worksheet 2D)*—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SP4E (Corresponds to Worksheet 2E)*—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections
- *Worksheet SP4F (Corresponds to Worksheet 2F)*—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections
- *Worksheet SP4H (Corresponds to Worksheet 2H)*—Crash Modification Factors for Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections
- *Worksheet SP4I (Corresponds to Worksheet 2I)*—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections
- *Worksheet SP4J (Corresponds to Worksheet 2J)*—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections
- *Worksheet SP4K (Corresponds to Worksheet 2K)*—Crash Severity Distribution for Urban and Suburban Arterial Intersections
- *Worksheet SP4L (Corresponds to Worksheet 2L)*—Summary Results for Urban and Suburban Arterial Intersections

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheet SP4A—General Information and Input Data for Urban and Suburban Arterial Intersections

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

Worksheet SP4A. General Information and Input Data for Urban and Suburban Arterial Intersections

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

Input Data	Base Conditions	Site Conditions
Intersection type (3ST, 3SG, 4ST, 4SG)	—	4SG
$AADT_{maj}$ (veh/day)	—	15,000
$AADT_{min}$ (veh/day)	—	9,000
Intersection lighting (present/not present)	not present	present
Calibration factor, C_i	1.00	1.00
Data for unsignalized intersections only:	—	—
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	N/A
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	N/A
Data for signalized intersections only:	—	—
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)	0	2
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)	0	2
Number of approaches with left-turn signal phasing	—	2
Number of approaches with right-turn-on-red prohibited	0	0
Type of left-turn signal phasing	permissive	protected/permissive
Intersection red-light cameras (present/not present)	not present	not present
Sum of all pedestrian crossing volumes (PedVol)	—	1,500
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	4
Number of bus stops within 300 m (1,000 ft) of the intersection	0	2
Schools within 300 m (1,000 ft) of the intersection (present/not present)	not present	present
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection	0	6

Worksheet SP4B—Crash Modification Factors for Urban and Suburban Arterial Intersections

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 7 of Worksheet SP4B which indicates the combined CMF value.

Worksheet SP4B. Crash Modification Factors for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CMF for Left-Turn Lanes	**CMF for Left-Turn Signal Phasing**	**CMF for Right-Turn Lanes**	**CMF for Right-Turn-on-Red**	**CMF for Lighting**	**CMF for Red-Light Cameras**	**Combined CMF**
CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{5i}	CMF_{6i}	CMF_{comb}
from Table 12-24	from Table 12-25	from Table 12-26	from Equation 12-35	from Equation 12-36	from Equation 12-37	(1)*(2)*(3)*(4)*(5)*(6)
0.81	0.98	0.92	1.00	0.91	1.00	0.66

Worksheet SP4C—Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

The SPF for multiple-vehicle collisions at the intersection in Sample Problem 4 is calculated using Equation 12-22 and entered into Column 4 of Worksheet SP4C. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 4 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 7 in Worksheet SP4B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of multiple-vehicle crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP4C. Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

(1)	(2)			(3)	(4)
	SPF Coefficients			**Overdispersion Parameter, k**	**Initial N_{bimv}**
	from Table 12-10				
Crash Severity Level	**a**	**b**	**c**	**from Table 12-10**	**from Equation 12-22**
Total	**−10.99**	**1.07**	**0.23**	**0.39**	**4.027**
Fatal and injury (FI)	−13.14	1.18	0.22	0.33	1.233
Property damage only (PDO)	−11.02	1.02	0.24	0.44	2.647

Worksheet SP4C. Continued

(1)	(5)	(6)	(7)	(8)	(9)
		Adjusted N_{bimv}	**Combined CMFs**		**Predicted N_{bimv}**
Crash Severity Level	**Proportion of Total Crashes**	**$(4)_{total}$*(5)**	**(7) from Worksheet SP4B**	**Calibration Factor, C_i**	**(6)*(7)*(8)**
Total	**1.000**	**4.027**	**0.66**	**1.00**	**2.658**
Fatal and injury (FI)	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$ 0.318	1.281	0.66	1.00	0.845
Property damage only (PDO)	$(5)_{total}-(5)_{FI}$ 0.682	2.746	0.66	1.00	1.812

Worksheet SP4D—Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

Worksheet SP4D presents the default proportions for collision type (from Table 12-11) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for multiple-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for multiple-vehicle crashes (from Column 9, Worksheet SP4C) into components by crash severity and collision type.

Worksheet SP4D. Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	**Predicted $N_{bimv\ (FI)}$ (crashes/year)**	**Proportion of Collision Type $_{(PDO)}$**	**Predicted $N_{bimv\ (PDO)}$ (crashes/year)**	**Predicted $N_{bimv\ (total)}$ (crashes/year)**
Collision Type	**from Table 12-11**	**$(9)_{FI}$ from Worksheet SP4C**	**from Table 12-11**	**$(9)_{PDO}$ from Worksheet SP4C**	**$(9)_{PDO}$ from Worksheet SP4C**
Total	1.000	0.845	1.000	1.812	2.658
		$(2)*(3)_{FI}$		$(4)*(5)_{PDO}$	(3)+(5)
Rear-end collision	0.450	0.380	0.483	0.875	1.255
Head-on collision	0.049	0.041	0.030	0.054	0.095
Angle collision	0.347	0.293	0.244	0.442	0.735
Sideswipe	0.099	0.084	0.032	0.058	0.142
Other multiple-vehicle collision	0.055	0.046	0.211	0.382	0.428

Worksheet SP4E—Single-Vehicle Crashes by Severity Level for Urban and Suburban Arterial Intersections

The SPF for single-vehicle crashes at the intersection in Sample Problem 4 is calculated using Equation 12-25 for total and property-damage-only (PDO) crashes and entered into Column 4 of Worksheet SP4E. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2, and 3; however, the overdispersion parameter is not needed for Sample Problem 4 (as the EB Method is not utilized). Column 5 of the worksheet presents the proportions for crash severity levels calculated from the results in Column 4. These proportions are used to adjust the initial SPF values (from Column 4) to assure that fatal-and-injury (FI) and property-damage-only (PDO) crashes sum to the total crashes as illustrated in Column 6. Column 7 represents the combined CMF (from Column 7 in Worksheet SP4B), and Column 8 represents the calibration factor. Column 9 calculates the predicted average crash frequency of single-vehicle crashes using the values in Column 6, the combined CMF in Column 7, and the calibration factor in Column 8.

