Part C—Introduction and Applications Guidance

C.1. INTRODUCTION TO THE *HIGHWAY SAFETY MANUAL* PREDICTIVE METHOD

Part C provides a predictive method for estimating expected average crash frequency (including by crash severity and collision types) of a network, facility, or individual site. The estimate can be made for existing conditions, alternatives to existing conditions (e.g., proposed upgrades or treatments), or proposed new roadways. The predictive method is applied to a given time period, traffic volume, and constant geometric design characteristics of the roadway.

The predictive method provides a quantitative measure of expected average crash frequency under both existing conditions and conditions which have not yet occurred. This allows proposed roadway conditions to be quantitatively assessed along with other considerations such as community needs, capacity, delay, cost, right-of-way, and environmental considerations.

The predictive method can be used for evaluating and comparing the expected average crash frequency of situations such as:

- Existing facilities under past or future traffic volumes;
- Alternative designs for an existing facility under past or future traffic volumes;
- Designs for a new facility under future (forecast) traffic volumes;
- The estimated effectiveness of countermeasures after a period of implementation; and
- The estimated effectiveness of proposed countermeasures on an existing facility (prior to implementation).

Part C—Introduction and Applications Guidance presents the predictive method in general terms for the first-time user to understand the concepts applied in each of the Part C chapters. Each chapter in Part C provides the detailed steps of the predictive method and the predictive models required to estimate the expected average crash frequency for a specific facility type. The following roadway facility types are included in Part C:

- *Chapter 10*—Rural Two-Lane, Two-Way Roads
- *Chapter 11*—Rural Multilane Highways
- *Chapter 12*—Urban and Suburban Arterials

The Part C—Introduction and Applications Guidance also provides:

- Relationships between Part C and Parts A, B, and D;
- Relationship between Part C and the Project Development Process;
- An overview of the predictive method;

- A summary of the predictive method;
- Detailed information needed to understand the concepts and elements in each of the steps of the predictive method;
- Methods for estimating the change in crash frequency due to a treatment;
- Limitations of the predictive method; and
- Guidance for applying the predictive method.

C.2. RELATIONSHIP TO PARTS A, B, AND D

All information needed to apply the predictive method is presented in Part C. The relationships of the predictive method in Part C to the contents of Parts A, B, and D are summarized below.

- Part A introduces concepts that are fundamental to understanding the methods provided in the HSM to analyze and evaluate crash frequencies. Part A introduces the key components of the predictive method, including safety performance functions (SPFs) and crash modification factors (CMFs). Prior to using the information in Part C, an understanding of the material in Chapter 3, Fundamentals is recommended.
- Part B presents the six basic components of a roadway safety management process. The material is useful for monitoring, improving, and maintaining an existing roadway network. Applying the methods and information presented in Part B can help to identify sites most likely to benefit from an improvement, diagnose crash patterns at specific sites, select appropriate countermeasures likely to reduce crashes, and anticipate the benefits and costs of potential improvements. In addition, it helps agencies determine whether potential improvements are economically justified, establish priorities for potential improvements, and assess the effectiveness of improvements that have been implemented. The predictive method in Part C provides tools to estimate the expected average crash frequency for application in Chapter 4, Network Screening and Chapter 7, Economic Appraisal.
- Part D contains all of the CMFs in the HSM. The CMFs in Part D are used to estimate the change in expected average crash frequency as a result of implementing a countermeasure(s). Some Part D CMFs are included in Part C for use with specific SPFs. Other Part D CMFs are not presented in Part C but can be used in the methods to estimate change in crash frequency described in Section C.7.

C.3. PART C AND THE PROJECT DEVELOPMENT PROCESS

- Figure C-1 illustrates the relationship of the Part C predictive method to the project development process. As discussed in Chapter 1, the project development process is the framework used in the HSM to relate crash analysis to activities within planning, design, construction, operations, and maintenance.