Worksheet SP4E. Single-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

(1)	(2)			(3)	(4)
	SPF Coefficients from Table 12-12			Overdispersion Parameter, k	Initial N_{bisv}
Crash Severity Level	a	b	c	from Table 12-12	from Equation 12-25; (FI) from Equation 12-25 or 12-27
Total	−10.21	0.68	0.27	0.36	0.297
Fatal and injury (FI)	−9.25	0.43	0.29	0.09	0.084
Property damage only (PDO)	−11.34	0.78	0.25	0.44	0.209

Worksheet SP4E. Continued

(1)	(5)	(6)	(7)	(8)	(9)
		Adjusted N_{bisv}	Combined CMFs		Predicted N_{bisv}
Crash Severity Level	Proportion of Total Crashes	$(4)_{total}$*(5)	(7) from Worksheet SP4B	Calibration Factor, C_i	(6)*(7)*(8)
Total	1.000	0.297	0.66	1.000	0.196
Fatal and injury (FI)	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$ 0.287	0.085	0.66	1.000	0.056
Property damage only (PDO)	$(5)_{total}-(5)_{FI}$ 0.713	0.212	0.66	1.000	0.140

Worksheet SP4F—Single-Vehicle Crashes by Collision Type for Urban and Suburban Arterial Intersections

Worksheet SP4F presents the default proportions for collision type (from Table 12-13) by crash severity level as follows:

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

Using the default proportions, the predicted average crash frequency for single-vehicle crashes by collision type is presented in Columns 3 (Fatal and Injury, FI), 5 (Property Damage Only, PDO), and 6 (Total).

These proportions may be used to separate the predicted average crash frequency for single-vehicle crashes (from Column 9, Worksheet SP4E) into components by crash severity and collision type.

Worksheet SP4F. Single-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{bisv\,(FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{bisv\,(PDO)}$ (crashes/year)	Predicted $N_{bisv\,(total)}$ (crashes/year)
Collision Type	Table 12-13	$(9)_{FI}$ from Worksheet SP4E	Table 12-13	$(9)_{PDO}$ from Worksheet SP4E	$(9)_{PDO}$ from Worksheet SP4E
Total	1.000	0.056 $(2)*(3)_{FI}$	1.000	0.140 $(4)*(5)_{PDO}$	0.196 (3)+(5)
Collision with parked vehicle	0.001	0.000	0.001	0.000	0.000
Collision with animal	0.002	0.000	0.002	0.000	0.000
Collision with fixed object	0.744	0.042	0.870	0.122	0.164
Collision with other object	0.072	0.004	0.070	0.010	0.014
Other single-vehicle collision	0.040	0.002	0.023	0.003	0.005
Single-vehicle noncollision	0.141	0.008	0.034	0.005	0.013

Worksheet SP4H—Crash Modification Factors for Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections

In Step 10 of the predictive method, crash modification factors are applied to account for the effects of site specific geometric design and traffic control devices. Section 12.7 presents the tables and equations necessary for determining the CMF values for vehicle-pedestrian collision. Once the value for each CMF has been determined, all of the CMFs are multiplied together in Column 4 of Worksheet SP4H which indicates the combined CMF value for vehicle-pedestrian collisions.

Worksheet SP4H. Crash Modification Factors for Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections

(1)	(2)	(3)	(4)
CMF for Bus Stops	CMF for Schools	CMF for Alcohol Sales Establishments	Combined CMF
CMF_{1p}	CMF_{2p}	CMF_{3p}	(1)*(2)*(3)
from Table 12-28	from Table 12-29	from Table 12-30	
2.78	1.35	1.12	4.20

Worksheet SP4I—Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections

The predicted number of vehicle-pedestrian collisions per year for base conditions at a signalized intersection, Nped-base, is calculated using Equation 12-30 and entered into Column 4 of Worksheet SP4I. The coefficients for the SPF and the overdispersion parameter associated with the SPF are entered into Columns 2 and 3; however, the overdispersion parameter is not needed for Sample Problem 4 (as the EB Method is not utilized). Column 5 represents the combined CMF for vehicle-pedestrian collisions (from Column 4 in Worksheet SP4H), and Column 6 represents the calibration factor. Column 7 calculates the predicted average crash frequency of vehicle-pedestrian collisions using the values in Column 4, the combined CMF in Column 5, and the calibration factor in Column 6. Since all vehicle-pedestrian crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP4I. Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections

(1)	(2)					(3)	(4)	(5)	(6)	(7)
	SPF Coefficients						$N_{pedbase}$	Combined CMF		Predicted N_{pedi}
	from Table 12-14						from Equation 12-30	(4) from Worksheet SP4H		
Crash Severity Level	a	b	c	d	e	Overdispersion Parameter, k			Calibration Factor, C_i	(8)*(9)*(10)
Total	−9.53	0.40	0.26	0.45	0.04	0.24	0.113	4.20	1.00	0.475
Fatal and injury (FI)	—	—	—	—	—	—	—	—	1.00	0.475

Worksheet SP4J—Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

The predicted average crash frequency of multiple-vehicle predicted crashes and single-vehicle predicted crashes from Worksheets SP4C and SP4E are entered into Columns 2 and 3 respectively. These values are summed in Column 4. Column 5 contains the bicycle crash adjustment factor (see Table 12-17). Column 6 presents the calibration factor. The predicted average crash frequency of vehicle-bicycle collision (Column 7) is the product of Columns 4, 5, and 6. Since all vehicle-bicycle crashes are assumed to involve some level of injury, there are no property-damage-only crashes.

Worksheet SP4J. Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv}	Predicted N_{bisv}	Predicted N_{bi}	f_{bikei}		Predicted N_{pedi}
Crash Severity Level	(9) from Worksheet SP4C	(9) from Worksheet SP4E	(2)+(3)	from Table 12-17	Calibration Factor, C_i	(4)*(5)*(6)
Total	2.658	0.196	2.854	0.015	1.00	0.043
Fatal and injury (FI)	—	—	—	—	1.00	0.043

Worksheet SP4K—Crash Severity Distribution for Urban and Suburban Arterial Intersections

Worksheet SP4K provides a summary of all collision types by severity level. Values from Worksheets SP4D, SP4F, SP4I, and SP4J are presented and summed to provide the predicted average crash frequency for each severity level as follows:

- Fatal-and-injury crashes (Column 2)
- Property-damage-only crashes (Column 3)
- Total crashes (Column 4)

Worksheet SP4K. Crash Severity Distribution for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	**Property Damage Only (PDO)**	**Total**
Collision Type	**(3) from Worksheets SP4D and SP4F; (7) from SP4I and SP4J**	**(5) from Worksheets SP4D and SP4F**	**(6) from Worksheets SP4D and SP4F; (7) from SP4I and SP4J**
MULTIPLE-VEHICLE COLLISIONS			
Rear-end collisions (from Worksheet SP4D)	0.380	0.875	1.255
Head-on collisions (from Worksheet SP4D)	0.041	0.054	0.095
Angle collisions (from Worksheet SP4D)	0.293	0.442	0.735
Sideswipe (from Worksheet SP4D)	0.084	0.058	0.142
Other multiple-vehicle collision (from Worksheet SP4D)	0.046	0.382	0.428
Subtotal	0.844	1.811	2.655
SINGLE-VEHICLE COLLISIONS			
Collision with parked vehicle (from Worksheet SP4F)	0.000	0.000	0.000
Collision with animal (from Worksheet SP4F)	0.000	0.000	0.000
Collision with fixed object (from Worksheet SP4F)	0.042	0.122	0.164
Collision with other object (from Worksheet SP4F)	0.004	0.010	0.014
Other single-vehicle collision (from Worksheet SP4F)	0.002	0.003	0.005
Single-vehicle noncollision (from Worksheet SP4F)	0.008	0.005	0.013
Collision with pedestrian (from Worksheet SP4I)	0.475	0.000	0.475
Collision with bicycle (from Worksheet SP4J)	0.043	0.000	0.043
Subtotal	0.574	0.140	0.714
Total	1.418	1.951	3.369

Worksheet SP4L—Summary Results for Urban and Suburban Arterial Intersections

Worksheet SP4L presents a summary of the results.

Worksheet SP4L. Summary Results for Urban and Suburban Arterial Intersections

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	**(Total) from Worksheet SP4K**
Total	3.369
Fatal and injury (FI)	1.418
Property damage only (PDO)	1.951

12.13.5. Sample Problem 5

The Project

A project of interest consists of four sites located on an urban arterial: a three-lane TWLTL segment; a four-lane divided segment; a three-leg intersection with minor-road stop control; and a four-leg signalized intersection. (This project is a compilation of roadway segments and intersections from Sample Problems 1 through 4.)

The Question

What is the expected crash frequency of the project for a particular year incorporating both the predicted crash frequencies from Sample Problems 1 through 4 and the observed crash frequencies using the site-specific EB Method?

The Facts

- 2 roadway segments (3T segment, 4D segment)
- 2 intersections (3ST intersection, 4SG intersection)
- 34 observed crashes (3T segment: 7 multiple-vehicle nondriveway, 4 single-vehicle, 2 multiple-vehicle driveway related; 4D: 6 multiple-vehicle nondriveway, 3 single-vehicle, 1 multiple-vehicle driveway related; 3ST: 2 multiple-vehicle, 3 single-vehicle; 4SG 6 multiple-vehicle, 0 single-vehicle)

Outline of Solution

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

Results

The expected average crash frequency for the project is 25.4 crashes per year (rounded to one decimal place).

WORKSHEETS

To apply the site-specific EB Method to multiple roadway segments and intersections on an urban or suburban arterial combined, three worksheets are provided for determining the expected average crash frequency. The three worksheets include:

- *Worksheet SP5A (Corresponds to Worksheet 3A)—* Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Urban and Suburban Arterials.
- *Worksheet SP5B (Corresponds to Worksheet 3B)*—Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials.
- *Worksheet SP5C (Corresponds to Worksheet 3C)*—Site-Specific EB Method Summary Results for Urban and Suburban Arterials

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheets SP5A—Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Urban and Suburban Arterials.

The predicted average crash frequencies by severity level and collision type determined in Sample Problems 1 through 4 are entered into Columns 2 through 4 of Worksheet SP5A. Column 5 presents the observed crash frequencies by site and collision type, and Column 6 presents the overdispersion parameters. The expected average crash frequency is calculated by applying the site-specific EB Method which considers both the predicted model estimate and observed crash frequencies for each roadway segment and intersection. Equation A-5 from Part C, Appendix A is used to calculate the weighted adjustment and entered into Column 7. The expected average crash frequency is calculated using Equation A-4 and entered into Column 8. Detailed calculation of Columns 7 and 8 are provided below.

Worksheet SP5A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Collision Type/Site Type	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, k	Weighted Adjustment, w	Expected Average Crash Frequency, $N_{expected\ (vehicle)}$
	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$			Equation A-5	Equation A-4
ROADWAY SEGMENTS							
Multiple-Vehicle Nondriveway							
Segment 1	4.967	1.196	3.771	7	0.66	0.234	6.524
Segment 2	2.524	0.702	1.822	6	1.32	0.231	5.197
Single-Vehicle							
Segment 1	1.182	0.338	0.844	4	1.37	0.382	2.924
Segment 2	0.485	0.085	0.401	3	0.86	0.706	1.224
Multiple-Vehicle Driveway-Related							
Segment 1	0.734	0.179	0.555	2	1.10	0.553	1.300
Segment 2	0.149	0.042	0.107	1	1.39	0.828	0.295
INTERSECTIONS							
Multiple-Vehicle							
Intersection 1	1.268	0.405	0.862	2	0.80	0.496	1.637
Intersection 2	2.658	0.845	1.812	6	0.39	0.491	4.359
Single-Vehicle							
Intersection 1	0.234	0.072	0.162	3	1.14	0.789	0.818
Intersection 2	0.196	0.056	0.140	0	0.36	0.934	0.183
Combined (Sum of Column)	14.397	3.920	10.476	34	—	—	24.461

Column 7—Weighted Adjustment

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

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

Multiple-Vehicle Nondriveway Collisions

Segment 1

$$w = \frac{1}{1 + 0.66 \times (4.967)} = 0.234$$

Segment 2

$$w = \frac{1}{1 + 1.32 \times (2.524)} = 0.231$$

Single-Vehicle Crashes

Segment 1

$$w = \frac{1}{1 + 1.37 \times (1.182)} = 0.382$$

Segment 2

$$w = \frac{1}{1 + 0.86 \times (0.485)} = 0.706$$

Multiple-Vehicle Driveway Related Collisions

Segment 1

$$w = \frac{1}{1 + 1.10 \times (0.734)} = 0.553$$

Segment 2

$$w = \frac{1}{1 + 1.39 \times (0.149)} = 0.828$$

Multiple-Vehicle Collisions

Intersection 1

$$w = \frac{1}{1 + 0.80 \times (1.268)} = 0.496$$

Intersection 2

$$w = \frac{1}{1 + 0.39 \times (2.658)} = 0.491$$

Single-Vehicle Crashes

Intersection 1

$$w = \frac{1}{1 + 1.149 \times (0.234)} = 0.789$$

Intersection 2

$$w = \frac{1}{1 + 0.36 \times (0.196)} = 0.934$$

Column 8—Expected Average Crash Frequency

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

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

Multiple-Vehicle Nondriveway Collisions

Segment 1 $N_{expected} = 0.234 \times 4.967 + (1 - 0.234) \times 7 = 6.524$

Segment 2 $N_{expected} = 0.231 \times 2.524 + (1 - 0.231) \times 6 = 5.197$

Single-Vehicle Crashes

Segment 1 $N_{expected} = 0.382 \times 1.182 + (1 - 0.382) \times 4 = 2.924$

Segment 2 $N_{expected} = 0.706 \times 0.485 + (1 - 0.706) \times 3 = 1.224$

Multiple-Vehicle Driveway Related Collisions

Segment 1 $N_{expected} = 0.553 \times 0.734 + (1 - 0.553) \times 2 = 1.300$

Segment 2 $N_{expected} = 0.828 \times 0.149 + (1 - 0.828) \times 1 = 0.295$

Multiple-Vehicle Collisions

Intersection 1 $N_{expected} = 0.496 \times 1.268 + (1 - 0.496) \times 2 = 1.637$

Intersection 2 $N_{expected} = 0.491 \times 2.658 + (1 - 0.491) \times 6 = 4.359$

Single-Vehicle Crashes

Intersection 1 $N_{expected} = 0.789 \times 0.234 + (1 - 0.789) \times 3 = 0.818$

Intersection 2 $N_{expected} = 0.934 \times 0.196 + (1 - 0.934) \times 0 = 0.183$

Worksheets SP5B—Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

Worksheet SP5B provides a summary of the vehicle-pedestrian and vehicle-bicycle crashes determined in Sample Problems 1 through 4.