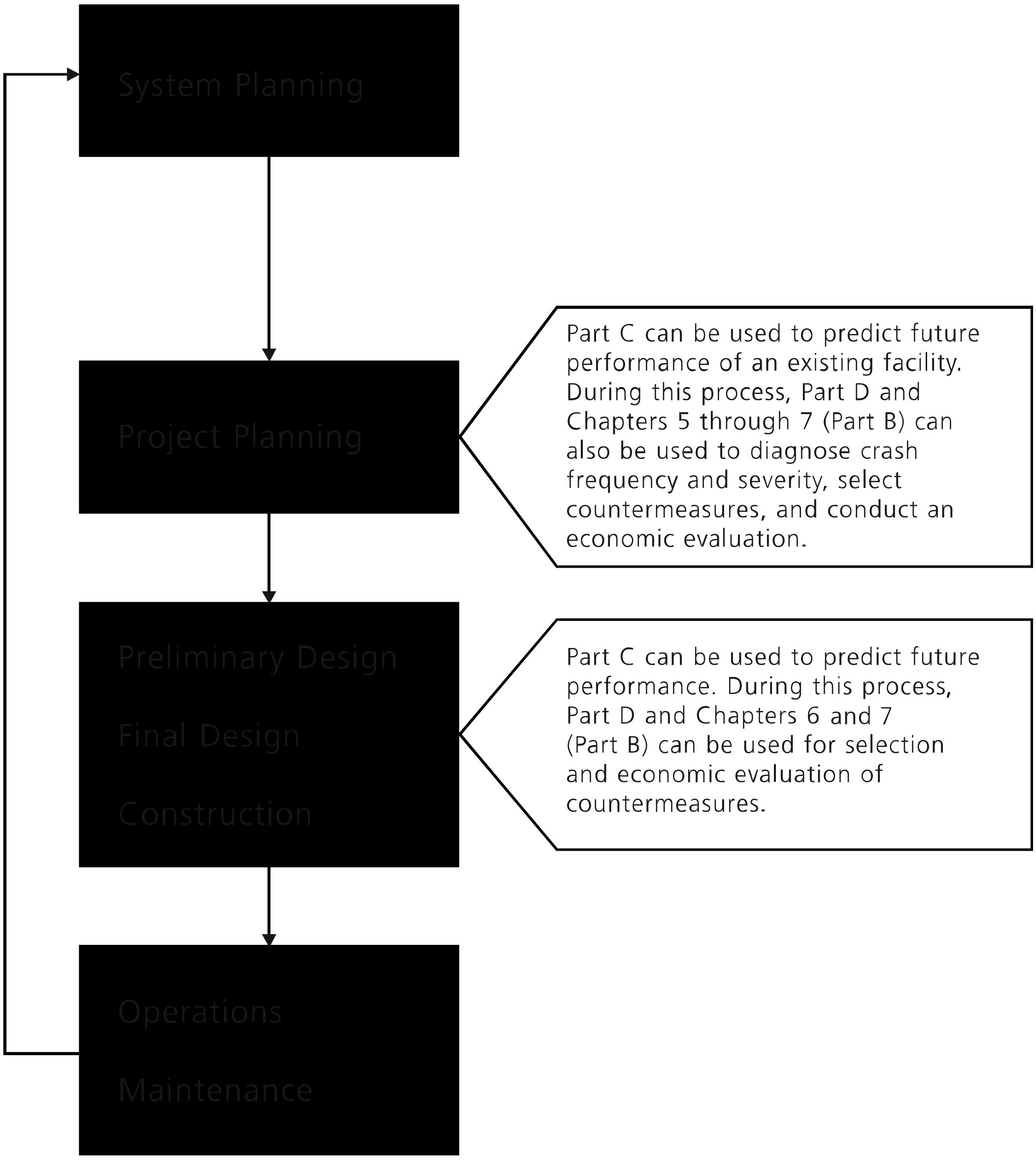

Figure C-1. Relation between Part C Predictive Method and the Project Development Process

C.4. OVERVIEW OF THE HSM PREDICTIVE METHOD

The predictive method provides an 18-step procedure to estimate the "expected average crash frequency" (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 that are either homogenous roadway segments or intersections. A facility consists of a contiguous set of individual intersections and roadway segments, each 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 or signalized and unsignalized intersections. A roadway network consists of a number of contiguous facilities.

The predictive method is used to estimate the expected average crash frequency of an individual site. The cumulative sum of all sites is 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 forecast. The estimate relies upon regression models developed from observed crash data for a number of similar sites.

The predicted average crash frequency of an individual site, $N_{predicted}$, is estimated based on the geometric design, traffic control features, and traffic volumes of that site. For an existing site or facility, the observed crash frequency, $N_{observed}$, for that specific site or facility is then combined with $N_{predicted}$, to improve the statistical reliability of the estimate. The result from the predictive method is the expected average crash frequency, $N_{expected}$. This is an estimate of the long-term average crash frequency that would be expected, given sufficient time to make a controlled observation, which is rarely possible. Once the expected average crash frequencies have been determined for all the individual sites that make up a facility or network, the sum of the crash frequencies for all of the sites is used as the estimate of the expected average crash frequency for an entire facility or network.

As discussed in Section 3.3.3, the observed crash frequency (number of crashes per year) will fluctuate randomly over any period and, therefore, using averages based on short-term periods (e.g., 1 to 3 years) may give misleading estimates and create problems associated with regression-to-the-mean bias. The predictive method addresses these concerns by providing an estimate of long-term average crash frequency, which allows for sound decisions about improvement programs.

In the HSM, predictive models are used to estimate the predicted average crash frequency, $N_{predicted}$, for a particular site type using a regression model developed from data for a number of similar sites. These regression models, called safety performance functions (SPFs), have been developed for specific site types and "base conditions" that are the specific geometric design and traffic control features of a "base" site. SPFs are typically a function of only a few variables, primarily average annual daily traffic (AADT) volumes.

Adjustment to the prediction made by an SPF is required to account for the difference between base conditions, specific site conditions, and local/state conditions. Crash modification factors (CMFs) are used to account for the specific site conditions which vary from the base conditions. For example, the SPF for roadway segments in Chapter 10 has a base condition of 12-ft lane width, but the specific site may be a roadway segment with a 10-ft lane width. A general discussion of CMFs is provided in Section C.6.4.

CMFs included in Part C chapters have the same base conditions as the SPFs in Part C and, therefore, the CMF = 1.00 when the specific site conditions are the same as the SPF base conditions.

A calibration factor (C_x) is used to account for differences between the jurisdiction(s) for which the models were developed and the jurisdiction for which the predictive method is applied. The use of calibration factors is described in Section C.6.5 and the procedure to determine calibration factors for a specific jurisdiction is described in Part C, Appendix A.1.

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

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

Where:

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

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

CMF_{2x} = crash modification factors specific to SPF for site type x; and

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

For existing sites, facilities, or roadway networks, the Empirical Bayes (EB) Method is applied within the predictive method to combine predicted average crash frequency determined using a predictive model, $N_{predicted}$, with the observed crash frequency, $N_{observed}$ (where applicable). A weighting is applied to the two estimates which reflects the statistical reliability of the SPF. The EB Method applies only when observed crash data are available. A discussion of the EB Method is presented in Part C, Appendix A.2. The EB Method may be applied at the site-specific level when crashes can be assigned to individual sites (i.e., detailed geographic location of the observed crashes is known). Alternatively, the EB Method can be applied at the project-specific level (i.e., to an entire facility or network) when crashes cannot be assigned to individual sites but are known to occur within general geographic limits (i.e., detailed geographic locations of crashes are not available). As part of the EB Method, the expected average crash frequency can also be estimated for a future time period, when AADT may have changed or specific treatments or countermeasures may have been implemented.