Worksheet SP5B. Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

(1)	(2)	(3)
Site Type	N_{ped}	N_{bike}
ROADWAY SEGMENTS		
Segment 1	0.089	0.048
Segment 2	0.212	0.041
INTERSECTIONS		
Intersection 1	0.032	0.024
Intersection 2	0.475	0.043
Combined (Sum of Column)	0.808	0.156

Worksheets SP5C—Site-Specific EB Method Summary Results for Urban and Suburban Arterials

Worksheet SP5C presents a summary of the results. Column 5 calculates the expected average crash frequency by severity level for vehicle crashes only by applying the proportion of predicted average crash frequency by severity level (Column 2) to the expected average crash frequency calculated using the site-specific EB Method. Column 6 calculates the total expected average crash frequency by severity level using the values in Column 3, 4, and 5.

Worksheet SP5C. Site-Specific EB Method Summary Results for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	N_{ped}	N_{bike}	$N_{expected\ (vehicle)}$	$N_{expected}$
Total	$(2)_{comb}$ Worksheet SP5A	$(2)_{comb}$ Worksheet SP5B	$(3)_{comb}$ Worksheet SP5B	$(13)_{comb}$ Worksheet SP5A	(3)+(4)+(5)
	14.397	0.808	0.156	24.461	25.4
Fatal and injury (FI)	$(3)_{comb}$ Worksheet SP5A	$(2)_{comb}$ Worksheet SP5B	$(3)_{comb}$ Worksheet SP5B	$(5)_{total}*(2)_{FI}/(2)total$	(3)+(4)+(5)
	3.920	0.808	0.156	6.660	7.6
Property damage only (PDO)	$(4)_{comb}$ Worksheet SP5A	—	—	$(5)_{total}*(2)_{PDO}/(2)_{total}$	(3)+(4)+(5)
	10.476	0.000	0.000	17.800	17.8

12.13.6. Sample Problem 6

The Project

A project of interest consists of four sites located on an urban arterial: a three-lane TWLTL segment; a four-lane divided segment; a three-leg intersection with minor-road stop control; and a four-leg signalized intersection. (This project is a compilation of roadway segments and intersections from Sample Problems 1 through 4.)

The Question

What is the expected average crash frequency of the project for a particular year incorporating both the predicted average crash frequencies from Sample Problems 1 through 4 and the observed crash frequencies using the **project-level EB Method?**

The Facts

- 2 roadway segments (3T segment, 4D segment)
- 2 intersection (3ST intersection, 4SG intersection)
- 34 observed crashes (but no information is available to attribute specific crashes to specific sites)

Outline of Solution

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

Results

The expected average crash frequency for the project is 26.0 crashes per year (rounded to one decimal place).

WORKSHEETS

To apply the project-level EB Method to multiple roadway segments and intersections on an urban or suburban arterial combined, three worksheets are provided for determining the expected average crash frequency. The three worksheets include:

- *Worksheet SP6A (Corresponds to Worksheet 4A)*—Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Urban and Suburban Arterials
- *Worksheet SP6B (Corresponds to Worksheet 4B)*—Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials
- *Worksheet SP6C (Corresponds to Worksheet 4C)*—Project-EB Method Summary Results for Urban and Suburban Arterials

Details of these sample problem worksheets are provided below. Blank versions of the corresponding worksheets are provided in Appendix 12A.

Worksheets SP6A—Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Urban and Suburban Arterials

The predicted average crash frequencies by severity level and collision type, excluding vehicle-pedestrian and vehicle-bicycle collisions, determined in Sample Problems 1 through 4 are entered in Columns 2 through 4 of Worksheet SP6A. Column 5 presents the total observed crash frequencies combined for all sites, and Column 6 presents the overdispersion parameters. The expected average crash frequency is calculated by applying the project-level EB Method which considers both the predicted model estimate for each roadway segment and intersection and the project observed crashes. Column 7 calculates N_{w0}, and Column 8 calculates N_{w1}. Equations A-10 through A-14 from Part C, Appendix A are used to calculate the expected average crash frequency of combined sites. The results obtained from each equation are presented in Columns 9 through 14. Part C, Appendix A.2.5 defines all the variables used in this worksheet. Detailed calculations of Columns 9 through 13 are provided below.

Worksheet SP6A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
	Predicted Crashes			**Observed Crashes,**	**Overdispersion**
Collision Type/Site Type	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$	$N_{observed}$ **(crashes/year)**	**Parameter, k**
ROADWAY SEGMENTS					
Multiple-Vehicle Nondriveway					
Segment 1	4.967	1.196	3.771	—	0.66
Segment 2	2.524	0.702	1.822	—	1.32
Single-Vehicle					
Segment 1	1.182	0.338	0.844	—	1.37
Segment 2	0.485	0.085	0.401	—	0.86
Multiple-Vehicle Driveway-Related					
Segment 1	0.734	0.179	0.555	—	1.10
Segment 2	0.149	0.042	0.107	—	1.39
INTERSECTIONS					
Multiple-Vehicle					
Intersection 1	1.268	0.405	0.862	—	0.80
Intersection 2	2.658	0.845	1.812	—	0.39
Single-Vehicle					
Intersection 1	0.234	0.072	0.162	—	1.14
Intersection 2	0.196	0.056	0.140	—	0.36
Combined (Sum of Column)	14.397	3.920	10.476	34	—

Worksheet SP6A continued on next page

Worksheet SP6A. Continued

(1)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
	$N_{predicted\ w0}$	$N_{predicted\ w1}$	w_0	N_0	w_1	N_1	$N_{expected/comb\ (vehicle)}$
Collision Type/Site Type	**Equation A-8 (6)*(2)²**	**Equation A-9 (sqrt((6)*(2))**	**Equation A-10**	**Equation A-11**	**Equation A-12**	**Equation A-13**	**Equation A-14**
ROADWAY SEGMENTS							
Multiple-Vehicle Nondriveway							
Segment 1	16.283	1.811	—	—	—	—	—
Segment 2	8.409	1.825	—	—	—	—	—
Single-Vehicle							
Segment 1	1.914	1.273	—	—	—	—	—
Segment 2	0.202	0.646	—	—	—	—	—
Multiple-Vehicle Driveway-Related							
Segment 1	0.593	0.899	—	—	—	—	—
Segment 2	0.031	0.455	—	—	—	—	—
INTERSECTIONS							
Multiple-**Vehicle**							
Intersection 1	1.286	1.007	—	—	—	—	—
Intersection 2	2.755	1.018	—	—	—	—	—
Single-Vehicle							
Intersection 1	0.062	0.516	—	—	—	—	—
Intersection 2	0.014	0.266	—	—	—	—	—
Combined (Sum of Column)	31.549	9.716	0.313	27.864	0.597	22.297	25.080

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

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

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

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

Column 9—w_0

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

$$w_0 = \frac{1}{1 + \frac{N_{\text{predicted } w0}}{N_{\text{predicted (total)}}}} = \frac{1}{1 + \frac{31.549}{14.397}} = 0.313$$

Column 10—N_0
The expected crash frequency based on the assumption that different roadway elements are statistically independent, N_0, is calculated using Equation A-11 as follows:

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

$$= 0.313 \times 14.397 + (1 - 0.313) \times 34$$

$$= 27.864$$

Column 11—w_1
The weight placed on predicted crash frequency under the assumption that crashes frequencies for different roadway elements are perfectly correlated, w_1, is calculated using Equation A-12 as follows:

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

$$= \frac{1}{1+\frac{9.716}{14.397}}$$

$$= 0.597$$

Column 12—N_1
The expected crash frequency based on the assumption that different roadway elements are perfectly correlated, N_1, is calculated using Equation A-13 as follows:

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

$$= 0.597 \times 14.397 + (1 - 0.597) \times 34$$

$$= 22.297$$

Column 13—$N_{\text{expected}/comb}$
The expected average crash frequency based of combined sites, $N_{\text{expected}/comb}$, is calculated using Equation A-14 as follows:

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

$$= \frac{27.864 + 22.297}{2}$$

$$= 25.080$$

Worksheets SP6B—Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

Worksheet SP6B provides a summary of the vehicle-pedestrian and vehicle-bicycle crashes determined in Sample Problems 1 through 4.

Worksheet SP6B. Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

(1)	(2)	(3)
Site Type	N_{ped}	N_{bike}
ROADWAY SEGMENTS		
Segment 1	0.089	0.048
Segment 2	0.212	0.041
INTERSECTIONS		
Intersection 1	0.032	0.024
Intersection 2	0.475	0.043
Combined (Sum of Column)	0.808	0.156

Worksheets SP6C—Project-Level EB Method Summary Results for Urban and Suburban Arterials

Worksheet SP6C presents a summary of the results. Column 5 calculates the expected average crash frequency by severity level for vehicle crashes only by applying the proportion of predicted average crash frequency by severity level (Column 2) to the expected average crash frequency calculated using the project-level EB Method. Column 6 calculates the total expected average crash frequency by severity level using the values in Column 3, 4, and 5.

Worksheet SP6C. Project-Level EB Method Summary Results for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	N_{ped}	N_{bike}	$N_{expected/comb\ (vehicle)}$	$N_{expected}$
Total	$(2)_{comb}$ Worksheet SP6A	$(2)_{comb}$ Worksheet SP6B	$(3)_{comb}$ Worksheet SP6B	$(13)_{comb}$ Worksheet SP6A	(3)+(4)+(5)
	14.397	0.808	0.156	25.080	26.0
Fatal and injury (FI)	$(3)_{comb}$ Worksheet SP6A	$(2)_{comb}$ Worksheet SP6B	$(3)_{comb}$ Worksheet SP6B	$(5)_{total}*(2)_{FI}/(2)_{total}$	(3)+(4)+(5)
	3.920	0.808	0.156	6.829	7.8
Property damage only (PDO)	$(4)_{comb}$ Worksheet SP6A	—	—	$(5)_{total}*(2)_{PDO}/(2)_{total}$	(3)+(4)+(5)
	10.476	0.000	0.000	18.250	18.3

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APPENDIX 12A—WORKSHEETS FOR PREDICTIVE METHOD FOR URBAN AND SUBURBAN ARTERIALS

Worksheet 1A. General Information and Input Data for Urban and Suburban Roadway Segments

General Information	**Location Information**	
Analyst	Roadway	
Agency or Company	Roadway Section	
Date Performed	Jurisdiction	
	Analysis Year	
Input Data	**Base Conditions**	**Site Conditions**
Road type (2U, 3T, 4U, 4D, 5T)	—	
Length of segment, L (mi)	—	
AADT (veh/day)	—	
Type of on-street parking (none/parallel/angle)	none	
Proportion of curb length with on-street parking	—	
Median width (ft)	15	
Lighting (present / not present)	not present	
Auto speed enforcement (present/not present)	not present	
Major commercial driveways (number)	—	
Minor commercial driveways (number)	—	
Major industrial/institutional driveways (number)	—	
Minor industrial/institutional driveways (number)	—	
Major residential driveways (number)	—	
Minor residential driveways (number)	—	
Other driveways (number)	—	
Speed Category	—	
Roadside fixed object density (fixed objects/mi)	not present	
Offset to roadside fixed objects (ft)	not present	
Calibration Factor, C_r	1.0	

Worksheet 1B. Crash Modification Factors for Urban and Suburban Roadway Segments

(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
CMF for On-Street Parking	**CMF for Roadside Fixed Objects**	**CMF for Median Width**	**CMF for Lighting**	**CMF for Auto Speed Enforcement**	**Combined CMF**
CMF_{1r}	CMF_{2r}	CMF_{3r}	CMF_{4r}	CMF_{5r}	CMF_{comb}
from Equation 12-32	from Equation 12-33	from Table 12-22	from Equation 12-34	from Section 12.7.1	(1)*(2)*(3)*(4)*(5)

Worksheet 1C. Multiple-Vehicle Nondriveway Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)
	SPF Coefficients		Overdispersion Parameter, k	Initial N_{brmv}
	from Table 12-3			
Crash Severity Level	a	b	from Table 12-3	from Equation 12-10
Total				
Fatal and injury (FI)				
Property damage only (PDO)				

Worksheet 1C. continued

(1)	(5)	(6)	(7)	(8)	(9)
		Adjusted N_{brmv}	Combined CMFs	Calibration Factor	Predicted N_{brmv}
Crash Severity Level	Proportion of Total Crashes	$(4)_{total}*(5)$	(6) from Worksheet 1B	C_r	(6)*(7)*(8)
Total					
Fatal and injury (FI)	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$				
Property damage only (PDO)	$(5)_{total}-(5)_{FI}$				

Worksheet 1D. Multiple-Vehicle Nondriveway Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{brmv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{brmv\ (PDO)}$ (crashes/year)	Predicted $N_{brmv\ (total)}$ (crashes/year)
Collision Type	from Table 12-4	$(9)_{FI}$ from Worksheet 1C	from Table 12-4	$(9)_{PDO}$ from Worksheet 1C	$(9)_{total}$ from Worksheet 1C
Total	1.000		1.000		
		$(2)*(3)_{FI}$		$(4)*(5)_{PDO}$	(3)+(5)
Rear-end collision					
Head-on collision					
Angle collision					
Sideswipe, same direction					
Sideswipe, opposite direction					
Other multiple-vehicle collision					