Advantages of the predictive method are that:

- Regression-to-the-mean bias is addressed as the method concentrates on long-term expected average crash frequency rather than short-term observed crash frequency.
- Reliance on availability of crash data for any one site is reduced by incorporating predictive relationships based on data from many similar sites.
- The SPF models in the HSM are based on the negative binomial distribution, which are better suited to modeling the high natural variability of crash data than traditional modeling techniques, which are based on the normal distribution.
- The predictive method provides a method of crash estimation for sites or facilities that have not been constructed or have not been in operation long enough to make an estimate based on observed crash data.

The following sections provide the general 18 steps of the predictive method and detailed information about each of the concepts or elements presented in the predictive method. The information in the Part C—Introduction and Applications Guidance chapter provides a brief summary of each step. Detailed information on each step and the associated predictive models are provided in the chapters for each of the following facility types:

- *Chapter 10*—Rural Two-Lane, Two-Way Roads
- *Chapter 11*—Rural Multilane Highways
- *Chapter 12*—Urban and Suburban Arterials

C.5. THE HSM PREDICTIVE METHOD

While the general form of the predictive method is consistent across the chapters, the predictive models vary by chapter and therefore the detailed methodology for each step may vary. The generic overview of the predictive method presented here is intended to provide the first time or infrequent user with a high level review of the steps in the method and the concepts associated with the predictive method. The detailed information for each step and the associated predictive models for each facility type are provided in Chapters 10, 11, and 12. Table C-1 identifies the specific facility and site types for which safety performance functions have been developed for the HSM.

Table C-1. Safety Performance Functions by Facility Type and Site Types in Part C

HSM Chapter/ Facility Type	Undivided Roadway Segments	Divided Roadway Segments	Intersections			
			Stop Control on Minor Leg(s)		Signalized	
			3-Leg	4-Leg	3-Leg	4-Leg
10—Rural Two-Lane, Two-Way Roads	✓	—	✓	✓	—	✓
11—Rural Multilane Highways	✓	✓	✓	✓	—	✓
12—Urban and Suburban Arterials	✓	✓	✓	✓	✓	✓

The predictive method in Chapters 10, 11, and 12 consists of 18 steps. The elements of the predictive models that were discussed in Section C.4 are determined and applied in Steps 9, 10, and 11 of the predictive method. The 18 steps of the HSM predictive method are detailed below and shown graphically in Figure C-2. Brief detail is provided for each step, and material outlining the concepts and elements of the predictive method is provided in the following sections of the Part C—Introduction and Applications Guidance or in Part C, Appendix A. In some situations, certain steps will not require any action. For example, a new site or facility will not have observed crash data and, therefore, steps relating to the EB Method are not performed.

Where a facility consists of a number of contiguous sites or crash estimation is desired for a period of several years, some steps are repeated. The predictive method can be repeated as necessary to estimate crashes for each alternative design, traffic volume scenario, or proposed treatment option within the same period to allow for comparison.

Apply site-specific EB method (if applicable).

Figure C-2. 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. The facility types included in the HSM are outlined in Section C.6.1. A site is either an intersection or homogeneous roadway segment. There are a number of different types of sites, such as signalized and unsignalized intersections or divided and undivided roadway segments. The site types included in the HSM are indicated in Table C-1.

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

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

Step 2—Define the period of interest.

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

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

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

Determining Traffic Volumes

The SPFs used in Step 9 (and some CMFs in Step 10), require AADT volumes (vehicles per day). For a past period, the AADT may be determined by 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 AADT of the major street, $AADT_{maj}$, and the AADT of the minor street, $AADT_{min}$. The method for determining $AADT_{maj}$ and $AADT_{min}$ varies between chapters because the predictive models in Chapters 10, 11, and 12 were developed independently.

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 determined by interpolation or extrapolation as appropriate. If there is not an established procedure for doing this, the following default rules can be applied:

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

Determining Availability of Observed Crash Data

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

The EB Method can be applied at the site-specific level (i.e., observed crashes are assigned to specific intersections or roadway segments in Step 6) or at the project level (i.e., observed crashes are assigned to a facility as a whole). The site-specific EB Method is applied in Step 13. Alternatively, if observed crash data are available but can not 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 would not be performed. In this case, the estimate of expected average crash frequency is limited to using a predictive model (i.e., the predicted average crash frequency).

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

In order to determine the relevant data required and avoid unnecessary collection of data, it is necessary to understand the base conditions of the SPFs in Step 9, and the CMFs in Step 10. The base conditions for the SPFs for each of the facility types in the HSM are detailed in Chapters 10, 11, and 12.

Step 5—Divide the roadway network or facility under consideration into individual 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. Section C.6.2 provides the general definitions of roadway segments and intersections used in the predictive method. When dividing roadway facilities into small homogenous roadway segments, limiting the segment length to no less than 0.10 miles will minimize calculation efforts and not affect results.

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

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

Crashes that occur at an intersection or on an intersection leg, and are related to the presence of an intersection, are assigned to the intersection and used in the EB Method together with the predicted average crash frequency for the intersection. Crashes that occur between intersections and are not related to the presence of an intersection are assigned to the roadway segment on which they occur, this includes crashes that occur within the intersection limits but are unrelated to the presence of the intersection. 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, go to Step 15.

In Step 5 the roadway network within the study limits is divided into a number of individual homogenous sites (intersections and roadway segments). At each site, all geometric design features, traffic control features, AADTs, and observed crash data are determined in Steps 1 through 4. For studies with a large number of sites, it may be practical to assign a number to each site.

The outcome of the HSM predictive method is the expected average crash frequency of the entire study network, i.e., 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 estimate for each site (roadway segments or intersection) is undertaken one at a time. Steps 8 through 14, described below, are repeated for each site.

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

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

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

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

Steps 9 through 13, described below, are repeated for each year of the evaluation period as part of the evaluation of any particular roadway segment or intersection.

Each predictive model in the HSM consists of a safety performance function (SPF), that is adjusted to site-specific conditions (in Step 10) using crash modification factors (CMFs) and adjusted to local jurisdiction conditions (in Step 11) using a calibration factor (C). The SPFs, CMFs, and calibration factor obtained in Steps 9, 10, and 11 are applied to calculate the predicted average crash frequency for the selected year of the selected site. The resultant value is the predicted average crash frequency for the selected year.