Worksheet 1E. Single-Vehicle Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)		(3)	(4)	(5)	(6)	(7)	(8)	(9)
	SPF Coefficients		Overdispersion Parameter, k	Initial N_{brsv}		Adjusted N_{brsv}	Combined CMFs	Calibration Factor	Predicted N_{brsv}
Crash Severity Level	from Table 12-5		from Table 12-5	from Equation 12-13	Proportion of Total Crashes	$(4)_{total}$*(5)	(6) from Worksheet 1B	C_r	(6)*(7)*(8)
	a	b							
Total									
Fatal and injury (FI)					$(4)_{FI}/((4)_{FI}+(4)_{PDO})$				
Property damage only (PDO)					$(5)_{total}-(5)_{FI}$				

Worksheet 1F. Single-Vehicle Collisions by Collision Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{brsv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{brsv\ (PDO)}$ (crashes/year)	Predicted $N_{brsv\ (total)}$ (crashes/year)
Collision Type	from Table 12-6	$(9)_{FI}$ from Worksheet 1E	from Table 12-6	$(9)_{PDO}$ from Worksheet 1E	$(9)_{total}$ from Worksheet 1E
Total	1.000	(2)*$(3)_{FI}$	1.000	(4)*$(5)_{PDO}$	(3)+(5)
Collision with animal					
Collision with fixed object					
Collision with other object					
Other single-vehicle collision					

Worksheet 1G. Multiple-Vehicle Driveway-Related Collisions by Driveway Type for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)
		Crashes per Driveway per Year, N_j	**Coefficient for Traffic Adjustment, t**	**Initial N_{brdwy}**	**Overdispersion Parameter, k**
Driveway Type	**Number of Driveways, n_j**	**from Table 12-7**	**from Table 12-7**	**Equation 12-16 n_j*N_j*(AADT/15,000)t**	**from Table 12-7**
Major commercial					—
Minor commercial					
Major industrial/ institutional					
Minor industrial/ institutional					
Major residential					
Minor residential					
Other					
Total	—	—	—		

Worksheet 1H. Multiple-Vehicle Driveway-Related Collisions by Severity Level for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Initial N_{brdwy}	**Proportion of Total Crashes (f_{dwy})**	**Adjusted N_{brdwy}**	**Combined CMFs**		**Predicted N_{brdwy}**
Crash Severity Level	**$(5)_{total}$ from Worksheet 1G**	**from Table 12-7**	**$(2)_{total}$ *(3)**	**(6) from Worksheet 1B**	**Calibration Factor, C_r**	**(4)*(5)*(6)**
Total						
Fatal and injury (FI)	—					
Property damage only (PDO)	—					

Worksheet 1I. Vehicle-Pedestrian Collisions for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted N_{brmv}	**Predicted N_{brsv}**	**Predicted N_{brdwy}**	**Predicted N_{br}**	**f_{pedr}**		**Predicted N_{pedr}**
Crash Severity Level	(9) from Worksheet 1C	(9) from Worksheet 1E	(7) from Worksheet 1H	(2)+(3)+(4)	from Table 12-8	**Calibration Factor, C_r**	(5)*(6)*(7)
Total							
Fatal and injury (FI)	—	—	—	—	—		

Worksheet 1J. Vehicle-Bicycle Collisions for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Predicted N_{brmv}	Predicted N_{brsv}	Predicted N_{brdwy}	Predicted N_{br}	f_{biker}		Predicted N_{biker}
Crash Severity Level	(9) from Worksheet 1C	(9) from Worksheet 1E	(7) from Worksheet 1H	(2)+(3)+(4)	from Table 12-9	Calibration Factor, C_r	(5)*(6)*(7)
Total							
Fatal and injury	—	—	—	—	—		

Worksheet 1K. Crash Severity Distribution for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	Property Damage Only (PDO)	Total
Collision Type	(3) from Worksheets 1D and 1F; (7) from Worksheet 1H; and (8) from Worksheets 1I and 1J	(5) from Worksheets 1D and 1F; and (7) from Worksheet 1H	(6) from Worksheets 1D and 1F; (7) from Worksheet 1H; and (8) from Worksheets 1I and 1J
MULTIPLE-VEHICLE			
Rear-end collisions (from Worksheet 1D)			
Head-on collisions (from Worksheet 1D)			
Angle collisions (from Worksheet 1D)			
Sideswipe, same direction (from Worksheet 1D)			
Sideswipe, opposite direction (from Worksheet 1D)			
Driveway-related collisions (from Worksheet 1H)			
Other multiple-vehicle collision (from Worksheet 1D)			
Subtotal			
SINGLE-VEHICLE			
Collision with animal (from Worksheet 1F)			
Collision with fixed object (from Worksheet 1F)			
Collision with other object (from Worksheet 1F)			
Other single-vehicle collision (from Worksheet 1F)			
Collision with pedestrian (from Worksheet 1I)			
Collision with bicycle (from Worksheet 1J)			
Subtotal			
Total			

Worksheet 1L. Summary Results for Urban and Suburban Roadway Segments

(1)	(2)	(3)	(4)
	Predicted Average Crash Frequency, $N_{predicted\ rs}$ (crashes/year)	**Roadway Segment Length, L (mi)**	**Crash Rate (crashes/mi/year)**
Crash Severity Level	(total) from Worksheet 1K		(2)/(3)
Total			
Fatal and injury (FI)			
Property damage only (PDO)			

Worksheet 2A. General Information and Input Data for Urban and Suburban Arterial Intersections

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

Input Data	**Base Conditions**	**Site Conditions**
Intersection type (3ST, 3SG, 4ST, 4SG)	—	
$AADT_{maj}$ (veh/day)	—	
$AADT_{min}$ (veh/day)	—	
Intersection lighting (present/not present)	not present	
Calibration factor, C_i	1.00	
Data for unsignalized intersections only:	—	
Number of major-road approaches with left-turn lanes (0, 1, 2)	0	
Number of major-road approaches with right-turn lanes (0, 1, 2)	0	
Data for signalized intersections only:	—	
Number of approaches with left-turn lanes (0, 1, 2, 3, 4)	0	
Number of approaches with right-turn lanes (0, 1, 2, 3, 4)	0	
Number of approaches with left-turn signal phasing	—	
Number of approaches with right-turn-on-red prohibited	0	
Type of left-turn signal phasing	permissive	
Intersection red-light cameras (present/not present)	not present	
Sum of all pedestrian crossing volumes (PedVol)	—	
Maximum number of lanes crossed by a pedestrian (n_{lanesx})	—	
Number of bus stops within 300 m (1,000 ft) of the intersection	0	
Schools within 300 m (1,000 ft) of the intersection (present/not present)	not present	
Number of alcohol sales establishments within 300 m (1,000 ft) of the intersection	0	

Worksheet 2B. Crash Modification Factors for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
CMF for Left-Turn Lanes	**CMF for Left-Turn Signal Phasing**	**CMF for Right-Turn Lanes**	**CMF for Right-Turn-on-Red**	**CMF for Lighting**	**CMF for Red-Light Cameras**	**Combined CMF**
CMF_{1i}	CMF_{2i}	CMF_{3i}	CMF_{4i}	CMF_{5i}	CMF_{6i}	CMF_{comb}
from Table 12-24	from Table 12-25	from Table 12-26	from Equation 12-35	from Equation 12-36	from Equation 12-37	(1)*(2)*(3)*(4)*(5)*(6)

Worksheet 2C. Multiple-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

(1)	(2)			(3)	(4)
	SPF Coefficients			**Overdispersion Parameter, k**	**Initial N_{bimv}**
	from Table 12-10				
Crash Severity Level	**a**	**b**	**c**	**from Table 12-10**	**from Equation 12-22**
Total					
Fatal and injury (FI)					
Property damage only (PDO)					

Worksheet 2C. Continued

(1)	(5)	(6)	(7)	(8)	(9)
		Adjusted N_{bimv}	**Combined CMFs**		**Predicted N_{bimv}**
Crash Severity Level	**Proportion of Total Crashes**	**$(4)_{total}$*(5)**	**(7) from Worksheet 2B**	**Calibration Factor, C_i**	**(6)*(7)*(8)**
Total					
Fatal and injury (FI)	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$				
Property damage only (PDO)	$(5)_{total}-(5)_{FI}$				

Worksheet 2D. Multiple-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	**Predicted $N_{bimv\ (FI)}$ (crashes/year)**	**Proportion of Collision Type $_{(PDO)}$**	**Predicted $N_{bimv\ (PDO)}$ (crashes/year)**	**Predicted $N_{bimv\ (total)}$ (crashes/year)**
Collision Type	from Table 12-11	$(9)_{FI}$ from Worksheet 2C	from Table 12-11	$(9)_{PDO}$ from Worksheet 2C	$(9)_{PDO}$ from Worksheet 2C
Total	1.000	$(2)*(3)_{FI}$	1.000	$(4)*(5)_{PDO}$	(3)+(5)
Rear-end collision					
Head-on collision					
Angle collision					
Sideswipe					
Other multiple-vehicle collision					

Worksheet 2E. Single-Vehicle Collisions by Severity Level for Urban and Suburban Arterial Intersections

(1)	(2)			(3)	(4)
	SPF Coefficients			Overdispersion Parameter, k	Initial N_{bisv}
	from Table 12-12				
Crash Severity Level	a	b	c	from Table 12-12	from Equation 12-25; (FI) from Equation 12-25 or 12-27
Total					
Fatal and injury (FI)					
Property damage only (PDO)					

Worksheet 2E. Continued

(1)	(5)	(6)	(7)	(8)	(9)
		Adjusted N_{bisv}	Combined CMFs		Predicted N_{bisv}
Crash Severity Level	Proportion of Total Crashes	$(4)_{total}$*(5)	(7) from Worksheet 2B	Calibration Factor, C_i	(6)*(7)*(8)
Total					
Fatal and injury (FI)	$(4)_{FI}/((4)_{FI}+(4)_{PDO})$				
Property damage only (PDO)	$(5)_{total}-(5)_{FI}$				

Worksheet 2F. Single-Vehicle Collisions by Collision Type for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)
	Proportion of Collision Type $_{(FI)}$	Predicted $N_{bisv\ (FI)}$ (crashes/year)	Proportion of Collision Type $_{(PDO)}$	Predicted $N_{bisv\ (PDO)}$ (crashes/year)	Predicted $N_{bisv\ (total)}$ (crashes/year)
Collision Type	Table 12-13	$(9)_{FI}$ from Worksheet 2E	Table 12-13	$(9)_{PDO}$ from Worksheet 2E	$(9)_{PDO}$ from Worksheet 2E
Total	1.000	$(2)*(3)_{FI}$	1.000	$(4)*(5)_{PDO}$	(3)+(5)
Collision with parked vehicle					
Collision with animal					
Collision with fixed object					
Collision with other object					
Other single-vehicle collision					
Single-vehicle noncollision					

Worksheet 2G. Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Stop-Controlled Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv}	Predicted N_{bisv}	Predicted N_{bi}	f_{pedi}		Predicted N_{pedi}
Crash Severity Level	(9) from Worksheet 2C	(9) from Worksheet 2E	(2)+(3)	from Table 12-16	Calibration Factor, C_i	(4)*(5)*(6)
Total						
Fatal and injury (FI)	—	—	—	—		

Worksheet 2H. Crash Modification Factors for Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections

(1)	(2)	(3)	(4)
CMF for Bus Stops	**CMF for Schools**	**CMF for Alcohol Sales Establishments**	**Combined CMF**
CMF_{1p}	**CMF_{2p}**	**CMF_{3p}**	
from Table 12-28	**from Table 12-29**	**from Table 12-30**	**(1)*(2)*(3)**

Worksheet 2I. Vehicle-Pedestrian Collisions for Urban and Suburban Arterial Signalized Intersections

(1)	(2)					(3)	(4)	(5)	(6)	(7)
	SPF Coefficients						**$N_{pedbase}$**	**Combined CMF**		**Predicted N_{pedi}**
	from Table 12-14									
Crash Severity Level	**a**	**b**	**c**	**d**	**e**	**Overdispersion Parameter, *k***	**from Equation 12-30**	**(4) from Worksheet 2H**	**Calibration Factor, C_i**	**(8)*(9)*(10)**
Total										
Fatal and injury (FI)	—	—	—	—	—	—	—	—		

Worksheet 2J. Vehicle-Bicycle Collisions for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted N_{bimv}	**Predicted N_{bisv}**	**Predicted N_{bi}**	**f_{bikei}**		**Predicted N_{pedi}**
Crash Severity Level	**(9) from Worksheet 2C**	**(9) from Worksheet 2E**	**(2)+(3)**	**from Table 12-17**	**Calibration Factor, Ci**	**(4)*(5)*(6)**
Total						
Fatal and injury (FI)	—	—	—	—		

Worksheet 2K. Crash Severity Distribution for Urban and Suburban Arterial Intersections