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

The facility types for which SPFs were developed for the HSM are shown in Table C-1. The predicted average crash frequency for base conditions is calculated using the traffic volume determined in Step 3 (AADT for roadway segments or $AADT_{maj}$ and $AADT_{min}$ for intersections) for the selected year.

The predicted average crash frequency may be separated into components by crash severity level and collision type. Default distributions of crash severity and collision types are provided in the Part C chapters. These default distributions can benefit from being updated based on local data as part of the calibration process presented in Part C, Appendix A.1.1.

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

Each SPF is applicable to a set of base geometric design and traffic control features, which are identified for each site type in the Part C chapters. In order to account for differences between the base geometric design and the specific geometric design 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 regarding the effects of simultaneous application of multiple CMFs. In using multiple CMFs, engineering judgment is required to assess the interrelationships, or independence, or both, of individual elements or treatments being considered for implementation within the same project.

All CMFs used in Part C have the same base conditions as the SPFs used in the Part C chapter in which the CMF is presented (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 Part C may be used as part of the Part C predictive method.

Part D contains all CMFs in the HSM. Some Part D CMFs are included in Part C for use with specific SPFs. Other Part D CMFs are not presented in Part C, but can be used in the methods to estimate change in crash frequency described in Section C.7.

For urban and suburban arterials (Chapter 12), the average crash frequency for pedestrian- and bicycle-base crashes is calculated at the end of this step.

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

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

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

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

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

Whether the site-specific EB Method is applicable is determined in Step 3 using criteria in Part C, Appendix A.2.1. If it is not applicable, then proceed to Step 14.

If the site-specific EB Method is applicable, Step 6 EB Method criteria (detailed in Part C, Appendix A.2.4.) is used to assign observed crashes to each individual site.

The site-specific EB Method combines the predictive model estimate of predicted average crash frequency, $N_{predicted}$, with the observed crash frequency of the specific site, $N_{observed}$. This provides a more statistically reliable estimate of the expected average crash frequency of the selected site.

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

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

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

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

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

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

This step is 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). The EB Method is discussed in Section C.6.6. 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 crashes or average crash frequency for the network

The total estimated number of crashes within the network or facility limits during the study period years is calculated using Equation C-2:

$$N_{\text{total}} = \sum_{\substack{\text{all}\\\text{roadway}\\\text{segments}}} N_{rs} + \sum_{\substack{\text{all}\\\text{intersections}}} N_{int} \tag{C-2}$$

Where:

N_{total} = total expected number of crashes within the roadway limits of the study for all years in 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 year; and

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

Equation C-2 represents the total expected number of crashes estimated to occur during the study period. Equation C-3 is used to estimate the total expected average crash frequency within the network or facility limits during the study period.

$$N_{\text{total aveage}} = \frac{N_{\text{total}}}{n} \tag{C-3}$$

Where:

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

n = number of years in the study period.

Regardless of whether the total or the total average is used, a consistent approach in the methods will produce reliable comparisons.

Step 17—Determine if there is an alternative design, treatment, or forecast AADT to be evaluated.
Steps 3 through 16 of the predictive method are repeated, as appropriate, not only for the same roadway limits, but also for alternative geometric design, treatments, or 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. The predictive method results may be used for a number of different purposes. Methods for estimating the effectiveness of a project are presented in Section C.7. Part B includes a number of methods for effectiveness evaluation and network screening, many of which use of the predictive method. Example uses include:

- Screening a network to rank sites and identify those sites likely to respond to a safety improvement;
- Evaluating the effectiveness of countermeasures after a period of implementation; and
- Estimating the effectiveness of proposed countermeasures on an existing facility.

C.6. PREDICTIVE METHOD CONCEPTS

The 18 steps of the predictive method are summarized in Section C.5. Section C.6 provides additional explanation of the some of the steps of the predictive method. 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 required in Steps 6, 13, and 15, is provided in Part C, Appendix A.2.

C.6.1. Roadway Limits and Facility Types

In Step 1 of the predictive method, the extent or limits of the roadway network under consideration are defined and the facility type or types within those limits is determined. Part C provides three facility types: Rural Two-Lane, Two-Way Roads, Rural Multilane Highways, and Urban and Suburban Arterials. In Step 5 of the predictive method, the roadway within the defined roadway limits is divided into individual sites, which are either homogenous roadway segments or 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.

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. 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.

For each facility type, SPFs and CMFs for specific individual site types (i.e., intersections and roadway segments) are provided. The predictive method is used to determine the expected average crash frequency for each individual site in the study for all years in the period of interest, and the overall crash estimation is the cumulative sum of all sites for all years.

The facility types and facility site types in Part C are defined below. Table C-1 summarizes the site types for each of the facility types that are included in each of the Part C chapters:

- *Chapter 10*—Rural Two-Lane, Two-Way Roads—includes all rural highways with two-lanes and two-way traffic operation. Chapter 10 also addresses two-lane, two-way highways with center two-way left-turn lanes and two-lane highways with added passing or climbing lanes or with short segments of four-lane cross-sections (up to two miles in length) where the added lanes in each direction are provided specifically to enhance passing opportunities. Short lengths of highway with four-lane cross-sections essentially function as two-lane highways with side-by-side passing lanes and, therefore, are within the scope of the two-lane, two-way highway methodology. Rural highways with longer sections of four-lane cross-sections can be addressed with the rural multilane highway procedures in Chapter 11. Chapter 10 includes three- and four-leg intersections with minor-road stop control and four-leg signalized intersections on all the roadway cross-sections to which the chapter applies.
- *Chapter 11*—Rural Multilane Highways—includes rural multilane highways without full access control. This includes all rural nonfreeways with four through travel lanes, except for two-lane highways with side-by-side passing lanes, as described above. Chapter 11 includes three- and four-leg intersections with minor-road stop control and four-leg signalized intersections on all the roadway cross-sections to which the chapter applies.
- *Chapter 12*—Urban and Suburban Arterial Highways—includes arterials without full access control, other than freeways, with two or four through lanes in urban and suburban areas. Chapter 12 includes three- and four-leg intersections with minor-road stop control or traffic signal control and roundabouts on all of the roadway cross-sections to which the chapter applies.

C.6.2. Definition of Roadway Segments and Intersections

The predictive models for roadway segments estimate the frequency of crashes that would occur on the roadway if no intersection were present. The predictive models for an intersection estimate the frequency of additional crashes that occur because of the presence of the intersection.

A roadway segment is a section of continuous traveled way that provides two-way operation of traffic, that is not interrupted by an intersection, and consists of homogenous geometric and traffic control features. A roadway segment begins at the center of an intersection and ends 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 C-3. When a roadway segments begins or ends at an intersection, the length of the roadway segment is measured from the center of the intersection.

Intersections are defined as the junction of two or more roadway segments. The intersection models estimate the predicted average frequency of crashes that occur within the limits of an intersection (Region A of Figure C-3) and intersection-related crashes that occur on the intersection legs (Region B in Figure C-3).

When the EB Method is applicable at the site-specific level (see Section C.6.6), observed crashes are assigned to individual sites. Some observed crashes that occur at intersections may have characteristics of roadway segment crashes and some roadway segment crashes may be attributed to intersections. These crashes are individually assigned to the appropriate site. The method for assigning and classifying crashes as individual roadway segment crashes and intersection crashes for use with the EB Method is described in Part C, Appendix A.2.3. In Figure C-3, all observed crashes that occur in Region A are assigned as intersection crashes, but crashes that occur in Region B may be assigned as either roadway segment crashes or intersection crashes depending on the characteristics of the crash.

Using these definitions, the roadway segment predictive models estimate the frequency of crashes that would occur on the roadway if no intersection were present. The intersection predictive models estimate the frequency of additional crashes that occur because of the presence of the intersection.

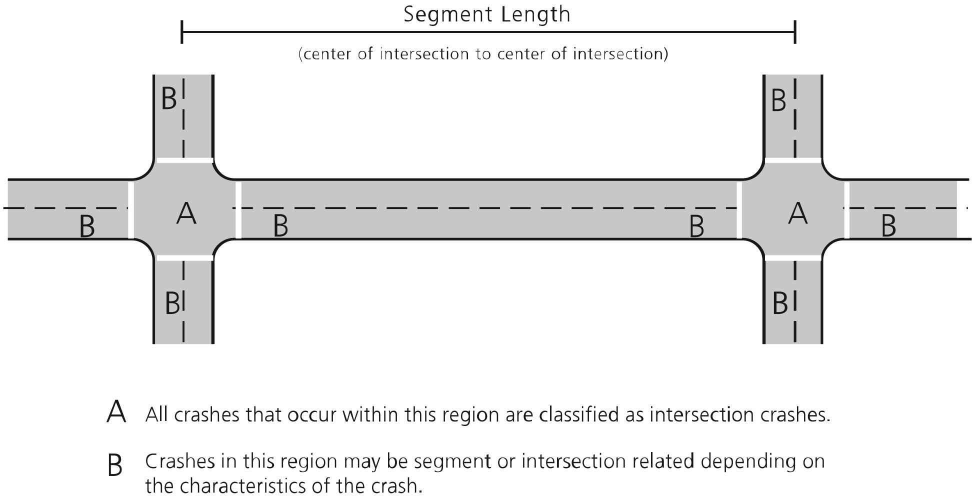

Figure C-3. Definition of Roadway Segments and Intersections

C.6.3 Safety Performance Functions (SPFs)

SPFs are regression models for estimating the predicted average crash frequency of individual roadway segments or intersections. In Step 9 of the predictive method, the appropriate SPFs are used to determine the predicted average crash frequency for the selected year for specific base conditions. Each SPF in the predictive method was developed with observed crash data for a set of similar sites. 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, in some cases a few additional variables such as the length of the roadway segment).

An example of an SPF (for rural two-way two-lane roadway segments from Chapter 10) is shown in Equation C-4.

$$N_{spf\,rs} = (AADT) \times (L) \times (365) \times 10^{(-6)} \times e^{(-0.312)} \tag{C-4}$$

Where:

$N_{spf\,rs}$ = predicted average crash frequency estimated for base conditions using a statistical regression model;

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

L = length of roadway segment (miles).

SPFs are developed through statistical multiple regression techniques using historic crash data collected over a number of years at sites with similar characteristics and covering a wide range of AADTs. The regression parameters of the SPFs are determined by assuming that crash frequencies follow a negative binomial distribution. The negative binomial distribution is an extension of the Poisson distribution which is typically used for crash frequencies. However, the mean and the variance of the Poisson distribution are equal. This is often not the case for crash frequencies where the variance typically exceeds the mean.

The negative binomial distribution incorporates an additional statistical parameter, the overdispersion parameter that is estimated along with the parameters of the regression equation. The overdispersion parameter has positive values. The greater the overdispersion parameter, the more that crash data vary as compared to a Poisson distribution with the same mean. The overdispersion parameter is used to determine a weighted adjustment factor for use in the EB Method described in Section C.6.6.

Crash modification factors (CMFs) are applied to the SPF estimate to account for geometric or geographic differences between the base conditions of the model and local conditions of the site under consideration. CMFs and their application to SPFs are described in Section C.6.4.

In order to apply an SPF, the following information relating to the site under consideration is necessary:

- Basic geometric design and geographic information of the site to determine the facility type and whether an SPF is available for that site type;
- AADT information for estimation of past periods, or forecast estimates of AADT for estimation of future periods; and
- Detailed geometric design of the site and base conditions (detailed in each of the Part C chapters) to determine whether the site conditions vary from the base conditions and therefore a CMF is applicable.