(1)	(2)	(3)	(4)
	Fatal and Injury (FI)	**Property Damage Only (PDO)**	**Total**
Collision Type	**(3) from Worksheets 2D and 2F; (7) from Worksheets 2G or 2I and 2J**	**(5) from Worksheets 2D and 2F**	**(6) from Worksheets 2D and 2F; (7) from Worksheets 2G or 2I and 2J**
MULTIPLE-VEHICLE COLLISIONS			
Rear-end collisions (from Worksheet 2D)			
Head-on collisions (from Worksheet 2D)			
Angle collisions (from Worksheet 2D)			
Sideswipe (from Worksheet 2D)			
Other multiple-vehicle collision (from Worksheet 2D)			
Subtotal			
SINGLE-VEHICLE COLLISIONS			
Collision with parked vehicle (from Worksheet 2F)			
Collision with animal (from Worksheet 2F)			
Collision with fixed object (from Worksheet 2F)			
Collision with other object (from Worksheet 2F)			
Other single-vehicle collision (from Worksheet 2F)			
Single-vehicle noncollision (from Worksheet 2F)			
Collision with pedestrian (from Worksheet 2G or 2I)			
Collision with bicycle (from Worksheet 2J)			
Subtotal			
Total			

Worksheet 2L. Summary Results for Urban and Suburban Arterial Intersections

(1)	(2)
	Predicted Average Crash Frequency, $N_{predicted\ int}$ (crashes/year)
Crash Severity Level	(Total) from Worksheet 2K
Total	
Fatal and injury (FI)	
Property damage only (PDO)	

Worksheet 3A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Site-Specific EB Method for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Collision Type/ Site Type	Predicted Average Crash Frequency (crashes/year)			Observed Crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, k	Weighted Adjustment, *w*	Expected Average Crash Frequency, $N_{expected}$ (vehicle)
	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$			Equation A-5	Equation A-4
ROADWAY SEGMENTS							
Multiple-Vehicle Nondriveway							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
Single-Vehicle							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
Multiple-Vehicle Driveway-Related							
Segment 1							
Segment 2							
Segment 3							
Segment 4							
INTERSECTIONS							
Multiple-Vehicle							
Intersection 1							
Intersection 2							
Intersection 3							
Intersection 4							
Single-Vehicle							
Intersection 1							
Intersection 2							
Intersection 3							
Intersection 4							
Combined (Sum of Column)					—	—	

Worksheet 3B. Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

(1)	(2)	(3)
Site Type	$\mathbf{N}_{ped}$	$\mathbf{N}_{bike}$
ROADWAY SEGMENTS		
Segment 1		
Segment 2		
Segment 3		
Segment 4		
INTERSECTIONS		
Intersection 1		
Intersection 2		
Intersection 3		
Intersection 4		
Combined (Sum of Column)		

Worksheet 3C. Site-Specific EB Method Summary Results for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$\mathbf{N}_{predicted}$	$\mathbf{N}_{ped}$	$\mathbf{N}_{bike}$	$\mathbf{N}_{expected\ (vehicle)}$	$\mathbf{N}_{expected}$
Total	$(2)_{comb}$ Worksheet 3A	$(2)_{comb}$ Worksheet 3B	$(3)_{comb}$ Worksheet 3B	$(13)_{comb}$ Worksheet 3A	(3)+(4)+(5)
Fatal and injury (FI)	$(3)_{comb}$ Worksheet 3A	$(2)_{comb}$ Worksheet 3B	$(3)_{comb}$ Worksheet 3B	$(5)_{total}$*$(2)_{FI}$/$(2)_{total}$	(3)+(4)+(5)
Property damage only (PDO)	$(4)_{comb}$ Worksheet 3A	— 0.000	— 0.000	$(5)_{total}$*$(2)_{PDO}$/$(2)_{total}$	(3)+(4)+(5)

Worksheet 4A. Predicted Crashes by Collision and Site Type and Observed Crashes Using the Project-Level EB Method for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Predicted Crashes			Observed Crashes, $N_{observed}$ (crashes/year)	Overdispersion Parameter, k	$N_{predicted\ wo}$
Collision Type/Site Type	$N_{predicted\ (total)}$	$N_{predicted\ (FI)}$	$N_{predicted\ (PDO)}$			Equation A-8 (6)*(2)^2
ROADWAY SEGMENTS						
Multiple-Vehicle Nondriveway						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
Single-Vehicle						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
Multiple-Vehicle Driveway-Related						
Segment 1				—		
Segment 2				—		
Segment 3				—		
Segment 4				—		
INTERSECTIONS						
Multiple-Vehicle						
Intersection 1				—		
Intersection 2				—		
Intersection 3				—		
Intersection 4				—		
Single-Vehicle						
Intersection 1				—		
Intersection 2				—		
Intersection 3				—		
Intersection 4				—		
Combined (Sum of Column)						

Worksheet 4A. continued

(1)	(8)	(9)	(10)	(11)	(12)	(13)
	$N_{predicted\ w1}$	w_o	N_o	w_1	N_1	$N_{expected/comb}$ (vehicle)
Collision Type/ 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						
Multiple-Vehicle Nondriveway						
Segment 1		—	—	—	—	—
Segment 2		—	—	—	—	—
Segment 3		—	—	—	—	—
Segment 4		—	—	—	—	—
Single-Vehicle						
Segment 1		—	—	—	—	—
Segment 2		—	—	—	—	—
Segment 3		—	—	—	—	—
Segment 4		—	—	—	—	—
Multiple-Vehicle Driveway-Related						
Segment 1		—	—	—	—	—
Segment 2		—	—	—	—	—
Segment 3		—	—	—	—	—
Segment 4		—	—	—	—	—
INTERSECTIONS						
Multiple-Vehicle						
Intersection 1		—	—	—	—	—
Intersection 2		—	—	—	—	—
Intersection 3		—	—	—	—	—
Intersection 4		—	—	—	—	—
Single-Vehicle						
Intersection 1		—	—	—		—
Intersection 2		—	—	—		—
Intersection 3		—	—	—		—
Intersection 4		—	—	—		—
Combined (Sum of Column)						

Worksheet 4B. Predicted Pedestrian and Bicycle Crashes for Urban and Suburban Arterials

(1)	(2)	(3)
Site Type	N_{ped}	N_{bike}
ROADWAY SEGMENTS		
Segment 1		
Segment 2		
Segment 3		
Segment 4		
INTERSECTIONS		
Intersection 1		
Intersection 2		
Intersection 3		
Intersection 4		
Combined (Sum of Column)		

Worksheet 4C. Project-Level EB Method Summary Results for Urban and Suburban Arterials

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	$N_{predicted}$	N_{ped}	N_{bike}	$N_{expected/comb\ (vehicle)}$	$N_{expected}$
Total	$(2)_{comb}$ Worksheet 4A	$(2)_{comb}$ Worksheet 4B	$(3)_{comb}$ Worksheet 4B	$(13)_{comb}$ Worksheet 4A	(3)+(4)+(5)
Fatal and injury (FI)	$(3)_{comb}$ Worksheet 4A	$(2)_{comb}$ Worksheet 4B	$(3)_{comb}$ Worksheet 4B	$(5)_{total}*(2)_{FI}/(2)_{total}$	(3)+(4)+(5)
Property damage only (PDO)	$(4)_{comb}$ Worksheet 4A	—	—	$(5)_{total}*(2)_{PDO}/(2)_{total}$	(3)+(4)+(5)
		0.000	0.000		