Updating Default Values of Crash Severity and Collision Type Distribution for Local Conditions

In addition to estimating the predicted average crash frequency for all crashes, SPFs can be used to estimate the distribution of crash frequency by crash severity types and by collision types (such as single-vehicle or driveway crashes). The distribution models in the HSM are default distributions.

Where sufficient and appropriate local data are available, the default values (for crash severity types and collision types and the proportion of night-time crashes) can be replaced with locally derived values when it is explicitly stated in Chapters 10, 11, and 12. Calibration of default distributions to local conditions is described in detail in Part C, Appendix A.1.1.

Development of Local SPFs

Some HSM users may prefer to develop SPFs with data from their own jurisdiction for use with the predictive method rather than calibrating the SPFs presented in the HSM. Part C, Appendix A provides guidance on developing jurisdiction-specific SPFs that are suitable for use with the predictive method. Development of jurisdiction-specific SPFs is not required.

C.6.4. Crash Modification Factors (CMFs)

In Step 10 of the predictive method, CMFs are determined and applied to the results of Step 9. The CMFs are used in Part C to adjust the predicted average crash frequency estimated by the SPF for a site with base conditions to the predicted average crash frequency for the specific conditions of the selected site.

CMFs are the ratio of the estimated average crash frequency of a site under two different conditions. Therefore, a CMF represents the relative change in estimated average crash frequency due to a change in one specific condition (when all other conditions and site characteristics remain constant).

Equation C-5 shows the calculation of a CMF for the change in estimated average crash frequency from site condition ‘a’ to site condition ‘b’.

$$CMF = \frac{\text{estimated average crash frequency with condition "b"}}{\text{estimated average crash frequency with condition "a"}} \quad \text{(C-5)}$$

CMFs defined in this way for expected crashes can also be applied to the comparison of predicted crashes between site condition ‘a’ and site condition ‘b’.

CMFs are an estimate of the effectiveness of the implementation of a particular treatment, also known as a countermeasure, intervention, action, or alternative design. Examples include: illuminating an unlighted road segment, paving gravel shoulders, signalizing a stop-controlled intersection, increasing the radius of a horizontal curve, or choosing a signal cycle time of 70 seconds instead of 80 seconds. CMFs have also been developed for conditions that are not associated with the roadway, but represent geographic conditions surrounding the site or demographic conditions with users of the site. For example, the number of liquor outlets in proximity to a site.

The values of CMFs in the HSM are determined for a specified set of base conditions. These base conditions serve the role of site condition 'a' in Equation C-5. This allows comparison of treatment options against a specified reference condition. For example, CMF values for the effect of lane width changes are determined in comparison to a base condition of 12-ft lane width. Under the base conditions (i.e., with no change in the conditions), the value of a CMF is 1.00. CMF values less than 1.00 indicate the alternative treatment reduces the estimated average crash frequency in comparison to the base condition. CMF values greater than 1.00 indicate the alternative treatment increases the estimated crash frequency in comparison to the base condition. The relationship between a CMF and the expected percent change in crash frequency is shown in Equation C-6.

$$\text{Percent Reduction in Accidents} = 100\% \times (1.00 - CMF) \tag{C-6}$$

For example,

- If a CMF = 0.90 then the expected percent change is 100% × (1 – 0.90) = 10%, indicating a 10% change in estimated average crash frequency.
- If a CMF = 1.20 then the expected percent change is 100% × (1 – 1.20) = –20%, indicating a –20% change in estimated average crash frequency.

Application of CMFs to Adjust Crash Frequencies for Specific Site Conditions

In the Part C predictive models, an SPF estimate is multiplied by a series of CMFs to adjust the estimate of average crash frequency from the base conditions to the specific conditions present at that site (see, for example, Equation C-1). The CMFs are multiplicative because the most reasonable assumption based on current knowledge is to assume independence of the effects of the features they represent. Little research exists regarding the independence of these effects. The use of observed crash data in the EB Method (see Section C.6.6 and Part C, Appendix A) can help to compensate for any bias which may be caused by lack of independence of the CMFs. As new research is completed, future HSM editions may be able to address the independence (or lack thereof) of CMF effects more fully.

Application of CMFs in Estimating the Effect on Crash Frequencies of Proposed Treatments or Countermeasures

CMFs are also used in estimating the anticipated effects of proposed future treatments or countermeasures (e.g., in some of the methods discussed in Section C.7). Where multiple treatments or countermeasures will be applied concurrently and are presumed to have independent effects, the CMFs for the combined treatments are multiplicative. As discussed above, limited research exists regarding the independence of the effects of individual treatments from one another. However, in the case of proposed treatments that have not yet been implemented, there are no observed crash data for the future condition to provide any compensation for overestimating forecast effectiveness of multiple treatments. Thus, engineering judgment is required to assess the interrelationships and independence for multiple treatments at a site.

The limited understanding of interrelationships among various treatments requires consideration, especially when several CMFs are being multiplied. It is possible to overestimate the combined effect of multiple treatments when it is expected that more than one of the treatments may affect the same type of crash. The implementation of wider lanes and shoulders along a corridor is an example of a combined treatment where the independence of the individual treatments is unclear because both treatments are expected to reduce the same crash types. When implementing potentially interdependent treatments, users should exercise engineering judgment to assess the interrelationship and/or independence of individual elements or treatments being considered for implementation within the same project. These assumptions may or may not be met by multiplying the CMFs under consideration together with either an SPF or with observed crash frequency of an existing site.

Engineering judgment is also necessary in the use of combined CMFs where multiple treatments change the overall nature or character of the site. In this case, certain CMFs used in the analysis of the existing site conditions and the proposed treatment may not be compatible. An example of this concern is the installation of a roundabout at an urban two-way, stop-controlled or signalized intersection. Since an SPF for roundabouts is currently unavailable, the procedure for estimating the crash frequency after installing a roundabout (see Chapter 12) is to first estimate the average crash frequency for the existing site conditions and then apply a CMF for conversion of a conventional intersection to a roundabout. Clearly, installing a roundabout changes the nature of the site so that other CMFs which may be applied to address other conditions at the two-way, stop-controlled location may no longer be relevant.

CMFs and Standard Error

Standard error is defined as the estimated standard deviation of the difference between estimated values and values from sample data. It is a method of evaluating the error of an estimated value or model. The smaller the standard error, the more reliable (less error) the estimate. All CMF values are estimates of the change in expected average crash frequency due to a change in one specific condition plus or minus a standard error. Some CMFs in the HSM include a standard error value, indicating the variability of the CMF estimation in relation to sample data values.

Standard error can also be used to calculate a confidence interval for the estimated change in expected average crash frequency. Confidence intervals can be calculated using multiples of standard error using Equation C-7 and values from Table C-2.

$$CI(X\%) = CMF \pm (SE \times MSE) \qquad \text{(C-7)}$$

Where:

$CI(X\%)$ = confidence interval, or range of estimate values within which it is X% probable the true value will occur;

CMF = crash modification factor;

SE = standard error of the CMF; and

MSE = multiple of standard error.

Table C-2. Constructing Confidence Intervals Using CMF Standard Error

Desired Level of Confidence	Confidence Interval (probability that the true value is within the estimated intervals)	Multiple of Standard Error (MSE) to Use in Equation C-7
Low	65–70%	1
Medium	95%	2
High	99.9%	3

CMFs in Part C

CMF values are either explained in the text (typically where there are a limited range of options for a particular treatment), in a formula (where treatment options are continuous variables) or in tables (where the CMF values vary by facility type or are in discrete categories).

Part D contains all of the CMFs in the HSM. Some Part D CMFs are included in Part C for use with specific SPFs. Other Part D CMFs are not presented in Part C but can be used in the methods to estimate change in crash frequency described in Section C.7.

C.6.5. Calibration of Safety Performance Functions to Local Conditions

The predictive models in Chapters 10, 11, and 12 have three basic elements: safety performance functions, crash modification factors, and a calibration factor. The SPFs were developed as part of HSM-related research from the most complete and consistent available data sets. However, the general level of crash frequencies may vary substantially from one jurisdiction to another for a variety of reasons including crash reporting thresholds and crash reporting system procedures. These variations may result in some jurisdictions experiencing substantially more reported traffic crashes on a particular facility type than in other jurisdictions. In addition, some jurisdictions may have substantial variations in conditions between areas within the jurisdiction (e.g., snowy winter driving conditions in one part of the state and only wet winter driving conditions in another part of the state). Therefore, for the predictive method to provide results that are reliable for each jurisdiction that uses them, it is important that the SPFs in Part C be calibrated for application in each jurisdiction. Methods for calculating calibration factors for roadway segments, C_r, and intersections, C_i, are included in Part C, Appendix A to allow highway agencies to adjust the SPF to match local conditions.

The calibration factors will have values greater than 1.0 for roadways that, on average, experience more crashes than the roadways used in developing the SPFs. Roadways that, on average, experience fewer crashes than the roadways used in the development of the SPF, will have calibration factors less than 1.0.

C.6.6. Weighting Using the Empirical Bayes Method

Step 13 or Step 15 of the predictive method are optional steps that are applicable only when observed crash data are available for either the specific site or the entire facility of interest. Where observed crash data and a predictive model are available, the reliability of the estimation is improved by combining both estimates. The predictive method in Part C uses the Empirical Bayes method, herein referred to as the EB Method.

The EB Method can be used to estimate expected average crash frequency for past and future periods and used at either the site-specific level or the project-specific level (where observed data may be known for a particular facility, but not at the site-specific level).

For an individual site (i.e., the site-specific EB Method) the EB Method combines the observed crash frequency with the predictive model estimate using Equation C-8. The EB Method uses a weighted factor, w, which is a function of the SPFs overdispersion parameter, k, to combine the two estimates. The weighted adjustment is therefore dependant only on the variance of the SPF model. The weighted adjustment factor, w, is calculated using Equation C-9.

$$N_{expected} = w \times N_{predicted} + (1.00 - w) \times N_{observed} \tag{C-8}$$

$$w = \frac{1}{1 + k \times \left(\sum_{\substack{\text{all study} \\ \text{years}}} N_{predicted} \right)} \tag{C-9}$$

Where:

$N_{expected}$ = estimate of expected average crash frequency for the study period;

$N_{predicted}$ = predictive model estimate of predicted average crash frequency for the study period;

$N_{observed}$ = observed crash frequency at the site over the study period;

w = weighted adjustment to be placed on the SPF prediction; and

k = overdispersion parameter from the associated SPF.

As the value of the overdispersion parameter increases, the value of the weighted adjustment factor decreases, and thus more emphasis is placed on the observed rather than the SPF predicted crash frequency. When the data used to develop a model are greatly dispersed, the precision of the resulting SPF is likely to be lower; in this case, it is reasonable to place less weight on the SPF estimation and more weight on the observed crash frequency. On the other hand, when the data used to develop a model have little overdispersion, the reliability of the resulting SPF is likely to be higher; in this case, it is reasonable to place more weight on the SPF estimation and less weight on the observed crash frequency. A more detailed discussion of the EB Method is included in Part C, Appendix A.

The EB Method cannot be applied without an applicable SPF and observed crash data. There may be circumstances where an SPF may not be available or cannot be calibrated to local conditions or circumstances where crash data are not available or applicable to current conditions. If the EB Method is not applicable, Steps 6, 13, and 15 are not conducted.

C.7. METHODS FOR ESTIMATING THE SAFETY EFFECTIVENESS OF A PROPOSED PROJECT

The Part C predictive method provides a structured methodology to estimate the expected average crash frequency where geometric design and traffic control features are specified. There are four methods for estimating the change in expected average crash frequency of a proposed project or project design alternative (i.e., the effectiveness of the proposed changes in terms of crash reduction). In order of predictive reliability (high to low) these are:

- *Method 1*—Apply the Part C predictive method to estimate the expected average crash frequency of both the existing and proposed conditions.
- *Method 2*—Apply the Part C predictive method to estimate the expected average crash frequency of the existing condition and apply an appropriate project CMF from Part D (i.e., a CMF that represents a project which changes the character of a site) to estimate the safety performance of the proposed condition.
- *Method 3*—If the Part C predictive method is not available, but a Safety Performance Function (SPF) applicable to the existing roadway condition is available (i.e., an SPF developed for a facility type that is not included in Part C of the HSM), use that SPF to estimate the expected average crash frequency of the existing condition. Apply an appropriate project CMF from Part D to estimate the expected average crash frequency of the proposed condition. A locally-derived project CMF can also be used in Method 3.
- *Method 4*—Use observed crash frequency to estimate the expected average crash frequency of the existing condition and apply an appropriate project CMF from Part D to the estimated expected average crash frequency of the existing condition to obtain the estimated expected average crash frequency for the proposed condition.

In all four of the above methods, the difference in estimated expected average crash frequency between the existing and proposed conditions/projects is used as the project effectiveness estimate.

C.8. LIMITATIONS OF THE HSM PREDICTIVE METHOD

The predictive method is based on research using available data describing geometric and traffic characteristics of road systems in the United States. The predictive models incorporate the effects of many, but not all, geometric designs and traffic control features of potential interest. The absence of a factor from the predictive models does not necessarily mean that the factor has no effect on crash frequency; it may merely indicate that the effect is not fully known or has not been quantified at this time.

While the predictive method addresses the effects of physical characteristics of a facility, it considers effect of non-geometric factors only in a general sense. Primary examples of this limitation are:

- Driver populations vary substantially from site to site in age distribution, years of driving experience, seat belt usage, alcohol usage, and other behavioral factors. The predictive method accounts for the statewide or community-wide influence of these factors on crash frequencies through calibration, but not site-specific variations in these factors, which may be substantial.

- The effects of climate conditions may be addressed indirectly through the calibration process, but the effects of weather are not explicitly addressed.
- The predictive method considers annual average daily traffic volumes, but does not consider the effects of traffic volume variations during the day or the proportions of trucks or motorcycles; the effects of these traffic factors are not fully understood.

Furthermore, the predictive method treats the effects of individual geometric design and traffic control features as independent of one another and ignores potential interactions between them. It is likely that such interactions exist, and ideally, they should be accounted for in the predictive models. At present, such interactions are not fully understood and are difficult to quantify.

C.9. GUIDE TO APPLYING PART C

The HSM provides a predictive method for crash estimation which can be used for the purposes of making decisions relating to designing, planning, operating, and maintaining roadway networks.

These methods focus on the use of statistical methods in order to address the inherent randomness in crashes. The use of the HSM requires an understanding of the following general principles:

- Observed crash frequency is an inherently random variable. It is not possible to precisely predict the value for a specific one year period—the estimates in the HSM refer to the expected average crash frequency that would be observed if the site could be maintained under consistent conditions for a long-term period, which is rarely possible.
- Calibration of an SPF to local state conditions is an important step in the predictive method.
- Engineering judgment is required in the use of all HSM procedures and methods, particularly selection and application of SPFs and CMFs to a given site condition.
- Errors and limitations exist in all crash data which affects both the observed crash data for a specific site, and also the models developed. Chapter 3 provides additional explanation on this subject.
- Development of SPFs and CMFs requires understanding of statistical regression modeling and crash analysis techniques. Part C, Appendix A provides guidance on developing jurisdiction-specific SPFs that are suitable for use with the predictive method. Development of jurisdiction-specific SPFs is not required.
- In general, a new roadway segment is applicable when there is a change in the condition of a roadway segment that requires application of a new or different CMF value, but where a value changes frequently within a minimum segment length, engineering judgment is required to determine an appropriate average value across the minimum segment length. When dividing roadway facilities into small homogenous roadway segments, limiting the segment length to greater than or equal to 0.10 miles will decrease data collection and management efforts.
- Where the EB Method is applied, a minimum of two years of observed data is recommended. The use of observed data is only applicable if geometric design and AADTs are known during the period for which observed data are available.

C.10. SUMMARY

The predictive method consists of 18 steps which provide detailed guidance for dividing a facility into individual sites, selecting an appropriate period of interest, obtaining appropriate geometric data, traffic volume data, and observed crash data, and applying the predictive models and the EB Method. By following the predictive method steps, the expected average crash frequency of a facility can be estimated for a given geometric design, traffic volumes, and period of time. This allows comparison to be made between alternatives in design and traffic volume forecast scenarios. The HSM predictive method allows the estimate to be made between crash frequency and treatment effectiveness to be considered along with community needs, capacity, delay, cost, right-of-way and environmental considerations in decision making for highway improvement projects.

The predictive method can be applied to either a past or a future period of time and used to estimate total expected average crash frequency or crash frequencies by crash severity and collision type. The estimate may be for an existing facility, for proposed design alternatives for an existing facility, or for a new (unconstructed) facility. Predictive models are used to determine the predicted average crash frequencies based on site conditions and traffic volumes. The predictive models in the HSM consist of three basic elements: safety performance functions, crash modification factors, and a calibration factor. These are applied in Steps 9, 10, and 11 of the predictive method to determine the predicted average crash frequency of a specific individual intersection or homogenous roadway segment for a specific year.

Where observed crash data are available, observed crash frequencies are combined with the predictive model estimates using the EB Method to obtain a statistically reliable estimate. The EB Method may be applied in Step 13 or 15 of the predictive method. The EB Method can be applied at the site-specific level (Step 13) or at the project-specific level (Step 15). 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.

The following chapters in Part C provide the detailed predictive method steps for estimating expected average crash frequency for the following facility types:

- *Chapter 10*—Rural Two-Lane, Two-Way Roads
- *Chapter 11*—Rural Multilane Highways
- *Chapter 12*—Urban and Suburban Arterials